Multi-cell Interference Management in In-band D2D communication under LTE-A Network

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Abstract— **Device-to-Device (D2D) communication is an active research area. As a part of this active research area, Device-to-Device (D2D) communication is largely exploited in Out-band non-cellular technologies, such as, Bluetooth or Wi-Fi network. However, it has not been fully incorporated into existing cellular networks. Interference management is the main challenge of this technology as it generates both intra and inter-cell interference resulting in severe network performance degradation. eNodeBs with high transmit power usually affects D2D user equipments (UEs) with high interference. It usually incurs severe interference to the cellular UEs and to the base station (eNB). The scenario becomes more critical in case of multi-cell environment, which is the main research focus in this paper. In order to encourage and increase frequent use of D2D communications, some changes in the network configuration are required for today's networking scenario. Flexible multi-cell D2D communication is required to reduce the network load. Interference management techniques are necessary in parallel to make the communication smooth, efficient and effective.**

This paper reviews multi-cell interference in In-Band D2D communications and investigates interference mitigation techniques in scenarios where two or more similar or different devices under same eNB or from two different eNBs can be connected as a D2D pair without compromising user experience and quality of service standard. These issues cannot be guaranteed by the current applications operated on unlicensed frequency band. The research also addresses the following related issues: mode selection, resource allocation (both for cellular and D2D environment), power control (both for eNB and D2D pair), and flexible frequency allocation techniques. The research aims to look at other issues, such as, achieving high SINR, improved system capacity, better throughput and transmission rate.

Keywords— Device-to-Device, LTE-A, Multi-cell, Interference, Resource Sharing, Resource Allocation, Power Control, Mode Selection

I. Introduction

The significant advancement in wireless communication network has created the ever-increasing demand from the mobile users. However, the frequency band is limited. For further enhancement and to fulfill future demands efficient reuse of existing frequency band is very important. In order to do so, various approaches like allocating more base stations in the cell-edge areas, deploying small cells such as micro-cell, femto-cell and pico-cells to boost the RSRP, use of cognitive radio to detect the appropriate communication channels in order to avoid interference [1], sharing of frequency spectrum or frequency reuse [2] have been adopted. Multi-antenna technique and direct communication between two or more users/devices known as Device-to-Device (D2D) communication is actually an add-on communication paradigm to the modern 5G wireless network that works as an ad-hoc technology and represents a direct communication between two or more devices without the help of any service operators (eNodeBs or Base Station) and co-exists easily with the existing cellular deployment [3]. D2D communications can be operated in unlicensed spectrum band (Out-Band such as Infra, Bluetooth, and WLANs) or in the same licensed band (In-Band) as cellular UEs [4]. However, the question of reliability in D2D communication using unlicensed band is an issue of concern because only a licensed band can guarantee a reliable connection and a controlled interference environment.

The main functional benefit of D2D technology is that it can provide significant improvements in spectral efficiency, energy efficiency and user experience. It can provide a significant contribution to the cell load balancing by allowing remote off-loading of the users. This will enable to communicate directly with each other, and it will also accommodate other out of coverage users by forming a peer-to-peer communication network [4]. In this way, the network coverage area can be extended, and cell-throughput and instantaneous data rate can be enhanced [5]. As a result, the overall network performance can be improved. The spectrum reuse in D2D communications is more efficient which can ensure a higher data rate and an increment in user capacity [6]. Bypassing eNodeBs during direct communication can easily reduce the number of hops in transmission. So, the data exchange between two adjacent UEs becomes faster, smoother and the transmission quality is also enhanced. This type of direct communication also reduces the end-to-end transmission delay. It also reduces battery consumption by the UEs significantly [7].

In spite of many advantages, D2D communication paradigm creates some new technical challenges. These include complex interference scenarios, device discovery, security, mobility management and modification of existing architectural design within LTE-A network [8],[9]. However, these challenges are opening the door for more research opportunities in this area. To find a best possible solution to incorporate the D2D communication under the Cellular network, researchers are working hard to deal with these challenges. In this context, multi-cell interference management in D2D communication underlying cellular network has been considered.

Interference: Types and Cause

There are different types of interferences based on network, frequency and control level. Depending on the network, there are two types of interferences: homogenous (two D2D/devices within the same cell) and heterogeneous (between two different D2D/devices from two different cells). In terms of frequency, there could be different interference issues based on uplink resource reuse and downlink resource reuse. According to control level, interference can be categorized into centralized and distributed. There are also different approaches used to manage interferences such as interference cancellation, interference avoidance and interference coordination. Another classification of interference in D2D communication based on two-tiered network architecture can be categorized as co-tier interference and cross-tier interference [10]. Co-tier interference occurs between a D2D user with a neighboring D2D user in the same tier, and the cross-tier interference takes place between one cellular user with one or multiple D2D users in different tiers.

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In real life LTE-Advanced cellular network, all users belong to a cell and every cell may be surrounded by multiple neighboring cells. Each cell has a central entity called eNB. Initially, all the users are cellular users as they communicate with other users through eNB. eNB is responsible for keeping track of its users' information and position. It also assigns resource blocks (RBs) efficiently to all of its users. When two or more devices come to a close proximity and satisfy the requirement for a D2D communication, a dedicated link is created between them by eNB. In case of multi-cell environment in LTE-Advanced network, each cell is assumed to have the same frequency band in order to maintain the spectral efficiency. To be able to communicate, the users need to establish a connection either through eNB in case of cellular communication or to their D2D receiver in case of D2D communication [11]. The only requirement here is to obtain a minimum Quality of Service at the receiver. So, in every cell cellular and D2D users exist together by sharing common RBs. Interference occurs due to this resource sharing by the cellular users of different neighboring cells or by the D2D pairs sharing same RBs either in the same cells or among neighboring cells. This type of resource sharing can be performed using different communication modes.

II. RELATED RESEARCH

Many researchers have worked on various issues associated with LTE and LTE-A, but very few of them actually paid attention to Device-to-Device communication under cellular environment. The main focus of these research works was on the interference issues related to D2D communication under cellular environment either on single-cell or on multi-cell environment. Some of the researchers worked on mode selection as a tool to mitigate D2D interference, whereas other researchers have taken power control or allocation of resources to mitigate interference in D2D communication. Few researchers have considered joint-approaches as their solution. Some of them also considered different approaches such as beam-forming, opportunistic interference alignment approach, and D2D neighbor discovery approach. In this context, an extensive review of the literature regarding different interference mitigation approaches is presented and analyzed in the following sections. This review paper aims to narrow down the gaps for a better solution in terms of performance.

Interference Mitigation Techniques

Most of the related research works in the context of D2D communication paradigm and interference management in D2D communications are based on the investigation in a single-cell scenario and few research works have addressed the multi-cell scenario [12],[13]. To overcome the interference issues [5],[12], various interference avoidance techniques in D2D communication have been studied in the literature such as mode selection [14],[15], transmit power control [3],[6],[8], efficient radio resource management schemes [3],[9], joint power control and resource allocation [7],[9],[18], MIMO techniques and standardization through protocol and architectural enhancement [6]. Some other unique approaches like opportunistic interference alignment approach [5], D2D neighbor discovery interference management, effective interference cancellation mechanism [12], and multi-antenna beam forming at the D2D receiver end have been introduced and investigated by the researchers. It is noted that power control has always been a popular choice by the researchers. However, interference situation especially in Inband-D2D communication is not easy to handle using conventional power control strategy on its own. This is because the communication here takes place as an underlay of cellular network, where D2D pairs coexist with cellular users by sharing spectrum simultaneously.

Again, in case of overlay mode, resource sharing will be performed orthogonally. So, interference mitigation using optimization algorithm may reduce the benefit of D2D resource reuse. The implication of this is the degradation in throughput because the bandwidth resources are not used efficiently. In addition, using MIMO in cellular downlink may also reduce the full potential of D2D communication because of inefficient use of bandwidth resources. When cellular users and D2D pairs share the same uplink (UL) resources, they impose interference on each other. The D2D receivers experience the interference from the cellular users whereas the D2D senders impose an interference on the cellular users. During the entire uplink transmission period, interference takes place in both way. Interference from cellular users to the D2D receiver in the UL period is not catered. Both D2D interference and cellular interference need to be suppressed during the UL period to protect the cellular network from D2D interference. This is also needed to improve the reliability of D2D communication and cellular communication. This area needs to be investigated further and this is also one of the significant reason for the researchers to choose joint mode [11] as a solution to increase efficiency. A detailed analysis of the literature is presented below.

A. Mode Selection

Transmission mode selection has a direct impact on D2D communication [14][15]. The underlay and overlay mode selection of D2D pair in a single cell scenario with or without relay node have been investigated in [14] where the mode selection depends on the positioning of the Cellular and D2D users. Their simulation shows that the selection of underlay mode performs better when the cellular users are closer to the proximity of the eNB/relay node as compared to the D2D users. It is shown in the simulation results that the system parameters affect the probability irrespective of whether D2D communication can reuse the cellular uplink resources. The final outcome of their research is the relay node increases chance of D2D communication to take place. It also expands the area of D2D pair using underlay mode. Another approach called two-armed Levy-Bandit approach which chooses between indirect and direct transmission mode [15]. Distance between the users, spectral efficiency, high throughput, interference avoidance, hardware complexity and cost are also considered during the mode selection process. Dynamic mode selection and constant switching between modes are expected to be the optimal solution.

B. Power Control

Among different techniques to avoid interference, Power Control is the most popular one. Adjusting the transmit power of the D2D sender while maintaining the minimum SINR requirement of the cellular communication, interference can be avoided or reduced [3],[6],[8]. This constraint can be set up by the eNB. However, this simple power control scheme may lead to under-utilization of D2D communications. The positioning of the D2D pairs, cellular users and eNBs plays a vital role in the power control technique. If the D2D pairs are in close proximity but they are far away from the eNB or cellular user equipment (CUE), D2D communication performance will not be affected much by reducing the power. But in case of vise-versa, reducing the power may completely stop the D2D communication to take place. So, it is certain that the conventional power control technique itself may not contribute highly to interference management.

C. Resource Allocation

Another method is Resource Allocation for interference mitigation in D2D communication [3],[16]. Assigning radio resources optimally to a group of D2D users or to all D2D pairs is one of the main challenge. Specially, this needs to be assigned in a way so that the co-channel users do not interfere with each other. It is important to carry out the resource allocation in an efficient manner to avoid interference. Recent resource allocation approach using centralized baseband processing in the cloud radio access network (C-RAN) architecture has been proposed in [13]. However, this approach incurs more signaling overheads to the eNB. A location-based and a distance-based resource allocation to mitigate interference between D2D users and cellular users using same resources have been studied by the researchers. However, the location-based resource allocation is lacking the spectral efficiency and flexibility because of the localization of users under certain regional areas. The distance-based resource allocation has a benefit of having low signaling overhead but it has a drawback that the exact location information of the D2D and cellular user is always required by the eNB to share resources among them. The orthogonal resource allocation is considered to be less-spectrum efficient and hence effective resource allocation by using orthogonal resource allocation is indeed a challenging task. So, dynamic resource allocation without limiting the spectrum usage for D2D and CUE is expected to bring optimal solution.

D. Joint Power Control and Resource Allocation

Power control in conjunction with resource allocation is an advanced approach to mitigate interference [3]. A novel interference avoidance model based on user location has been studied in [10]. An interference limited area has been proposed instead of controlling or limiting the transmit power of D2D sender with a restriction in resource sharing among the Cellular and D2D users within this area. Their simulation work shows certain performance gain, but their model reduces multi-user diversity. The physical constraint also limits the scheduling efficiency of the eNB. The proposed approach is expected to be based on dynamic resource allocation and power control where eNBs assign resources to CUE and then to D2D users and D2D users reuse resources of CUE on demand. At the same time, eNB keeps track of the channel gain and it dynamically adjusts the transmit power of D2D sender accordingly.

E. Interference Management

The most recent research on Interference Management in D2D communication has been presented in [9]. A beam forming technique applied on the D2D pair has been discussed in this paper. The pre-coding vector is aligned towards the direct link between the D2D pair. This helps in nullifying interference to the cellular users. However, no performance measure or simulation is presented in this paper. Other related research areas are Effective Interference Alignment [5], Effective Interference cancellation Mechanism [12], LTE Uplink Performance with Interference from In-Band D2D communication, and Interference-aware Discovery and Optimal Uplink Scheduling for D2D communication in LTE Networks. However, they have restricted their simulation set up to a single cell and thus in case of communication under different eNBs, the devices will be treated as a cellular pair only. Effective Interference Alignment in Device-to-Device Communication underlying Multi-cell Interference Network is presented in [5]. Inter-cell near-far interference avoidance in a multi-cell environment is proposed in [12]. In this research, neighboring eNBs monitor the control channel of D2D subsystem and exchange necessary information to identify cellular users causing the interference due to UL resource reuse and the victims (D2D users) of interference. The serving eNB can stop scheduling transmission of interferer (CU) until D2D transmission ends. However, their model limits the flexibility and efficiency of the system by stopping the transmission. It also requires a reliable control channel sensing. A log-distance model in different environment with greedy grouping algorithm is proposed in [17] to reduce interference in D2D communication where their performance measure is based on the SINR (Signal to Interference & Noise Ratio) requirement. However, this model is more suitable for sub-urban areas only. They need to include different propagation model to achieve the performance gain over severe interference scenario. There are other techniques for interference mitigation in D2D communication, such as MIMO technique and Spectrum Splitting Technique, which have been discussed in the literature. Adopting Time Division Multiplexing (TDM) technology to separate cellular and D2D communication may effectively reduce interference but that may lead to an inefficient use of spectrum and also it only reduces cross-tier interference. To reduce the co-tier interference, different mechanism is required.

Other related research works are still on going in D2D communication and its contribution to 5G network. Dynamic RB sharing scheme is investigated in [18]. The paper has looked at the RB sharing between the D2D users and cellular users in a multi-cell cellular network using a novel Repeated Game approach where players share allotted resource to maximize their utility. The proposed scheme shows better throughput performance in comparison to other similar existing techniques. Throughput, power consumption and overall system performance can be benefitted through the architectural enhancement in D2D communication [19] but these will certainly be complicated and costly. Some researchers have paid attention to D2D communication as an efficient way to achieve load balancing through these technologies [4]. A successful D2D communication can also create new service opportunities and reduce eNB load for short-range data intensive peer-to-peer communication [19]. Many proximity-based applications can also be enabled and enhanced by this technology [19]. The main motivation behind D2D communication technology is to enhance user experience [7] and one of its major use is in public safety [20], especially when there is any calamity or natural disaster. However, QoS (Quality of Service) and data rate enhancement are required to ensure a secure communication during an emergency situation [20].

Based on these findings, the proposed research is expected to consider a three-step approach to find an effective and efficient solution for the interference problem, where the first step is to find the appropriate communication mode depending on different situation, the second step is to find an efficient allocation of the RBs among cellular and D2D users by avoiding or reducing interference and the third step is to address an efficient allocation of the power transmission.

III. INTERFERENCE SCENARIOS IN D2D COMMUNICATION

D2D communication underlying cellular network is beneficial as long as D2D communications do not affect the overall performance of the cellular communication and cellular communications do not affect the efficiency of a D2D communication. However, the problem occurs when D2D UEs need to reuse or share cellular resources in order to achieve spectral efficiency and high data rate. As a result, D2D links may reduce the cellular capacity and efficiency, which ends up in both intra-cell and inter-cell interference [6]. Fig 1 shows a simple interference scenario with one eNB, one D2D pair (UE1 and UE2) and one Cellular UE (UE3). While UE1 is transmitting to UE2, it is generating interference to the eNB and while cellular UE is transmitting to eNB, it is generating interference to the recipient of the D2D pair (UE2). Different interference scenarios in D2D communications in case of single and multi-cells are presented in Fig 2, and Fig 3 respectively where intra-cell, inter-cell and multi-cell interference are addressed. These scenarios have been used for the proposed research work.

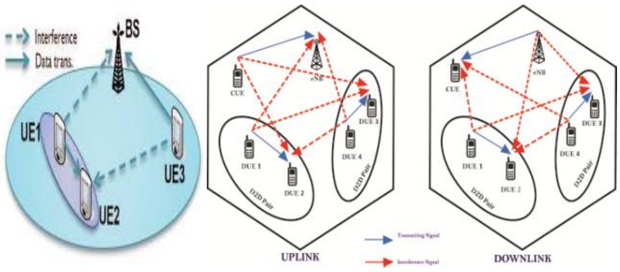

Figure 1: Interference in a single cell - UL and DL Setup [6]

The scenario in Fig. 2 further explains in the context of UL (uplink) and DL (downlink) transmission where there are one eNB, one cellular UE (CUE) and two D2D pairs. In one pair DUE 1 is transmitting to DUE2 and in another pair DUE4 is transmitting to DUE3. The possible interference here can be identified in three different categories: (a) Interference from D2D communication to the cellular communication, (b) interference from cellular communication to D2D communication, and (c) Interference between D2D pairs.

In case of (a), both DUE1 and DUE 4 in UL direction are generating interference to eNB, which receives data from its CUE. On the other hand, CUE is receiving data from eNB in DL direction while at the same time it is experiencing interference from both DUE1 and DUE4.

In case of (b), interference is generated by CUE in UL direction, which transmits to eNB. In this case, recipient sides of the D2D pairs (i.e. DU2 and DUE 3) are the victims of interference from the CUE, whereas in DL, DUE2 and DUE3 are the victims again but the source of interference is from eNB this time while it is transmitting to CUE.

Finally, in case of (c), interference is always caused by the transmitting DUEs towards receiving DUEs (from DUE1 and DUE4 to DUE2 and DUE3 respectively) regardless of the transmission direction.

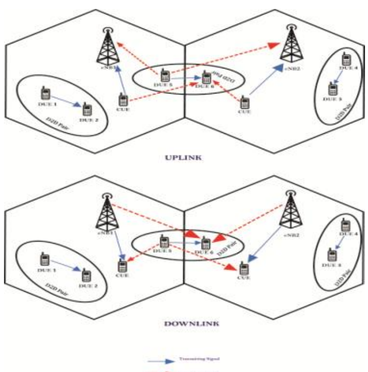

Figure 2: Interference in Inter-cell environment - UL and DL

In Fig 2, DUE 5 is transmitting to DUE 6. Apart from the intra-cell interferences, DUE 6 is experiencing additional interference from the CUE of both adjacent cells and DUE 5 is generating interference to both eNB1 and eNB2 in uplink, whereas, in downlink mode, DUE 6 is experiencing interference from both eNB1 and eNB2 of two adjacent cells but DUE 5 is generating interference to both CUEs of two adjacent cells.

D2D communications can be initiated under multi-cell scenario, which is shown in Fig 3.

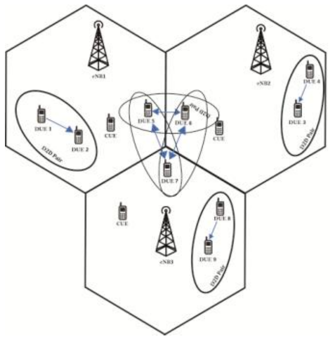
Figure 3: Overall Interference scenario in a multi-cell environment

IV. CONCLUSION

Device-to-Device communications are going to become an indispensable part of future mobile networks. So, a significant attention to this technology could offer new service opportunities and potential revenues for the cellular operators. Its real time traffic distribution can bring significant efficiency in network load balancing. A critical review of recent literature has been presented in this paper, which relates the significance and challenges of D2D technology. The main challenge of In-Band D2D communications is interference management, which has been addressed under different interference (Intra-cell, Inter-cell and Multi-cell) scenarios. The paper also investigates the possible solutions to this interference management issues in D2D communications in multi-cell environment. It looks at issues, such as dynamic resource allocation, communication mode-selection, switching dynamically between modes and proper power control scheme. The present research work is hoping to establish an efficient interference management technique in in In-Band D2D communication under LTE-A network.

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