

Interference Mitigation in D2D Communication Underlying LTE-A Network

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Abstract— The mobile data traffic has risen exponentially in recent days due to the emergence of data intensive applications such as online gaming, video sharing etc. It is driving the telecommunication industry as well as the research community to come up with new paradigms that will support such high data rate requirements within the existing wireless access network, in an efficient and effective manner. To respond to this challenge, Device-to-Device (D2D) communication in cellular networks is viewed as a promising solution, which is expected to operate, either within the coverage area of the existing eNB and under the same cellular spectrum (in-band) or separate spectrum (out-band). D2D provides the opportunity for users located in close proximity of each other to communicate directly, without traversing data traffic through the eNB. It results in several transmission gains, such as improved throughput, energy gain, hop gain, reuse gain, etc. However, integration of D2D communication in cellular systems at the same time introduces new technical challenges that need to be addressed. Containment of the interference among D2D nodes and cellular users is one of the major problems. D2D transmission radiates in all directions, generating undesirable interference to primary cellular users and other D2D users sharing the same radio resources resulting in severe performance degradation. Efficient interference mitigation schemes are a principal requirement in order to optimize the system performance. This work presents a comprehensive review of the existing interference mitigation schemes present in the open literature. Based on the subjective and objective analysis of the work available to date, it is also envisaged that adopting a multi-antenna beamforming mechanism with power control such that the transmit power is maximized towards the direction of the intended D2D receiver node and limited in all other directions will minimize the interference in the network. This could maximize the sum throughput and hence, guarantees the reliability of both the D2D and cellular connections.

Index Terms—D2D, LTE-A, Interference Mitigation, Underlay

I. INTRODUCTION

THE ever-increasing popularity of smart devices (smartphone, tablet PC, etc.) and portable applications

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designed with various mobile applications that provides multimedia-rich services e.g. Video over IP, online game, Internet Protocol Television (IPTV), etc., have directly increased the demand for high mobile data traffic. This results in the wireless cellular network to be one of the main access systems to the Internet, for majority of customers, due to its pervasive availability. Thus, today's mobile data traffic consumes a lot of bandwidth within the cellular network. For instance, it was estimated that global mobile data traffic would experience 13-fold rise from 2012 to 2017 [1-2].

Since the evolution of mobile communication standards 2G, 3.5G and now in the 4G era, the wireless cellular network have been integrating advanced technologies to improve data rates, network capacity and coverage. The 3GPP group have proposed LTE-A standard to be an enhanced version of LTE, which aims at supporting peak data rate in the order of Gbits/sec. To achieve this performance, the LTE-A have been specified to integrate emerging technologies such as multi-antenna technique and carrier aggregation to provide higher channel capacity, Device-to-Device (D2D) communication, etc. D2D communication is a radio access technology that provides users the ability to communicate directly between them when they are in close proximity, without traversing traffic through the network infrastructure [3]. It is envisaged as an import part of future 5G and Internet-of-Things (IoT) applications [4-5][4]. Traditionally, in conventional cellular network, all data transmission traverses the base station also referred to as evolved Node B (eNB), i.e. data packets are first uploaded to the eNB using the uplink resources, and then routed to the intended destination along the downlink [6]. However, this traffic generates a significant overhead to the eNB, as it provide services to many mobile users. With the implementation of D2D, data transmission can follow a direct communication channel, established between two devices that are in close proximity. This therefore, offload data traffic from the eNB, providing it with ability to serve other devices which are not in close proximity and are using the same channel, thus easing network congestion and increase in network capacity. For two devices to operate in D2D mode, they must satisfy proximity conditions. Proximity here implies not only close range, but also includes good channel condition above a pre-defined SINR target, average throughput, delay, density and load [6].

Figure 1.a illustrates direct communication between D2D pair i.e. D2D transmitter (D2D Tx) and D2D receiver (D2D

communication, location-aware advertisement, public safety (disaster management and rescue operations). D2D is currently being specified in 3GPP LTE-Release 12 and also recognised as one of the technologies components of future wireless networks (i.e. 5G) [7]. Figure 2 shows the various use cases and applicability of D2D-enabled cellular system.

D2D communication in cellular network promises several benefits to the network providers as well as end users. Firstly, it improves spectral efficiency, by re-using the same frequency resources occupied by cellular users. Secondly, it reduces communication delay and increases network throughput, due to its short distance communication. Thirdly, D2D improves energy efficiency, since the mobile terminals use less transmission power when communicating directly between each other. Hop gain is another key benefit of using D2D, in which either the uplink or downlink resources is only used for the direct communication link.

From economic perspectives, the advent of D2D drives the network application developers to design new mobile applications with proximity-aware features such as social content, multicasting applications, etc., [8-10]. The mobile operators will also benefit from an increased revenue generation, through additional charges for providing D2D services to subscribers, using the same licensed cellular spectrum band. However, this is still an open research question, especially when considering how the operators will control and charge for D2D communications (same operator and different operators scenarios), and also how can the relay devices be compensated using their resources (battery life, data storage, system processing power, etc.) [11]. Therefore, an efficient and reliable pricing models needs to be developed and implemented for the benefits of both operators and user devices that may act as relay terminals for D2D communication. Furthermore, organizations can benefit from location-based advertisement, through advertising their product and services as part of discovery information to near-by devices that are in close proximity. The end-user would benefit from an improve data rates, reduced latency due to direct short range communication and overall improve user experience.

D2D communication has been introduced in the heterogeneous mobile network architecture to enhance the efficiency of mobile cloud computing services as well as the conventional cloud computing. The benefit of such adoption is to decentralize the computationally intensive big cloud into distributed small mobile clouds (cloudlets), which can be managed by mobile devices with high processing capability. The significance of D2D communication in mobile cloud

computing and a new hierarchical heterogeneous architecture consisting of D2D relay – based cloud services was described in [12]. As shown in Figure 1.b, the cloudlets offload data traffic from the general static cloud, provide services to its associated cloud members (e.g. sensing devices, terminal devices). Various cloudlets are interconnected through a direct D2D link from their individual master devices. These therefore utilizes the benefits of D2D communication to improve load balancing, energy efficiency, user experience and reduces computational overhead. On the other end, the existing mobile cloud computing models i.e. are used to provide services between the general static cloud and the mobile dynamic cloud.

On the other hand, enabling D2D communication in existing cellular network opens up new technical challenges that need to be tackled. These are device discovery, mode selection, interference management, radio resource management, power control, security, mobility management and modification to the existing architectural design of LTE-A network. The aforementioned challenges have motivated a lot of research studies towards, proposing optimal solutions to achieve efficient and reliable D2D – enabled cellular system. Detail analysis of these challenges is presented in the subsequent sections.

II. D2D – THE COMPELLING ISSUE

Although the integration of D2D communication in cellular network would offer enormous benefits such as higher achievable data rates and spectrum efficiency, improved capacity, ease of congestion, reduced power consumption, etc., however, it may subject the primary cellular users to harmful interference due to spectrum sharing, in addition to mutual interference among the multiple D2D pairs reusing the time-frequency resources. The presence of undesirable interfering signals could result in performance degradation of the communications in wireless networks generally [13] and in cellular and the D2D communication system, specifically. In other words, enabling D2D in cellular system should not cause service disruption to cellular users (CUs). Therefore, efficient interference coordination schemes need to be implemented to guarantee the quality of service (QoS) constraint of both transmission systems, and to also provide reliable communication environment. In this regards, various interference avoidance techniques have been studied in the literature such as transmit power control [14-16], efficient radio resource management schemes [14-15], joint power control and resource allocation [16-17], MIMO techniques [18-19].

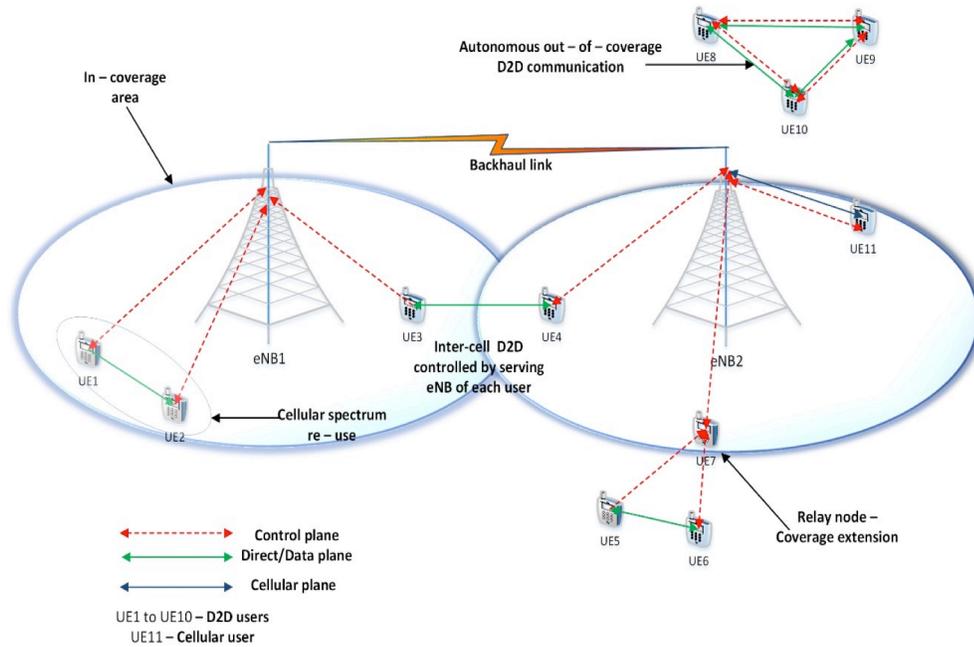


Fig. 2. Illustration of D2D-enabled cellular network concepts and use-cases.

The conventional power control strategy alone cannot handle the interference problem in this heterogeneous network where D2D pairs coexist with cellular network, because there is the presence of new interference situation due to simultaneous spectrum sharing. Whereas mitigating the interference problem in D2D enabled cellular network through the optimization of diverse resource sharing algorithms limits the benefits of D2D reuse. This results in low throughput due to inefficient use of bandwidth resources. Consequently, the application of MIMO transmission scheme at cellular downlink to mitigate the interference caused by D2D communication does not exploit the full potentials of D2D communication in cellular network. This is because; it does not cater for interference from cellular users to the D2D receiver in the UL period, when CU and D2D pair shares the same UL resources. This necessitates the need to further investigate this area, in order to efficiently eliminate the interference problems in D2D communication.

Therefore to protect the cellular network from D2D interference and also improve the reliability of both D2D communication and cellular networks, there is need to suppress both D2D interference and cellular interference during the UL period, when both D2D pairs and cellular users share the same UL resources. This can be achieved by exploiting beamforming strategy at the D2D pair, in which the precoding vector can be aligned towards the direct link between the D2D pair, and at the same time nulling interference to the cellular users.

The remainder of this paper is organised as follows; Section III describes the classification of D2D communication. Section IV examines the technical challenges of enabling D2D communication in cellular networks. Detailed analysis of interference management in D2D communication is presented in Section V, whereas section VI finally concludes the paper.

III. CLASSIFICATION OF D2D COMMUNICATION

Basically, there are two types of D2D communication, namely, In-band and Out-band. The major difference between the two is the frequency spectrum band in which the D2D communication is operating. Figure 3 shows a block diagram illustrating the available classes and sub-classes of D2D communication.

A. In-Band D2D Communication

In in-band communication, D2D share licensed cellular spectrum along with other cellular users in the LTE-A network. The network infrastructure i.e. eNB have total/partial control over the D2D users. The eNB is responsible for discovering potential D2D devices, link establishment based on channel state information, radio resource allocation either uplink or downlink, power control based on some certain pre-defined threshold level as well as interference coordination between the cellular and D2D users [20]. The in-band D2D communication is further divided into underlay (non-orthogonal) and overlay (orthogonal) modes.

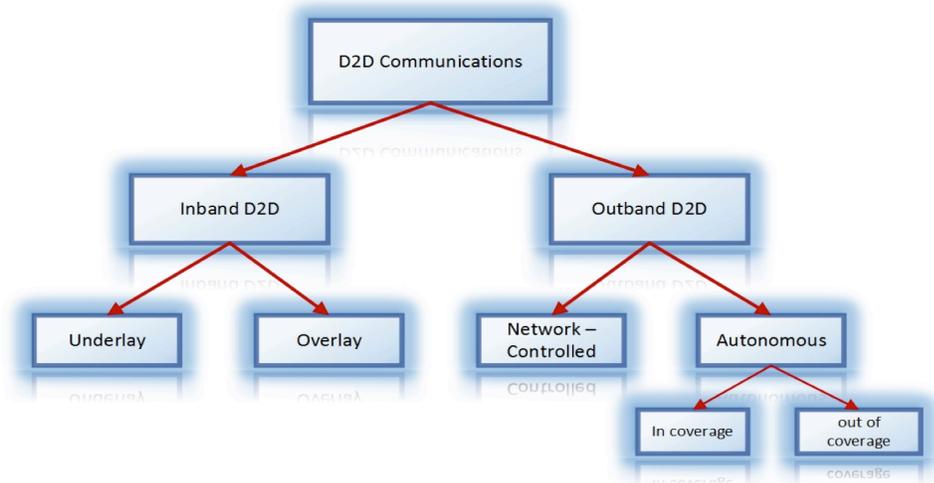


Fig. 3. Classification of D2D communication.

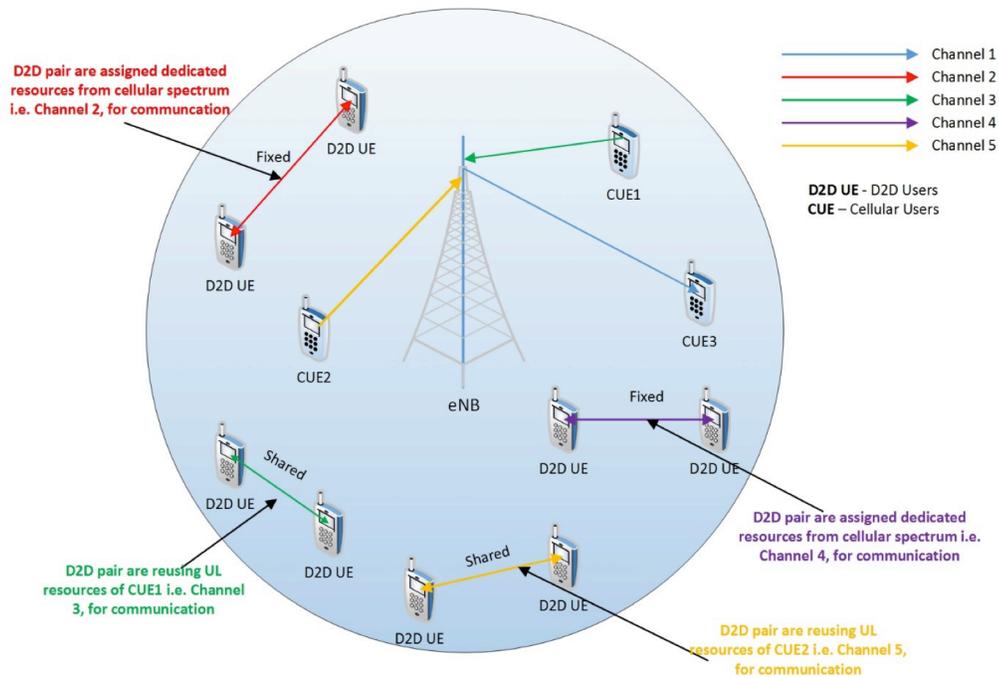


Fig. 4. A single cell comprising of multiple cellular links, and D2D links using different D2D communication modes.

1) Underlay In-Band

In underlay in-band, the D2D users and cellular users are allocated the same radio resources simultaneously by the eNB. The eNB reuses either the uplink or downlink resource blocks for D2D communication based on certain performance metrics such as mutual distance between D2D and cellular users, transmit power level, interference limited area etc. This type of implementation is also known as the reuse mode (non-orthogonal resource sharing). The reuse mode can achieve higher spectrum efficiency compared with overlay. However, it introduces severe interference problem between the D2D and cellular users, since both users are simultaneously using the same physical resource blocks [21-22]. Since the cellular users

are the primary users of the spectrum band, underlaying D2D communication on the same band, implies that, QoS of the cellular communication as well as the D2D itself becomes a challenge [15]. Furthermore, the reliability issue of both communications needs to be addressed. A number of literatures exist in this area, focusing on providing novel approaches in solving these aforementioned challenges.

2) Overlay In-Band

In this type of D2D communication also referred to as dedicated mode, fixed (orthogonal) resources are allocated for D2D communication by the eNB from the cellular band. For this reason, the mutual interference between cellular and D2D users is eliminated, since each

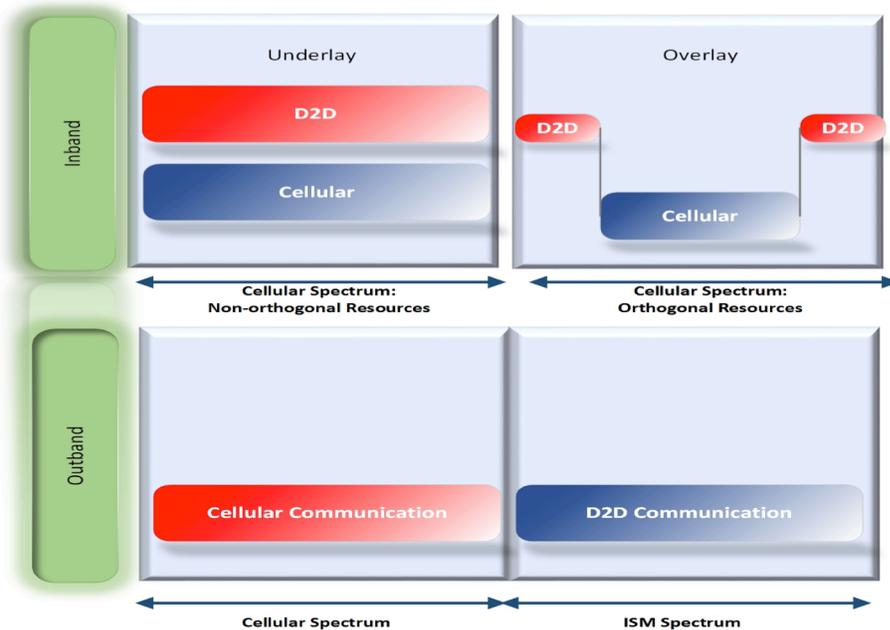


Fig. 5. Schematic frequency band occupancy of D2D communication in cellular networks.

communication mode occupy a separate and dedicated physical resource blocks for their individual communication [23]. But still, there is mutual interference among the D2D users since multiple D2D links can reuse the same RBs for their transmissions, which affect the overall network throughput. The overlay in-band has a major drawback of underutilization of radio resources as compared to underlay mode. This is because when there is no any D2D session; the dedicated resources are left ideal, which translate to inefficient spectrum usage [6]. Therefore, underlay D2D is gaining more popularity in the industry as well as the academia due to its higher spectral efficiency than overlay. Figure 4 illustrates random distribution of D2D and cellular users in a single cell scenario, where some D2D pairs reuse CU's uplink (UL) resources, while others use non-overlapping resources, for D2D communication.

B. Out-Band D2D Communication

Out-band D2D communication exploit the unlicensed ISM frequency band for its operations [24]. This is similar to the operating band of WLAN and Bluetooth technologies. In out-band D2D, coordination and management of D2D connections can either be controlled by the eNB also known as *network-controlled*, or by the D2D users themselves, referred to as *autonomous*. The main advantage of this category of D2D is that it eliminate the interference problem between cellular and D2D links. Also, resource allocation becomes easier since the scheduler (i.e. eNB) does not need to take into account frequency, time and location of users when assigning resource blocks (RBs) to both D2D and cellular users.

Furthermore, users can simultaneously maintain cellular and D2D connections using the two radio interfaces. However, the major drawback is its uncontrollable inter-system interference due to the presence of other communicating entities e.g. Wi-Fi

and Bluetooth devices that operate in the same unlicensed band. Thus, sharing unlicensed spectrum might not provide a stable controllable environment and would lead to congestion and poor QoS experience, and also affect the overall network throughput. In addition, security of D2D transmission [12], and coordinating communication over two different bands with independent radio interfaces incurs crucial power management problem [25]. For these reasons and other related issues, researchers and mobile operators pay much attention to in-band D2D communication, specifically underlay. Therefore, this paper will focus on underlay in-band D2D communication. Figure 5 shows schematic frequency band occupancy of D2D communication in cellular networks.

Out-band D2D communication can be categorised either as network-assisted (network controlled) or autonomous D2D depending on the level of network involvement in managing and coordinating D2D communication.

1) Network-Assisted D2D Communication

In network-assisted, the eNB is responsible for synchronizing D2D users in time, frequency and phase using primary synchronization signal (PSS) and secondary synchronization signal (SSS) during cell search procedure. It provides control information signals via physical downlink control channel (PDCCH), for device discovery, session setup, link establishment, resource scheduling assignment, power control, routing, etc. Also, the eNB monitors the D2D links to ensure that the D2D policies are not violated. The D2D users periodically feedback current status report on direct link and other control information surrounding the environment, to the eNB via physical uplink shared channel (PUSCH), random access channel (RACH), etc. Such report information includes channel state information (CSI), signal to interference and noise ratio (SINR), device discovery request, scheduling request

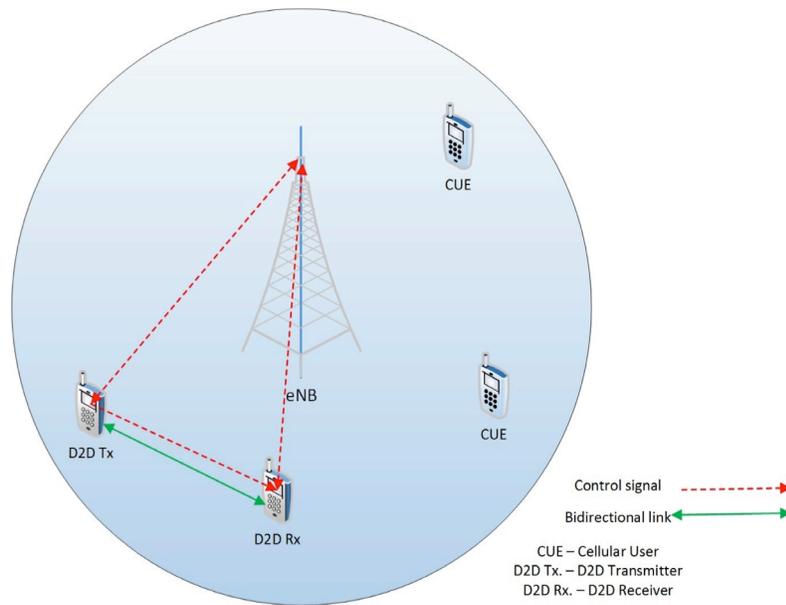


Fig. 6. Network-assisted D2D control message exchange and link establishment procedure

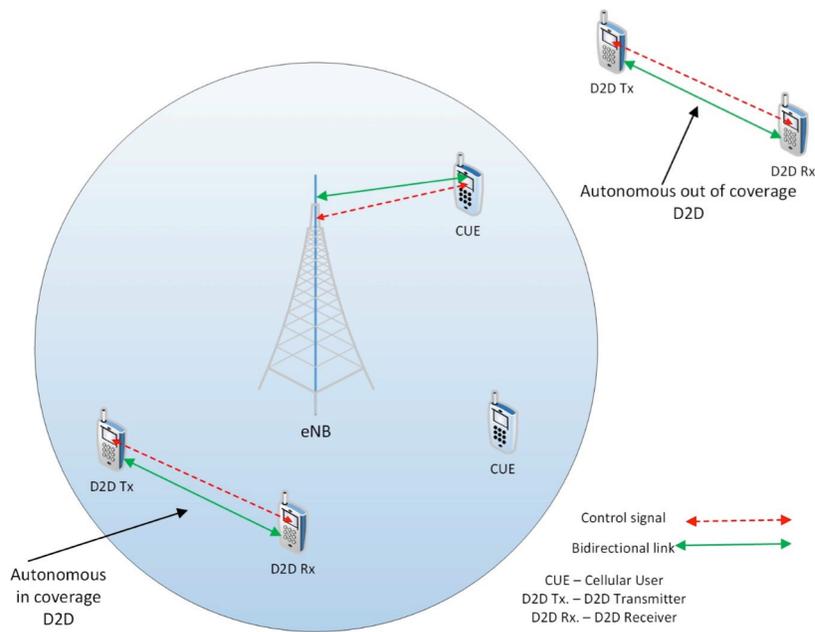


Fig. 7. Device – controlled discovery and session setup procedures.

and so on [26]. In essence, the eNB have total control of all D2D link activities, performs radio resource management (RRM) effectively, and hence, any undesirable interfering signals both from the cellular and D2D communications can easily be coordinated. Network-assisted D2D provides the benefits of satisfying the QoS requirements of cellular communication while managing D2D communications effectively and efficiently, with the aim of improving the overall system throughput. However, it incurs high signalling overhead necessary to manage and control D2D activities. For example, the eNB require the knowledge of the full CSI of all involved links for

interference avoidance techniques. This increases complexity on the part of the eNB. Figure 6 demonstrates a network-assisted D2D for a single cell scenario, where the D2D procedures are managed by the eNB.

2) Autonomous D2D Communication

In autonomous D2D communication, the eNB have partial control over the activities of the D2D users or links. The eNB performs radio resource allocation in a large time scale, put restriction on the maximum transmit power allowed at the side of D2D users, etc. D2D users independently establish communication session through

direct discovery, by announcing and monitoring process between the D2D pair, as shown in Figure 7. At the same time, the D2D users are able to control radio resource allocation and schedule their own transmission and set power control autonomously in a distributed fashion. Autonomous D2D communication is applicable in both in-coverage and out-of-coverage area scenarios where there is serving eNB and no cellular network infrastructure, respectively. In both cases, the D2D pair can independently establish communication between each other. The key benefits of autonomous D2D is that the eNB incur less signalling overhead, which allows it to serve other cellular users. However, interference management among D2D users, high implementation complexity on part of the D2D users, is among the major challenges for the autonomous D2D.

IV. D2D COMMUNICATION UNDERLAYING CELLULAR NETWORK – THE CHALLENGES

D2D communication as an underlay in LTE-A network enables fast access to the spectrum band with controlled interference by the network infrastructure. With underlay implementation, D2D communications can provide higher spectral efficiency and network throughput, which are the two main requirements for the LTE-A network. Also, D2D aims to achieve four types of gains, namely: Proximity, Hop, Reuse and Pairing. Proximity gain is achieved through short direct range communication via D2D links, which results in high data rate, low latency and low power consumption. Secondly, the hop gain, where D2D transmission uses only one hop, as compared to traditional cellular communication via eNB, in which both uplink and downlink resources are used. Re-use gain is achieved by simultaneously allocating the same radio resources to both D2D and cellular links. Lastly, pairing gain, which enables new type of wireless local – area services, e.g. social services, and a UE can choose between cellular and D2D communication modes. Song et al. indicate that with D2D communication, the overall network throughput may rise up to 65% compared with the situation in which all the D2D traffic follow conventional cellular mode [18]. In addition, the D2D operation i.e. pairing, handover etc., can be fully transparent to the users, as compared to Wireless Local Area Network (WLAN) or Bluetooth technologies. Although D2D communication provides several benefits in terms of performance improvement, but there are challenges facing the integration of D2D in LTE-A network. This section provides an in-depth discussion on these challenges.

A. Device Discovery

Device discovery is one of the major challenges in D2D communication, as devices needs to identify the presence of other devices, knows each other's identity, get information of services on offer and satisfy the proximity conditions, before establishing the direct communication path. Devices can periodically broadcast their identity information so that other devices can be aware of their existence and decide whether or not, to respond to their discovery request, and subsequently initiate a D2D direct or device relaying communication. This

is known as peer discovery, from D2D point of view. Peer discovery is performed by exchanging signalling messages referred to as beacon signals, between users that want to communicate in D2D mode, and between them and the eNB for control purposes [27]. These beacon signals contain the identity of each potential D2D user, type of service, and also serves as pilot (reference) signals for measuring the channel quality indicator (CQI) of the direct path [28]. Furthermore, the devices need to determine appropriate modulation and coding schemes to be used, as such, reference signals like LTE UL demodulation reference signal (DM-RS's) can be inserted at the D2DTx for channel estimation and demodulation at the D2DRx [29]. The eNB uses the CQI value, mapped it to SINR, to establish the direct path between the D2D pair, when the SINR is above a pre – defined threshold i.e. favourable for D2D communication.

There are two main techniques in D2D discovery process, namely Priori and Prosteri [30]. In former, a user initiates the discovery process by broadcasting beacon signals at regular intervals, prior to the actual communication session between the users. While in the latter, a discovery process is initiated by the eNB, while a communication session is ongoing between users. In such case, the eNB identify the users as potential D2D pairs, by analysing their IP addresses, and therefore, recommend them to switch over to D2D mode, so as to achieve better performance and higher gain. In both cases, the eNB reserves a discovery resource pool, which is utilized for D2D discovery purposes. Several research works have been conducted in D2D discovery, aiming at proposing efficient peer discovery algorithms that will conform to LTE-A discovery protocols with less signalling overhead and high performance in terms of discovery speed, discovery resource utilization, energy consumption and success probability [31]. Research is still going on to find optimal D2D discovery solutions that strike balance between cost, complexity and performance.

B. Mode Selection

Another challenging task in D2D communication is how to select the optimal transmission mode (i.e. either cellular or D2D mode) for potential D2D users after discovering each other. Although potential D2D users might be in the vicinity of each other, but it may not be optimal for them to operate in the D2D mode from performance perspective.

Mode selection means that the network (eNB) and/or the D2D users themselves choose to operate either in D2D mode (via direct communication link) or cellular mode (via the eNB), depending on some selection metrics such as path loss [32], distance between D2D and cellular users [33], channel quality condition [34-36] interference among D2D pairs, energy efficiency [37]. Channel quality condition and SINR is the most common selection metric proposed in the literature because it generates less signalling overhead, with less implementation complexity. The mode selection criterion is used to determine which D2D-eligible flow will actually use the direct link based on predefined SINR threshold, with the aim of maximizing system throughput and improving system

TABLE I
COMPARATIVE ANALYSIS OF D2D COMMUNICATION

Criteria	Inband		Outband	
	Overlay	Underlay	Network-assisted	Autonomous
Spectral efficiency	Medium	Very High	Low	Low
Interference between cellular and D2D users	Very Low	High	Negligible	Negligible
Interference among D2D users	Medium	Medium	High	High
Controlled interference environment	Yes	Yes	No	No
Implementation complexity	Medium	Low	High	High
Extra signalling overhead to network	Medium	High	High	Very low
Inter – platform coordination	No	No	Yes	Yes
Network controlled	Full/Hybrid	Full/Hybrid	Full	Loose
Cell coverage	In coverage/partial coverage	In coverage/partial coverage	In coverage	In coverage and out of coverage
Simultaneous D2D and Cellular transmission	No	No	Yes	Yes
Energy efficiency	High	High	Low	Low

TABLE II
USER COMMUNICATION MODES IN D2D ENABLE CELLULAR NETWORKS

Communication mode	Resource sharing scheme	Spectrum efficiency
D2D Shared Mode	Non – orthogonal	High
D2D Dedicated Mode	Orthogonal	Low
Cellular Mode	Conventional cellular resource allocation	None

capacity. On contrary, users can be in cellular mode, when there are no available resources to reuse due to interference problem, or when the D2D pair is at a distance that is not feasible for D2D communication. Table II categorised the available communication modes.

In network-controlled D2D, the eNB is responsible for selecting either D2D or cellular mode, based on the channel quality report from the users. The eNB keeps track of D2D link quality when D2D mode is selected, and handovers to cellular mode in case if the D2D proximity conditions are no longer met, or if there is a drop in the D2D link quality, while cellular link achieves higher throughput. This is in contrast to autonomous D2D, where the D2D users themselves choose to operate between these modes. In essence, proper mode selection plays an important role in determining the performance of D2D communication in cellular network. This is because, when D2D mode is appropriately chosen, the reuse factor increases, while, inadequate mode selection results in generating harmful interference within the system.

C. Radio Resource Management

Once the appropriate transmission mode is selected, a media access control (MAC) level packet scheduler that actually determines which RBs goes to which flow on each

transmission time interval (TTI) is required. In contrast to traditional LTE scheduling, radio resources are simultaneously allocated to the D2D and cellular links. The ultimate goal is to find the optimal RB assignment solution for both the traditional cellular and D2D communication links, based on which the communication links can efficiently perform their individual transmission while avoiding undesirable interference to each other.

An RB is the basic representation of radio resources in LTE-A networks. It occupies one slot in the time domain and 180 kHz in the frequency domain i.e. 12 subcarriers with 15 kHz subcarrier spacing [38]. The RBs are assigned using either a centralized allocation scheme or a distributed allocation scheme. The eNB is responsible for the allocation of the RBs in the centralized resource allocation scheme, while the users select from a resource pool that is pre-configured statically or semi-statically by the eNB in the distributed resource allocation scheme. Hence, eNB's participation in making scheduling decision for both the D2D and cellular users incurs more signalling and computational overhead especially in high network density areas. The distributed resource allocation scheme is therefore; gaining attention in D2D communication due to its scalability, low complexity and less overhead in resource assignment. A

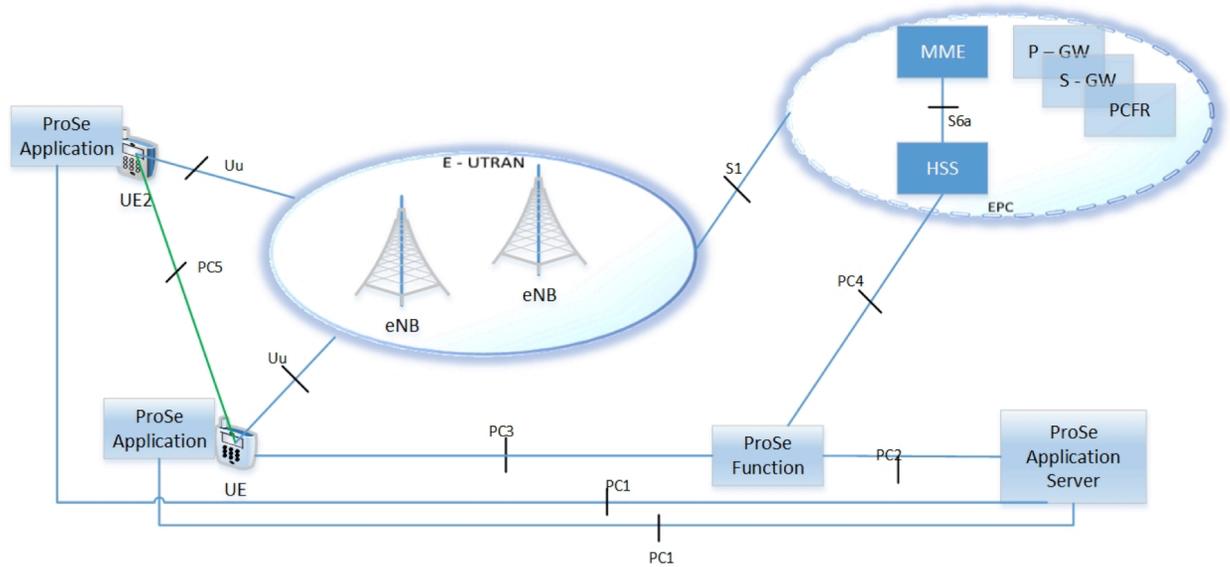


Fig. 8. Schematic representation of D2D enhanced LTE architecture.

robust spectrum sensing and access mechanism, similar to one used in the cognitive radio networks is highly required to reduce harmful interference to cellular users.

D2D transmissions can reuse either the uplink or downlink or both resources of the licensed cellular spectrum. UL resources are widely considered to be the efficient reuse candidates for D2D transmission because they are less utilized than DL (due to the well-known traffic asymmetry) [23, 39-41]. Also, user equipment (UE) has less transmit power compared to eNB and the victim of D2D interference is mainly the eNB from cellular communication perspective. Therefore, in view of this, interference can easily be coordinated and controlled. However, reusing UL resources requires the mobile terminals to be equipped with single carrier frequency-division multiple access (SC-FDMA) receiver, which results in increased system complexity than equipping the mobile terminals with orthogonal frequency-division multiple access (OFDMA) transmitter, for the case of DL resource sharing.

In addition, the same RBs can be spatially reused among different D2D pairs. This improves spectrum utilization, since more UE's that are distant apart can be simultaneously served with the same RBs. However, spatial reuse generates mutual interference among the D2D users, and therefore must be coordinated effectively. It is noticed that instantaneous interference among multiple D2D pair and cellular users depends on efficient resource scheduling technique [42]. Various optimization framework have been proposed in the literature, on how to jointly allocate radio resources with power control, either centralized [43], fully-distributed or semi-distributed schemes [44], to improve spectral efficiency. Thus, intelligent and reliable allocation of the shared resource blocks for D2D and cellular communications would results in optimal spectrum utilization and minimizes harmful interference in the network.

D. Modification to LTE-A Architecture

The existing centralized LTE-A architecture needs to be modified and new features have to be implemented in order to accommodate D2D procedures such as device discovery, mode selection, D2D session management set-up, physical layer procedures, resource allocation, etc. [45] describes the architectural design and protocol modifications that needs to be integrated on the existing cellular standard in order to support D2D communication. Similarly, the integration of new functional nodes and interfaces to the existing LTE-A architecture to support D2D services is proposed in [7], as shown in Figure 8.

The ProSec Function and ProSe Application server nodes are incorporated and connected to the EPC and E-UTRAN. These nodes are responsible to aid D2D operations such as D2D discovery, authorization and policy, device identifier allocation, call establishment procedures, mobility tracking, service identification and other support services. On one hand, a ProSe Application is added on the D2D user side and logically connected to ProSe Function and ProSe Application Server nodes for signalling purposes and other D2D procedure message exchange. The direct communication between D2D users is carried out via the PC5 interface. This interface is integrated in the existing physical layer design of LTE-A and will be used for exchanging all D2D control and data signals, e.g. peer discovery, synchronization, user data transfer, etc., [6]. Furthermore, the existing MME, HSS nodes are enhanced to provide user information for authorization and other D2D functionalities.

E. Security in D2D

The co-existence of the D2D and cellular communication increases the potential risk of new threats to the security of the system. This is because various combinations of user devices, protocols and network topologies are integrated to work

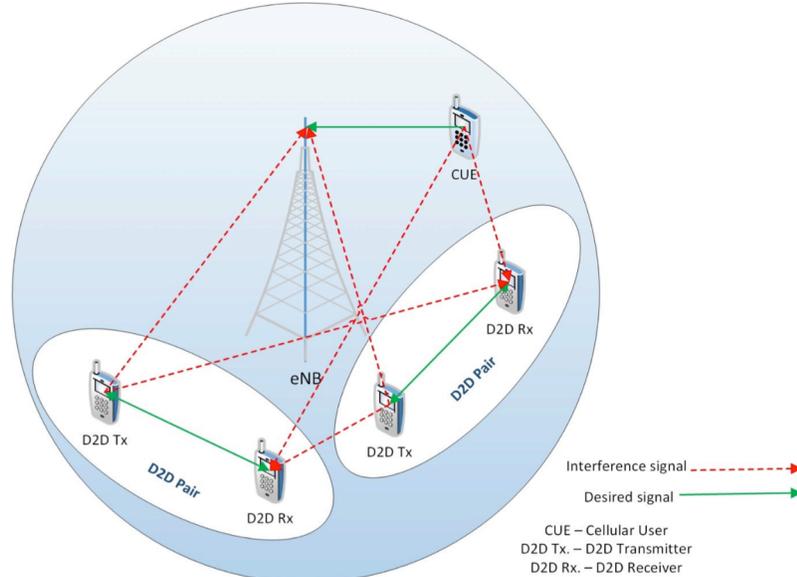


Fig. 9. Interference scenario of D2D and cellular links under uplink resource reuse.

together as a single platform. This therefore makes the system more vulnerable and susceptible to different types of network attacks such as denial of service, man-in-the-middle, replay attacks, etc. The security aspect of D2D is yet to be given considerate attention from the research community, and very few works is done in this area. The security framework of D2D is categorised into two [12], namely: Open Access and Closed Access. In the former, there is no restriction to any device that want to operate in D2D mode, any device can be discovered and is discoverable, and also, any device can act as relay for all other potential D2D devices. This category poses a security concern, because authentication and authorization policy is required for potential D2D users. On the other hand, the closed access provides a list of trusted devices that can be discovered and are discoverable, to ensure a level of privacy. Other study are of the view that, the present security framework of LTE-A network can be adopted in D2D communication, since both communications operate on the same platform [8]. Nevertheless D2D security is an immature area, which require adequate attention in order to develop efficient cryptographic techniques that will ensure secure D2D networks with confidentiality, integrity and availability features.

F. Mobility Management

Majority of work on D2D communication provides analysis on the single cell deployment scenarios. Some even suggests that D2D communications should be designed for rather static nodes with limited mobility support, but still, movement from one cell to another cannot be neglected. Therefore, mobility management and handover have significant impact on the performance of D2D communication. Firstly, the maximum distance between D2D pairs in different deployment scenarios in accordance to QoS requirement and interference constraints to cellular links needs to be studied. Secondly, movement of D2D transceivers from one cell to another during an ongoing

communication session is practically possible, and thus, service continuity is required. This however, would leads to a handover. Thus, a resilience handover process is required, in order to realise seamless communication on the D2D links. Alternatively, the D2D transceivers may be switched-over to cellular mode when it is no longer possible to continue transmission in D2D mode, due to mobility or excessive interference levels experienced from neighbouring cells. Therefore new decision – making handover algorithms to handle movement from single to multi-cell scenarios, or switched to cellular mode need to be proposed.

V. INTERFERENCE IN D2D

D2D communication underlying cellular network is expected to operate within the same coverage area of an existing cell of LTE-A network and share the same cellular spectrum. Thus, reusing the same radio resource blocks of cellular users by D2D users introduces undesirable interference (known as cross-tier interference) from cellular users to D2D users and from D2D users to cellular users. When reusing the downlink RBs, D2D users suffers harmful interference from the eNB, due to the high transmit power of the eNB. This makes it difficult to guarantee the quality of D2D services, decreases the SINR and hence, results in poor performance of the D2D systems.

On the other hand, reusing uplink RBs generates less undesirable interference to the D2D users, because the traffic overhead and control signalling of uplink are much lower than that of downlink in cellular networks [31]. Hence, the total interference level in uplink spectrum is less than that in downlink spectrum.

Figures 9 and 10 illustrate the interference scenarios for UL and DL reuse cases, respectively. For UL resource sharing, it can be observed in Figure 9 that the D2D transmitter causes undesirable interference to the eNB, while the cellular uplink

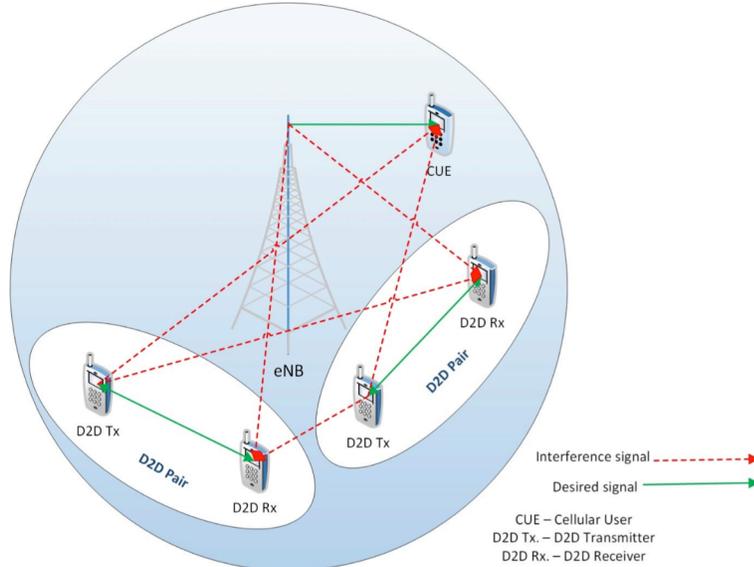


Fig. 10. Interference scenario of D2D and cellular links under downlink resource reuse.

TABLE III
CLASSIFICATION OF INTERFERENCE SCENARIOS FOR DIFFERENT RESOURCE SHARING PERIOD

Case	Resource sharing direction	Aggressor	Victim	Type of Interference	Priority
1	UL	D2D Tx	eNB	Cross – tier	Yes
2	UL	CU	D2D Rx	Cross – tier	No
3	DL	D2D Tx	CU	Cross – tier	Yes
4	DL	eNB	D2D Rx	Cross – tier	No
5	UL/DL	D2D Tx	D2D Rx	Co – tier	No

user generates interference to the D2DRxs. For DL case (Figure 10), the eNB is the aggressor interfering with more than one D2D receivers and also D2D transmitter is the aggressor interfering with cellular downlink user. Furthermore, there exist mutual interference among D2D pairs that simultaneously share the same RBs in both UL and DL reuse cases, which is referred to as co – tier interference. Therefore, it is highly necessary to mitigate interference introduced by D2D users, in order not to cause service disruption to the legacy cellular users. In this research work, we are focusing on uplink resource reuse for D2D links, for better performance in terms of D2D channel rate and operability. The basic interference scenarios in D2D-enabled cellular network are summarized in Table III. Cases 1 and 3 are interferences from D2D communication to legacy cellular network when reusing UL and DL resources. These interference situations have high priority in order to protect the legacy cellular users from service disruption. On the other hand, case 2 and 4 are interference situations from cellular communication to D2D users, for UL and DL reuse period. These interference cases reduce the reliability of D2D communication, and therefore, must be overcome. Case 5 is the interference situation among multiple D2D pairs sharing the same UL/DL resources simultaneously. This interference

further degrades the performance of D2D communication. All these interference cases must be mitigated efficiently, in order to guarantee the QoS of cellular network, fulfill the prioritized cellular service requirements and improve the reliability of D2D communication.

A. Interference Management Techniques in D2D

Recently, the research community has been focusing on developing novel interference management techniques to mitigate the interference generated due to the coexistence of D2D communication in cellular networks. In traditional cellular systems, power control algorithms and radio resource management are often used to mitigate interference [18]. Optimal interference awareness/avoidance and coordination solutions must also be applied in D2D communication to improve the overall network throughput of both LTE-A and D2D systems and satisfy the QoS constraint.

1) Power Control (PC) Technique

One of the most common interference avoidance scheme is adjusting the transmit power of D2DTx below a predefined threshold while meeting the SINR target of cellular communication [14-16]. The eNB can set up constraint on the transmit power level of the D2D transmitter, to limit the interference caused to the cellular receivers. With adequate

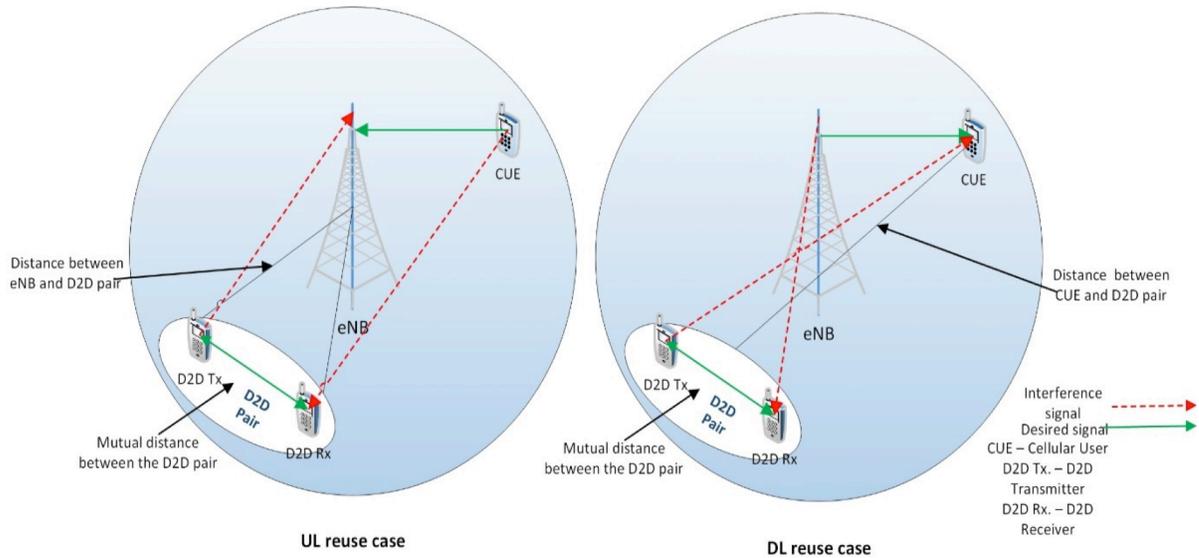


Fig. 11. D2D Power control model.

power control scheme, more D2D pairs can reuse the same resources simultaneously, which translate to higher spectrum efficiency. Nevertheless, this simple power control scheme results in underutilization of D2D communication among-potential D2D users, due to the restriction on transmission power level. In other words, D2D cannot always be feasible.

Figure 11 shows the schematic representation of power control strategy. The applicability of power control scheme largely depends on; mutual the distance between the D2D pairs, the distance between the D2D pairs and the eNB or the CUE, for UL reuses case and DL reuse case, respectively. If the D2D pairs are far away from the eNB or CUE, and at the same time, the D2D pairs are in close proximity, reducing the power control won't affect the performance of the D2D communication. On the contrary, when the eNB or CUE are relatively close to the D2D pair and the distance between the D2D pair is large, decreasing the transmit power of D2D users could result in very low probability of D2D communication or even prevent D2D communication at all between the D2D pairs.

The aforementioned power control schemes can mitigate interference from D2D to cellular communication, but they are only applicable when the D2D pair are close to each other and/or at a sufficient distance from the eNB or CUE. Also, the stringent restriction of limiting the transmission power of D2D users may degrade the performance D2D communication. As such, power control scheme cannot be the optimal interference mitigation solution in D2D communication.

2) Radio Resource allocation Techniques

A different method for interference mitigation in D2D communication is by utilizing various radio resource allocation algorithms. The main aim here is to optimally

assign radio resources to a group of or all D2D pairs efficiently, and at the same time ensure that co-channel users do not interfere with each other.

A novel interference mitigation solution by intelligent selection of either UL or DL spectrum band for D2D link reuse, based on the received power as the radio distance metric is proposed in [46]. The received power is measured from an eNB, if it above a predefined threshold, then the DL is selected otherwise UL is selected for D2D link reuse. As such, the interfering signals from D2D communication to cellular users are reduced, and the overall cellular gain is improved. However, their scheme incurs more signalling overhead to the eNB and is delay bound since the band selection decision-making is carried out on every TTI.

A location-based resource allocation method to mitigate mutual interference between D2D and CU users sharing the same UL resources was studied in [24] through the concept of accessible and reusable regions. Only D2D users located in the accessible regions can simultaneously share the same radio resources with cellular users that are located in reusable regions. Otherwise, the reuse scheme is not feasible. From their results, the outage probabilities of both D2D and cellular users are minimized, with improved system reliability. However, localization of users bounded by regional areas yields less spectrum efficiency and flexibility. Similarly, a distance-based resource allocation scheme to mitigate interference from CUE to D2D Rx is proposed in [47]. This scheme benefits from low signalling overhead, because the eNB assigns resources to the D2D pair according to the mutual distance between them and CU, rather than CSI measurement between the links. Though, the exact location of individual cellular and D2D users need to be known by the eNB in order to share the resources effectively.

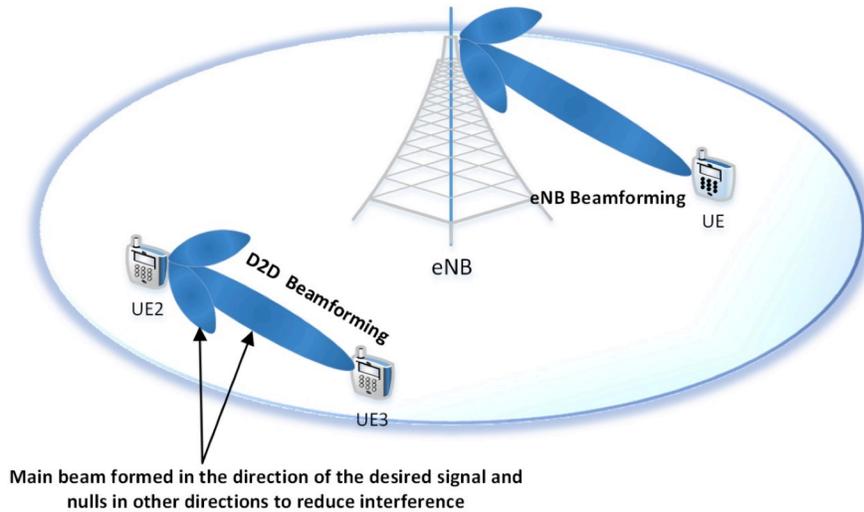


Fig. 12. Schematic representation of beamforming with eNB and D2D users equipped with multiple antenna elements.

The problem of interference management in D2D communication underlying LTE-A network is formulated as an interference-aware graph model [38]. An interference-aware graph is then proposed based on the radio resource reuse algorithms that can effectively improve the system throughput and mitigate co-channel interference among D2D and cellular users. Presented simulation results demonstrate an improved system performance in terms of overall network sum-rate, with low computational overhead. Also, [48] has modelled the problem of co-channel interference between D2D and cellular users with the aid of an advanced mathematical tool, game theory. In their work, an interference-aware resource allocation using sequential second price auction scheme was proposed to optimize the overall sum rate of the D2D system. Simulation results demonstrate an achievable performance of the system sum rate, but at high complexity cost.

A mechanism to avoid inter-cell near-far interference problem in a multi-cell environment is proposed in [49]. In their procedure, the neighbouring eNBs monitors the control channels of a D2D subsystem and exchange necessary information, to identify the interference D2D victims and CUs causing the interference due to UL spectrum sharing. Based on this knowledge, the serving eNB can stop scheduling transmission of interferer (i.e. CU) until D2D transmission ends. Simulation results shows that the performance of D2D communication is enhanced, but at the cost of reliable control channel sensing. A similar procedure was adopted in [48], to solve the interference problem in a single cell scenario.

An interference mitigation solution based on evaluating the neighbour distance and Tolerant Interference Degree (TID) level among potential D2D pairs is proposed in [50]. The TID performance metric was defined as the number of D2D pairs that can coexist with a given D2D pair to reduce the undesirable interference at the D2D receiver. Although their approach is less complex and incurs less signalling

overhead to the eNB, but, the orthogonal resource allocation scheme considered is less spectrum efficient.

The objective of radio resource allocation techniques is to optimize the resource usage between primary cellular users and D2D pairs. Adopting these diverse techniques suppress the interference problem when D2D communication coexists with cellular network. However, the main drawback with this approach is underutilization of radio resources and reducing multi-user diversity because the physical separation limits the scheduling alternatives of the eNB.

3) Joint Power Control and Radio Resource allocation Techniques

A more advanced approach for mitigating interference in D2D/LTE system is to jointly use power control with various resource allocation techniques in order to realize the full potentials of D2D communication. Several works have investigated this joint optimization problem, where they focus on interference management and control between cellular links and D2D links, with the aim of complementing and enhancing the overall performance of a single scheme. A combined effect of dynamic power control and resource allocation to reduce D2D interference to cellular network was studied in [17]. In their approach, the eNB initially assign resources to CUE, then to D2D users, and finally reuse CUE's resources to D2D users when the demand is high. Then, the eNB dynamically adjust the transmit power of the D2D transmitter by determining the channel gain between individual terminals, in order to avoid harmful interference when both D2D and CUE occupy the same resources. The performance of this scheme was measured based on the SINR level achieved in both transmission systems. However, the centralized nature of dynamic power control by eNB incurs significant overhead on part of the eNB.

The authors describe a power control and distance-based

resource allocation mechanism to mitigate the interference among cellular and D2D users sharing UL resources [1]. To avoid interference from cellular users to D2D communication, the D2D users only reuse the UL resource blocks of CUs that are not in close proximity. On the other hand, the D2D users adjust their transmission power in a manner that the interference from D2D communication to eNB is below a tolerable threshold. Their results reveal that the overall system throughput is enhanced by 41% under the proposed mechanism.

Meanwhile, a novel interference avoidance model based on user location is proposed in [51]. In their work, rather than limiting the transmit power of D2D users as in conventional interference management scheme, an interference limited area is proposed. Within this area, no cellular user will share the same resources with a D2D pair. As such, excessive interference between D2D and cellular communication is avoided. Although their simulation results show a significant performance gain, however, the major drawback of this scheme is reducing multi-user diversity because the physical constraint limits the scheduling efficiency of the eNB.

A power control and distance-based interference mitigation algorithm has been proposed in [52]. The scheme limits the maximum transmit power of the D2DTx in accordance with the minimum acceptable SINR target of the eNB, such that the interfering signal from the D2DTx to eNB is reduced. Then, the eNB selects the optimal UL resources to share with the D2D link, by estimating the distances between D2D users and various CUEs using location estimator. Then, the CU that minimizes the outage probability of the D2D link is chosen accordingly. In other words, the longer the distance between the CUE and D2D link, the better performance D2D communication would experience. As such, the interference from CU to D2DRx is reduced. Their numerical results show that the performance of D2D communication is improved in terms of outage probability gain. However, mutual interference among D2D pairs sharing the same radio resources was ignored.

4) *Spectrum Splitting Techniques*

Spectrum splitting is the easiest way to avoid interference in D2D enabled cellular network. Adopting time division multiplexing (TDM) technology to separate cellular and D2D transmissions could effectively reduce the interference level in the hybrid cellular network with D2D

communication [53-55]. However, this method would lead to inefficient utilization of the available spectrum. Also, it only accounts for cross-tier interference between cellular and D2D users. Therefore, additional mechanism is required to mitigate the interference among multiple D2D users, which share the same set of resources.

5) *Other Interference Mitigation Techniques*

A solution to the interference issue in D2D communication through the application of network coding technique has been proposed in [56]. To mitigate the interfering D2D signals to eNB, helper nodes are selected to assist in cellular UL transmission to eNB, and network coding is applied for the actual transmission. Although the performance of cellular communication is improved, but on the other hand, additional interference is generated by the helper nodes, which have a negative influence on D2D transmission.

The application and impact of interference-aware interference mitigation algorithms in network-assisted D2D communication is investigated in [26]. In the proposed scheme, the gain of interference-aware algorithms are evaluated using simultaneous non-unique decoding (SND), and decoding cellular interfering signals at the D2D receiver reduces interference. Their results indicate that interference-aware algorithms enhance the throughput of D2D communication. However, both D2D and cellular users need to operate on interference-aware algorithms under the control of an eNB.

From the foregoing, it can be observed that the majority of the existing literatures focus extensively on proposing interference mitigation solutions based on transmission power control of D2D transmitters, diverse resource allocation techniques, interference limited areas, combined power control and resource allocation mechanisms, etc.

6) *Multiple-Input Multiple-Output Techniques*

Multiple-input multiple-output (MIMO) antenna systems have become an important component in today's cellular wireless network standards to improve overall system performance [57]. These MIMO transmission methods such as beamforming, interference cancellation technique, can be utilized in D2D communication to further avoid interference between cellular links and D2D links with the prior knowledge of the interfering channels CSI.

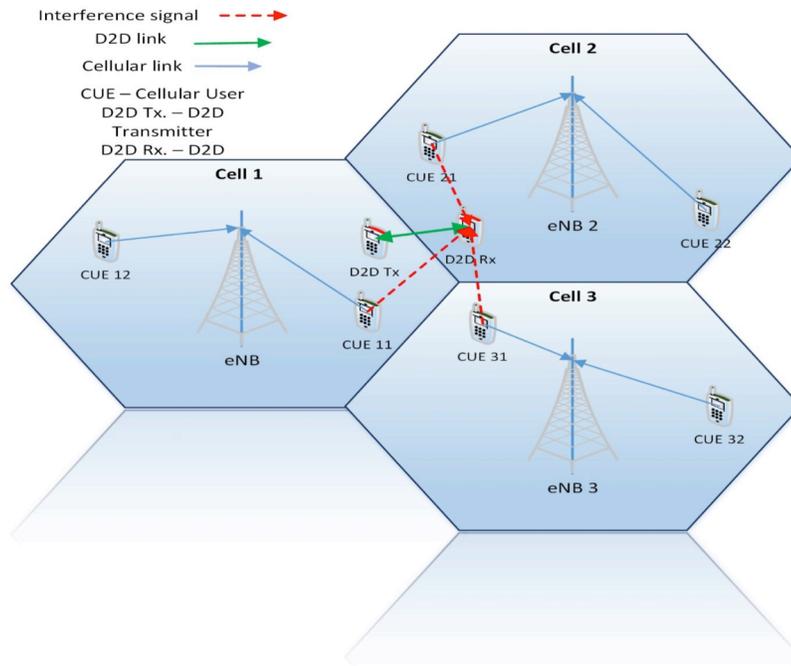


Fig. 13. Interference scenario in multi-cell network

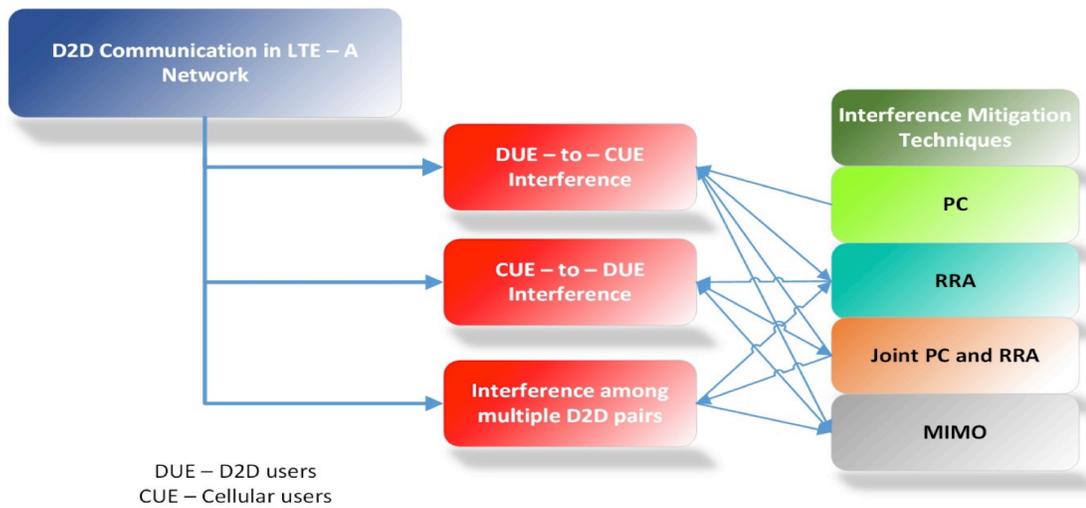


Fig. 14. Overview of Interference Mitigation Techniques in D2D communication underlying LTE - A Network.

Beamforming also utilizes multiple transmit and receive antenna elements to generate directional antenna beam pattern. The generated beam (desired signal) is steered in the direction of the intended recipient, while at the same time cancelling out undesirable interference in the direction of other users [58]. In other words, the transmit power is maximized towards the receiver angle, while minimizing the signal in the null space. When transmitting, a beamformer controls the phase and relative amplitude of the signal at each transmitter, thereby producing a high directional beam pattern in the direction of the intended recipient and null in the direction of interference. This increases the SINR of the intended user and reduces the wastage of transmitted power

in the undesired direction. Other benefits of beamforming includes high spectrum reuse factor, increase in capacity, etc. Therefore, the use of such multi-antenna beamforming either at downlink or uplink transmission can mitigate the interference levels between cellular and D2D transmission, improves system capacity and further guarantee the feasibility of D2D transmission.

eNB beamforming, that is performing beamforming on the cellular downlink (eNB) to mitigate the effect of interference have gain attention in the research community and some literatures exist in this area. In such a system design approach, the eNB is equipped with an array of multiple-antennas with different precoding strategies. In

TABLE IV
SUMMARY OF LITERATURES ON INTERFERENCE MITIGATION TECHNIQUES IN D2D COMMUNICATION UNDERLAYING LTE-A NETWORK

Article	Interference Mitigation technique	D2D Reuse resources	Interference type	Network complexity
[1] [17]	Joint power control with resource allocation	UL	Cellular to D2D and vice versa	Single cell
[16] [19] [20]	Joint power control with MIMO Beamforming	DL	Cellular to D2D	Single cell
[14] [15] [16]	Power control with SNIR target	DL/UL	D2D to cellular	Single cell
[24] [46] [47] [52]	Distance/location – based resource allocation	UL	Cellular to D2D and vice versa	Single cell
[26]	Interference – aware algorithms	UL/DL	Cellular to D2D	Single cell
[53]	Time division duplexing	UL/DL	Cellular to D2D	Single cell
[50]	Greedy orthogonal resource allocation	UL/DL	Between multiple D2D users	Single cell
[56] [61]	Network coding	UL	D2D to cellular	Single cell
[59]	Beamforming and Interference cancellation	DL	Cellular to D2D	Single cell
[60]	MIMO beamforming	UL	D2D to cellular	Single cell
[49]	Channel – based resource allocation	UL	Cellular to D2D	Multi cell

particular, the eNB avoid generating cross-tier interference to D2D receiver (UE3) sharing the same resources by aligning the transmitted signal from the eNB to the null space of the eNB–D2D interference channel, as illustrated in Figure 12.

Investigations have been made in [59] about the performance of D2D communication system sharing downlink resources with multi-antenna eNB, for both beamforming and interference cancellation strategies at the eNB under quantized channel estimation and perfect CSI. Also, D2D receivers' interference mitigation schemes are proposed in [16] which use MIMO eNB downlink transmission, in a single cell scenario. The eNB can utilize any MIMO transmission scheme by designing transmitter weights for a projected downlink channel, and then, the downlink-precoding matrix can be computed as the multiplication product of the projection matrix and the designed transmitter weights. The simulation results have shown that D2D links experiences higher SINR thereby increasing the reuse factor, whereas the CUE undergoes marginal decrease in SINR. However, this approach only works when the downlink RBs are being considered as the reuse resources for D2D transmission. Moreover, the eNB requires the CSI of the interfering links.

Performance related investigation of a joint beamforming and power – control method to mitigate the interference from eNB to D2D users in the downlink resource reuse scenario is made in [18]. In their scheme, the eNB is equipped with multiple antennas and performs beamforming to avoid the interference experienced by D2D receivers, while the user terminals have single antennas. The eNB calculates the beamforming matrix based on the interfering

link CSI obtained from D2D receivers and data link CSI obtained from the cellular user. The eNB then determines transmit powers based on the SINR thresholds of both cellular and D2D links. The presented results show that beamforming improves the performance of D2D communication such that the SINR criteria limit the interference experienced by D2D receivers from eNB. Also, controlling the transmit power of the D2D transmitter enhances the performance of the cellular communication, as it reduces the interference experienced by cellular users. However, this scheme is based on downlink resource sharing, in which eNB have high transmit power that subject the D2D receivers to more excessive interference signals. In addition, their analysis is based on single cell deployment, without taking into account interference from neighbouring cells.

An optimized joint beamforming with power control scheme to reduce the mutual interference that co – exist between D2D and cellular users, and to minimize power consumption while satisfying the QoS constraint of both systems is proposed in [19]. The optimization problem for the transmit power and beamforming weight vectors was solved based on support vector machine (SVM) algorithms, with the aid of statistical CSI estimation. A novel analytical expression of the ergodic capacity (EC) and average symbol error rate (ASER) of all the users in the system was obtained. Both system simulation results and theoretical analysis have shown that the proposed scheme achieves a good performance in terms of system throughput and capacity. However, there performance analysis considered only single D2D pair within the system model. Thus, multiple D2D pairs are needed to be deployed, in order to

TABLE V
COMPARATIVE ANALYSIS OF INTERFERENCE MITIGATION TECHNIQUES IN D2D COMMUNICATION

Characteristics	Power control		Radio Resource allocation		MIMO
	Fixed	Dynamic	Channel – based RA	Distance – based RA	Beamforming
Target	Cellular QoS guaranteed, maximize throughput	Cellular QoS guaranteed, maximize throughput	Interference reduction, D2D capacity enhancement, improve SINR,	Interference reduction, D2D capacity enhancement, improve SINR	Improve D2D link quality, interference avoidance, maximize total system throughput
Central control	eNB	eNB	Depends on design requirement	Depends on design requirement	Depends on design requirement
Complexity/cost	Low	High	High	Medium	High
Interference reduction level	Low	Low	High	Medium	High
Interference control type	Centralized	Centralised	Centralized	Centralized	Centralized/Distributed
Spectrum efficiency	Medium	Medium	Low	Low	High
Side information	Control signals	Periodical CSI feedback	Channel measurement and feedback	User location information via GPS	CSI
Flexibility	Fixed	Dynamic	Dynamic		

ascertain the level of interference suppression of their proposed scheme. An interference-aware scheduling algorithm for D2D communication in multi-antenna system is proposed in [36]. In their approach, D2D links are only paired to share the same UL resources with a CU such that the interference caused to both communication systems are below certain thresholds; otherwise, the D2D links are scheduled on default resources. Then, an optimum beamforming is applied based on SNIR metric to further reduce the interference level and improve the system performance. Simulation results shows that the pairing algorithm together with beamforming technique increases overall system throughput while satisfying QoS constraints of both D2D and cellular communication.

Few studies have exploited multi-antenna beamforming technique on the DL eNB infrastructure to mitigate interference experienced by D2D receivers. On the other hand, D2D beamforming, that is performing beamforming on user devices to avoid any undesirable interference generated from D2D transmitter to cellular user and to other co-channel D2D users, is still yet to be studied extensively. To support this approach, already, uplink multi-antenna transmission is among add-on features proposed in Release 10 of LTE-A [18], as part of 3GPP's effort to satisfy the requirements of the LTE-A system.

Therefore, uplink multi-antenna design on user devices can be utilize to achieve D2D beamforming, by steering the beam towards D2D receiver and null in other direction. This

will effectively reduce the interference levels in D2D communication. But, to the best of our knowledge, the only work that exploit D2D beamforming in which a null-space based robust interference mitigation scheme for D2D systems sharing UL cellular resources is modelled is proposed in [60-61]. In their work, the interfering channel's CSI to eNB and from CU, was estimated using linear minimum mean-square error (LMMSE) method. Then, transmit and receive beamforming was designed at the D2D transceivers pointing signals only to the direction of the null space estimated channel, in order to effectively minimize the interference generated to eNB and from CU. Simulation results shows that the scheme improves D2D system throughput. However, there was no any comparison with other similar studies, to indicate the relevance of their optimized interference technique [62-64].

Table IV shows a summary of the studies on interference management for D2D enabled cellular networks in terms of interference mitigation technique, D2D reuse case, interference mitigation case and scenario. It can be observed that the techniques of interference mitigation differ slightly, depending on the interference scenario to be solved. For instance, the power control technique is utilized mostly for interference from D2D to cellular communication. On the other hand, diverse radio resource allocation and advanced antenna techniques such as MIMO, beamforming addresses both cross-tier and co-tier interference problems.

TABLE VI
PROS AND CONS OF D2D INTERFERENCE MITIGATION TECHNIQUES

Scheme	Pros	Cons
Power control	<ul style="list-style-type: none"> • Transmission power can be optimized in an adaptive manner to suppress interference • Simple to implement, especially when the D2D pairs are in close range • Low computational cost 	<ul style="list-style-type: none"> • Low probability of D2D communication between D2D pairs due to limited transmit power • Not effective in mitigating interference from cellular users to D2D users • Limited performance from D2D communication perspective • Unable to dynamically reflect channel variations, especially when fixed PC is employed
RRA	<ul style="list-style-type: none"> • Resource allocation algorithms can be optimized to suitably avoid interference • Fractional frequency reuse improves channel quality by utilizing different resources for D2D and cellular communication 	<ul style="list-style-type: none"> • Inefficient utilization of the licensed spectrum • Requires channel statistics and exact knowledge of user location, which incurs additional signalling overhead to the eNB • Longer scheduling time due to large signalling overhead • Low throughput for high payload case • Computationally intensive when multiple D2D pair share the same resources with a cellular user
Joint PC and RRA	<ul style="list-style-type: none"> • Combines the advantages of PC and RRA 	<ul style="list-style-type: none"> • Computationally intensive • Requires implementation of joint RRA and power algorithms • Increase in coordination and signalling overhead
Beamforming	<ul style="list-style-type: none"> • Robust interference mitigation solution • Directional beam targets the intended D2D recipient while creating a null towards other users 	<ul style="list-style-type: none"> • Requires precoder design, which incurs computational overhead • Requires accurate CSI of all involved links • Cost of hardware (multiple antenna elements) implementation

Also, it can be seen that majority of the previous works considers one D2D pair scenario in their system model. Hence, multiple D2D pair case needs to be investigated, so as to mimic practical cellular network environment. With multiple D2D pair, the reuse factor increases, which results in increase in resource utilization.

However, this increases the interference levels, which requires to be managed effectively, while meeting the QoS requirement of both D2D and CU users. Also, 99% of studies on D2D and their performance analysis are based on interference within a single cell scenario. However, this assumption is far from reality, as interference from neighbouring cells including the interference from both

cellular and D2D transmissions in the neighbouring cells should be taken into consideration, as illustrated in Figure 13. In fact, the performance of cell edge users is predominantly affected by neighbouring cell interferences. In Figure 13, although the D2D pair (i.e. D2D Tx and D2D Rx) are in close proximity, but they are two boundary users located in different cells, cell 1 and cell 2, respectively. Sharing the same resources implies that they may be interfered by several cellular users from neighbouring cells, such as CUE 11 in Cell 1, CUE 21 in Cell 2 and CUE 31 in Cell 3. The interference mitigation solutions proposed for single cell system cannot be equally applied in a multi-cell environment, due to the independent radio resource management and coordination by each eNB. This means

that the serving eNBs in each cell most coordinate in allocating resources for D2D reuse, thereby mitigating the inter-cell interference problem.

B. Comparative analysis of D2D Interference Mitigation Techniques

Most of the interference mitigation techniques for D2D enabled cellular network in the literature employs the PC, RRA, hybrid/joint and multi-antenna schemes (Figure 14). Other schemes proposed such as networking coding, spectrum splitting, etc., were not given considerable attention. Hence, comparative analysis of the main schemes, i.e. PC, RRA, and MIMO is already presented in Table V, whereas Table VI shows pros and cons of the above mentioned interference mitigation schemes.

To sum it all, techniques to minimize the total power consumption are simple to implement, but offer limited performance gain from D2D communication perspective.

Majority of the RRA techniques employed; (1) channel sensing and (2) geographical user location-aware reuse approaches, to schedule cellular and D2D users efficiently, while avoiding interference in the cross-tier system. Although these RRA schemes are viable solution to effectively mitigate interference, but these methods mostly do not admit D2D pairs to operate on frequency resources that will violate the required QoS constraints of the cellular users. This means that the D2D pair may not operate on some radio resources at all, which translate to inefficient resource utilization. In addition, the RRA techniques are mostly based on one to one matching policy, in which only one D2D pair reuses the cellular resources either in the UL or DL period. This also results in low frequency reuse gain. Joint PA and RRA solutions have high implementation cost because of the complexity of the proposed joint algorithms. It is therefore necessary to find a trade-off between high system performance and low complex algorithm.

The common characteristics of PC, RRA and the joint/hybrid interference mitigation techniques in D2D communication is that they involve mode selection criterion, which implies that D2D communication cannot be feasible on some radio resources, even if the D2D pair are in close proximity [65-66].

On the other hand, MIMO techniques are more promising and yield remarkable performance compared with other interference mitigation techniques. However, these MIMO schemes are yet to be exploited in the UL reuse direction. As earlier mentioned, reusing UL channel may have a better performance than reusing DL channel.

VI. CONCLUSION

D2D communication is a promising technology that aims at maximizing system throughput through enhanced spectrum efficiency. However, spectrum reuse results in harmful interference among the primary cellular users and the secondary D2D users, in addition to mutual interference between multiple D2D pairs that are sharing the same resources. This undesirable interference degrades the overall

network performance, which must be tackled. Various interference mitigation schemes such as power-control, efficient resource allocation, multi-antenna beamforming among others have been reviewed and critically analysed. The power control scheme is not enough to handle the mutual interference between D2D communication and cellular network. Various resource allocation strategies proposed which aimed at eliminating interference problem in D2D/LTE system, leads to underutilization of the licensed spectrum. Furthermore, the multi-antenna beamforming schemes studied mainly focused on suppressing downlink interference from eNB to D2D receivers while ignoring the problem of uplink precoding for interference mitigation from D2D communication to cellular users. This necessitates the need to further investigate this area, in order to efficiently mitigate cross-tier and co-tier interference during uplink resource sharing. This will guarantee the performance of the cellular network, improve D2D link quality and enhances the reliability of D2D communication.

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