Effective Interference Cancellation Mechanisms for D2D Communication in Multi-Cell Cellular Networks

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***Abstract*—In a Device-to-Device (D2D) underlaying cellular system, interference cancellation is a key problem when uplink spectrums are shared and this problem becomes more complex in a multi-cell cellular network. In this paper, we propose an effective near-far interference avoidance scheme in a multi-cell cellular system. After monitoring the related control channels of a D2D subsystem and exchanging necessary information among neighboring eNBs, an eNB may stop scheduling the interfering cellular devices or facilitate power control mechanisms for the victim D2D users such that the inter-cell near-far interference can be mitigated. Simulations prove that our mechanism is effective and satisfying performance improvement can be obtained.**

***Index Terms*—Device-to-Device communication; hybrid system; multi-cell networks; near-far interference; Long Term Evolution**

I. INTRODUCTION

Recently, major efforts have been spent on the development of Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) for the higher data rate and system capacity. Many candidate radio interface technologies have been submitted to the International Telecommunications Union (ITU) to prepare new technology components for LTE to meet IMT-A requirements. Among which, Device-to-Device (D2D) communication has received increasing attentions as a promising component to improve spectral efficiency [1].

Unlike the infrastructure based cellular network, D2D users do not communicate via the central coordinator (base station, NodeB or evolved NodeB) but operate as an underlay and communicate directly with each other or more hops. Excluding the unnecessary core network involvement, D2D communication is a promising concept which can provide several advantages such as low cost, plug-and-play convenience, and flexibility. Its usage of bandwidth and battery power is more efficient and interference can be reduced if two near terminals in different cells communicate directly. Furthermore, increased network efficiency supports more services or improves current services and applications [2–5]. ndeed, such D2D communication is likely to become integral to the future beyond 3G world to form a hybrid network [4, 6]. Fig.1 illustrates the basic and extended concept of D2D communications and hybrid networks.

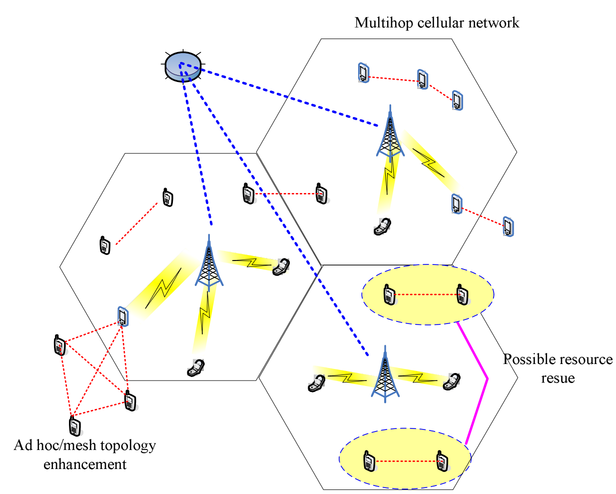

Figure 1. Illustration of D2D communication as an underlay to a cellular system.

Until now most researches of D2D transmission focus on the scenario that D2D UEs reuse the UL spectrum of an LTE system [5, 7] because of available transmission time intervals (TTIs) [7] and underutilization [8]. However, working autonomously and fully sharing frequency resources with cellular users, D2D UEs may sustain near-far interference from cellular terminals. Such interference becomes more complex in a multi-cell network and this problem can be illustrated in Fig.2. In Fig.2, the D2D pair (D_TxUE and D_RxUE) are two boundary users located in different cells. Reusing the same spectrums, they may be interfered by several UEs from other cells, such as CeUE11 in Cell 1, CeUE21 and CeUE22 in Cell 2,

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and CeUE31 in Cell 3. Although some feasible methods have been proposed to cancel near-far interference in a single-cell system [7], it is difficult to apply them directly in a multi-cell environment due to independent radio resource management (RRM) by each eNB. However, the lower transport delay and higher throughput can be obtained by D2D communication for such boundary users compared with by the traditional eNB-relayed communication. Hence, such inter-cell near-far interference must be suppressed.

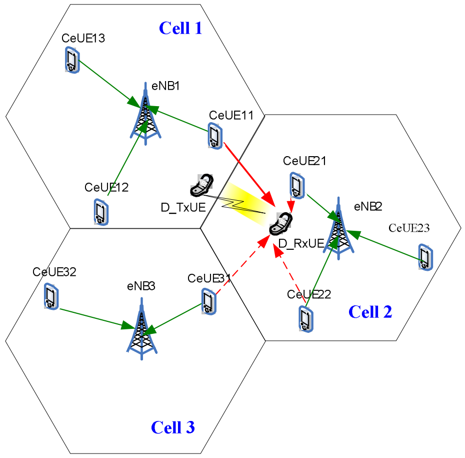

Figure 2. An interference example in a multi-cell network.

In our work, an effective mechanism to mitigate inter-cell near-far interference is proposed. By monitoring the related control channels of a D2D subsystem and exchanging necessary information, the adjacent eNBs will identify the interfered D2D users and interferers. Based on such knowledge, when the communication priority of the victim D2D users is higher than interfering cellular users, an eNB may stop scheduling these interferers. On the contrary, D2D users with a lower communication priority may transmit data with the interferers simultaneously but using a reliable power control scheme. Simulation results which are conducted in a LTE based system show that the satisfying performance can be achieved by using the proposed interference cancellation mechanisms.

The paper will be organized as follows. In Section II, we outline the system model and address the problem. In Section III, the proposed mechanism aiming to efficiently using UL cellular spectrums and avoiding the inter-cell near-far interference is elaborated and the implementation details are described in a real cellular system. Performance evaluation and discussion are presented in Section IV. Finally, some concluding remarks are given in Section V.

II. SYSTEM MODEL

In this study, the potential of the LTE technology as a platform for D2D communication is addressed and the mechanisms to reuse LTE UL spectrums meanwhile avoiding harmful inter-cell interference from cellular users are raised.

In this paper, we consider that the D2D UEs are located in different cells and reuse the whole UL frequency bands with cellular UEs in an LTE FDD system. When UL spectrums are used, the victim cellular device is the eNB. Given that fractional power control in LTE can be used on D2D communication, the interference from D2D user to the eNB can be avoided efficiently according to the existing study. Consequently, the interference from different cellular terminals to D2D transmission will be addressed in this paper. In the initial stage, a D2D UE should firstly register in their anchored cell to obtain some essential information from the eNB, such as Cell-ID of the anchored cell, the allocated Cell Radio Network Temporary Identifier (C-RNTI) and fractional power control parameters used by this cell. Furthermore, autonomous D2D transmission is assumed which means each D2D pair autonomously determines the resource allocation by using some useful knowledge from eNBs. Since an eNB allocates the resources to cellular UEs in a dynamic way, which means that the cellular UL resource allocation can not be predicted accurately by the accumulated knowledge. Therefore, blind interference avoidance methods are difficult to work if there is no tight time correlation among resource allocation of cellular users.

III. INTERFERENCE CANCELLATION MECHANISMS IN MULTI-CELL NETWORKS

In this section, we will elaborate the proposed mechanism to share the UL frequency bands meanwhile avoiding the deleterious inter-cell near-far interference to D2D devices. To facilitate the description, we denote by C_UE and D_UE a cellular UE and a D2D UE respectively, and D_TxUE and D_RxUE the transmitter and receiver of a D2D pair.

The peculiarity utilized by the hybrid system is that D2D users operate in an underlay mode which means that the cellular eNB controls D2D users loosely by sending limited assisting information to facilitate D2D RRM. Furthermore, based on the explanation of the handshaking process during the D2D communication [2], control signaling is always transmitted on the Common Control Channel (CCCH) and Data Control Channel (DCCH) which are two dedicated channels for D2D communication. Hence, the sensed signals from them are assumed to be reliable. The proposed scheme in a multi-cell hybrid system is presented as follows.

Step1: All cellular UEs and D2D UEs register to its anchored eNB (A-eNB) and obtain information such as Cell-ID and power control. Neighbouring eNBs (N-eNBs) also exchange information to know which D2D devices are located in.

Step2: A-eNB broadcasts CCCH information on time and frequency and C_UEs monitor this channel. Here a power threshold is used to determine if this C_UE can interfere with the adjacent D2D users.

Step3: C_UE decodes the signaling from the CCCH to obtain the ID of the neighboring D2D UE. After that, it reports to its A-eNB by using either of the following two formats.

Format 1: C_UE reports to its position information and the IDs of interfered D2D users if it is equipped with a GPS device.

Format 2: C_UE reports its ID and the IDs of victim D2D users to its A-eNB directly.

Two examples are shown in Table I and II. Note that a power threshold of CCCH needs to be defined and only the C_UE which detects a higher power than the threshold reports to its A-eNB.

TABLE I. INTERFERENCE REPORT FORMAT 1

Position of C_UE	ID of D_UE
(X1,Y1)	D_UE1
	D_UE2
(X5, Y5)	D_UE5
	D_UE6
……	……

TABLE II. INTERFERENCE REPORT FORMAT 2

ID of C_UE	ID of D_UE
C_UE1	D_UE1
	D_UE2
C_UE5	D_UE5
	D_UE6
……	……

Step4: After checking the received IDs of D2D users, an eNB may determine which interfered D2D users are not in its cell and exchanges the corresponding information with its N-eNB by using the either format as follows.

Format 1: The A-eNB sends the position information of the interfering C_UE and the IDs of victim D2D users to its N-eNBs.

Format 2: The A-eNB sends the transmission power of the interfering C_UE and the IDs of victim D2D users to its N-eNBs.

Table III and IV give two examples corresponding to Format 1 and Format 2, respectively.

TABLE III. EXCHANGING INFORMATION FORMAT 1

Position of C_UE	ID of D_UE
(X1,Y1)	D_UE1
	D_UE2
……	……

TABLE IV. EXCHANGING INFORMATION FORMAT 2

Transmission power of C_UE	ID of D_UE
P_1	D_UE1
	D_UE2
……	……

Step 5: An N-eNB sends the obtained information from the *Step 4* to the corresponding D_UE in its cell. Two kinds of formats which are same to Table III and IV can be used according to if the position information of the interfering C_UE can be known. This information will be used to perform reliable power control by the victim D2D devices.

Format 1: The N-eNB broadcasts the position information of interfering C_UE and the IDs of victim D_UEs.

Format 2: The N-eNB sends the transmission power information of interfering C_UE and the IDs of victim D_UEs.

Step 6: Based on the above description, when a D_UE needs to send data, the following procedures will be performed.

1) By using the assisting information from its A-eNB, a D_RxUE can identify the available Data Traffic Channel (DTCH) information [10]. Here, the C_RNTIs of cellular UEs are needed.

2) According to the description of the handshake procedure [2], multiple D2D pairs compete for the communication resource. Different from the single-cell scenario, a priority index is included in clear to send (CTS) signaling to indicate the importance of this D2D communication.

3) On reception of CTS signaling successfully means this D2D pair obtains the resource. The D_RxUE sends the available DTCH information immediately on the CCCH to inform D_TxUE.

4) D_TxUE sends data to D_RxUE on the identified DTCH and the information on data control is sent on the DCCH simultaneously.

Note that if an A-eNB finds the victim D2D UEs are in its cell, no information exchanging among N-eNBs happens.

Step 7: After monitoring the CTS signaling on the CCCH, an interfering C_UE sends the priority index of this D2D communication to its A-eNB in the latest UL TTI.

Step 8: The A-eNB compares with the priority between the interfering C_UE and the victim D2D UE, then two mechanisms may be used to avoid the deleterious near-far interference as follows.

Mechanim 1: If D2D communication has a higher priority, the A-eNB will stop scheduling this C_UE within one period until the D2D communication ends. During this period, this C_UE will check the DCCH to determine the ending of this D2D communication.

Mechanim 2: If this C_UE has a higher priority, D2D users share the spectrum with the cellular UEs but using a power control scheme which is based on the information of the transmission power or the position knowledge of the interferer cellular UEs from *Step 4*.

Note that if a D2D pair is interfered by several cellular UEs, an average power control factor will be used by synthesizing these interferers. From this point of view, the performance of D2D communication can be guaranteed.

The complete procedure of our proposed inter-cell near-far interference avoidance mechanism can be illustrated in Fig.3.

IV. SIMULATION AND PERFORMANCE ANALYSIS

A. Simulation Parameters

A multi-cell system with 3 cells is considered and there are 50 D2D users placed with regards to the number of cellular UEs is 200 in every cell. For each cell, the topology of the hybrid system will be modeled in a fashion way where D2D users are distributed in a randomly placed cluster with a radius of 10m and cellular users are also dropped uniformly through the cell with a radius of 300m. Such a topology is more realistic in modeling urban environments [10]. Considering the small distance between a D2D pair and the radius of each cell, a simple power control scheme is utilized by letting the transmission power of D_TxUE 30dB lower than that of cellular users. The used system bandwidth is 5MHz, i.e., 25 RBs altogether. By reserving 2 RBs for the CCCH and DCCH of the D2D subsystem, the left 23 RBs are available to transmit data for both subsystems.

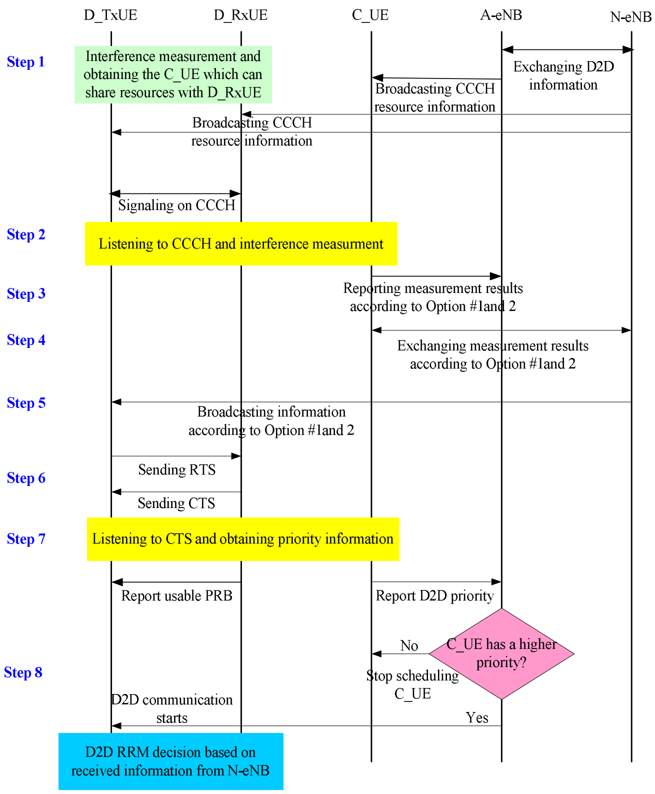

Figure 3. The complete procedure of the proposed method to avoid inter-cell near-far interference.

To qualify the interference from cellular users, here an interference circle threshold $TH_{\text{interference-circle}}$ is defined. By using $TH_{\text{interference-circle}}$ we mean that when the received interference by D2D users is beyond this value, cellular users can impose interference on D2D users. On the contrary, such interference can be ignored. The adopted threshold by cellular users to determine if D2D users are close to them is the received power from D2D users and this value is denoted as $TH_{\text{interference-cancellation}}$. In general, $TH_{\text{interference-circle}}$ should be several dBs lower than $TH_{\text{interference-cancellation}}$. The other parameters are presented in Table V [11].

TABLE V. PARAMETERS FOR SIMULATION

Parameter	Value
Cellular layout	3 adjacent cells
Cell radius	300 m
Noise Power Density	-174 dBm/Hz
Noise figure	5 dB
Path loss model for cellular link	128.1+37.6log10(r [km]), r is the transmitter-receiver separation in kilometers.
Path loss model for D2D link	148+40log10(r [km]), r is the transmitter-receiver separation in kilometers.
RB bandwidth	180 kHz
Carrier frequency	2000MHz
TTI length	1ms
System bandwidth	5 MHz

B. Simulation Results and Discussions

Fig. 4 and 5 plot the average throughput vs. $TH_{\text{interference-cancellation}}$ by using Mechanism 1 when $TH_{\text{interference-circle}}$ changes from -3dB to -6dB. To investigate our method, four results are presented which correspond to the all UEs in the hybrid system and only D2D UEs in the D2D subsystem with and without interference mitigation. From them three observations can be made. Firstly, cellular users impose significant interference on D2D communication when uplink resources are shared and such interference can degrade the D2D subsystem performance greatly. After using Mechanism 1, such interference is mitigated substantially. Secondly, performance improvement is highly related to the used threshold $TH_{\text{interference-cancellation}}$. As the decrease of the $TH_{\text{interference-cancellation}}$, a better performance can be obtained. This result is feasible and can be explained by the fact that more interference will be found and suppressed when the interference circle threshold is reduced. Thirdly, the performance gain is also impacted by $TH_{\text{interference-circle}}$. By comparing with these two figures we can see that a higher performance gain benefits from a lower $TH_{\text{interference-circle}}$ due to more interferers can be involved.

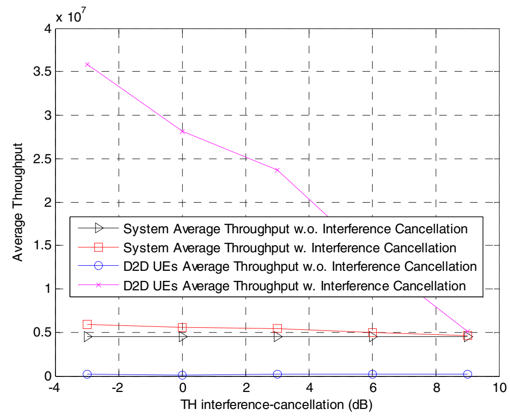

Figure 4. Average throughput vs. $TH_{\text{interference-cancellation}}$ when $TH_{\text{interference-circle}}$ is -3dB and Mechanism 1 is used.

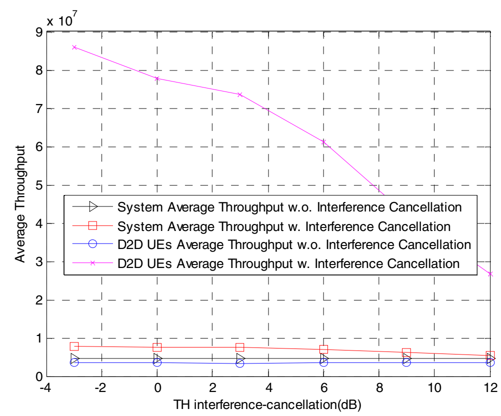

Figure 5. Average throughput vs. $TH_{\text{interference-cancellation}}$ when $TH_{\text{interference-circle}}$ is -6dB and Mechanism 1 is used.

To evaluate Mechanism 2, we compare the average throughput of D2D subsystem vs. $TH_{\text{interference-cancellation}}$ when $TH_{\text{interference-circle}}$ is -4dB and the result is shown in Fig. 6. Here a power control factor α is used to represent that how much the transmission power is boosted and α = 10dB, 5dB and 3dB are used in our simulations, respectively. From this figure we can see that after Mechanism 2 is implemented, the average throughput is increased obviously. For example, even for the lowest factor of α = 3dB, an increase of 22% can be obtained by using the proposed mechanism.

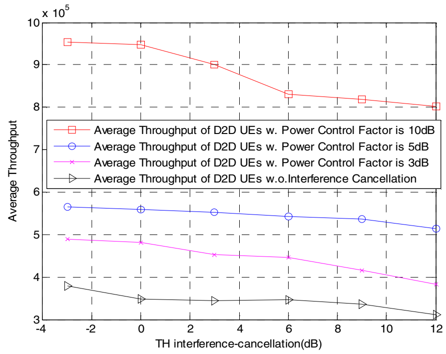

Figure 6. Average throughput of D2D UEs vs. $TH_{\text{interference-cancellation}}$ when $TH_{\text{interference-circle}}$ is -4dB and Mechanism 2 is used.

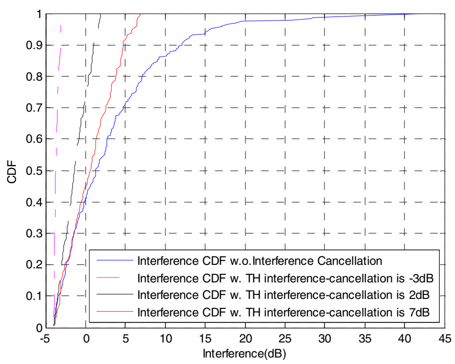

Figure 7. CDF of inter-cell near-far interference from cellular transmission when $TH_{\text{interference-circle}}$ is -4dB and Mechanism 1 is used.

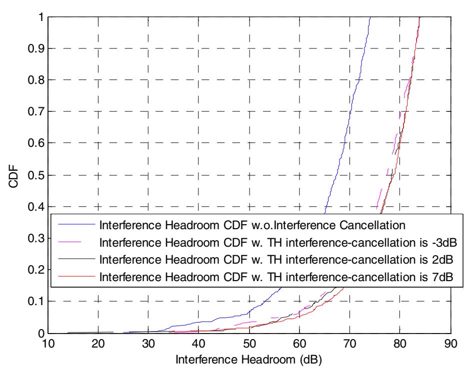

Figure 8. CDF of interference headroom for Mechanism 2 when $TH_{\text{interference-circle}}$ is -4dB.

To get insight into the above results, the cumulative distribution function (CDF) curves of received interference from the cellular subsystem and the interference headroom for the D2D users are collected for Mechanism 1 and 2 and they are shown in Fig. 7 and 8, respectively. Here, interference headroom is defined as the difference of transmission power of a D2D UE and its received interference. A power control factor of α = 10dB is used when Mechanism 2 is studied in Fig. 8. For these two figures, $TH_{\text{interference-circle}}$ is -4dB and $TH_{\text{interference-cancellation}}$ changes from -3dB to 7dB. From Fig. 7 we can conclude that the interference is mitigated significantly after using our Mechanism 1 comparing with the result that no approach is implemented to avoid such interference. Correspondingly, Fig. 8 proves that using Mechanism 2 can obtain more interference headroom which makes the D2D subsystem is more robust against the inter-cell interference.

V. Conclusions

Interference management is a key problem in the D2D underlaying cellular system and this problem will be more complex in a multi-cell cellular network. In this paper, the mechanisms of sharing uplink spectrums with cellular users in a multi-cell hybrid system are proposed. By monitoring the related control channels of a D2D subsystem and exchanging necessary information among multiple eNBs, the uplink frequency bands can be used efficiently meanwhile avoiding the harmful interference from multiple cellular networks. Simulations proved that performance improvement is satisfying by using the proposed methods.

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