



Priority-Based Device Discovery in Public Safety D2D Networks with Full Duplexing

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Abstract. Device-to-device (D2D) services are gaining popularity in public safety (PS) applications. The existing half-duplex (HD) D2D discovery has the constraint that the devices sending beacon cannot be discovered at the same time, resulting in large time delays. To counter this problem, in-band full duplex (IB-FD) communications can be used to discover the user quickly by enabling simultaneous transmission and reception during same time-frequency block. In this paper, we exploit the benefits of IB-FD system where PS users are given priority in resource allocation. Moreover, to efficiently utilize the spectrum, we propose a time-efficient device discovery resource allocation (TE-DDRA) scheme where a user can switch the transmission mode from HD to IB-FD when the demand exceeds the available resources in HD mode. The simulation results prove that in comparison with random mode, the PS priority mode saves around 37% discovery time.

Keywords: D2D discovery · Full duplex device discovery · 5G systems · Public safety

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1 Introduction

The fifth-generation (5G) systems are targeting high data rate and low-latency demands of the mobile users [2,3,11,14,15]. To meet these demands, the deployment of device-to-device (D2D) communications [17] attracts the service providers because of their capability to provide efficient spectrum utilization. D2D communications can allow data flow from one device to another without the help of a base station (BS) resulting in increased data rate and reduced latency [5]. However, prior to link establishment, the discovery of devices lying in the neighborhood is the first and important phase. The discovery should be completed in a short time to maintain the 5G latency requirements by utilizing the limited available spectrum.

D2D discovery underlying cellular architecture can be performed under different levels of operator controls. The third generation partnership project (3GPP) categorized the D2D discovery as fully controlled (user-specific type-2) and partially controlled (user-specific type-1) [1]. We implement user-specific type-2 discovery scheme for public safety (PS) users, whereas for non-PS (NPS) users we consider the user-specific type-1 discovery [9]. Since NPS users have no strict requirements, therefore we implement user-specific type-1 discovery scheme for them (Fig. 1).

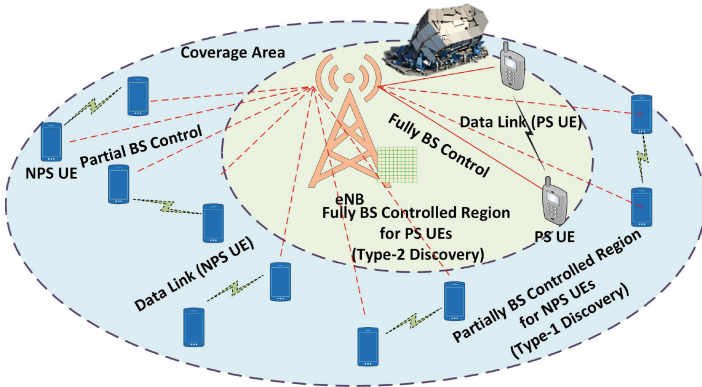


Fig. 1. Types of D2D discovery schemes for public safety networks.

In literature, numerous power control [8,16] and scheduling schemes [10,12] has been implemented to reduce interference among the heterogeneous networks, but unfortunately these schemes cannot be implemented for D2D scenario. Moreover, some solutions related to D2D discovery resource allocation such as location-based device discovery [7], device discovery to enable proximity services and [4] also exists in the literature. These schemes reduce the discovery time of users only for half-duplex (HD) mode. Therefore, their discovery time inevitably increases as compared to in-band full-duplex (IB-FD) mode.

In IB-FD system, a device can transmit and receive the beacon during the same time frequency block, which helps to reduce the discovery time. Previously, due to excessive self-interference (SI), IB-FD systems were considered impractical. However, recent advancements in SI cancellation make it feasible and practical for implementation in D2D discovery [6].

In this paper, we propose a time-efficient device discovery resource allocation (TE-DDRA) scheme for IB-FD system. The proposed TE-DDRA scheme has the option to switch from HD mode to IB-FD mode when the demand of resource allocation is not met in HD mode. Moreover, to reduce the discovery time for PS users, this scheme uses multi-channel ALOHA (MC-ALOHA) with energy sensing (MCALOHA-ES)[13] to reduce discovery time. The NPS user on the other hand, use conventional ALOHA.

2 System Model

We consider a multi-cell deployment scenario with a single cell as an example. In the multi-cell system, each cell has a radius R and an enhanced node B (eNB) at the origin. Moreover, a total of K users are deployed in the coverage area that follow a homogeneous Poisson point process (PPP) with density λ . We assume N PS user equipments (PS UEs) and M NPS UEs. Furthermore, we consider that every k -th user is transmitting a beacon with maximum power P_k^{\max} . Also, the uplink (UL) Long-term evolution advanced (LTE-A) system with bandwidth B is considered.

A UE is discovered when the received signal-to-interference-plus-noise-ratio (SINR) is greater than a pre-defined threshold γ^{th} . The selection of SINR threshold depends upon particular scenario because the receive SINR is different for PS and NPS scenarios. For example, for PS scenario, we require a low SINR threshold to discover far users, however for NPS scenario threshold can be selected high or low depending upon QoS requirements. Thus, the SINR of the received signal in case of HD system for the 0-th UE can be calculated as

$$\gamma_0^{\text{HD}}(j, d) = \frac{P_s^t(j, d)|H_s(j, d)|^2}{\sum_{k=1, k \neq s}^K P_k^t(j, d)|H_k(j, d)|^2 + \sigma^2}, \quad (1)$$

where $|H_s(j, d)|^2$ is the squared envelope of the channel gain between the transmitting UE and the 0-th receive UE on resource block d during the j -th subframe, and σ^2 is the noise variance. In HD system, a UEs transmitting the beacon cannot listen to beacon at the same time which results in less number of discovered users and increased interference. In this paper, the PS user can switch from HD and IB-FD mode if the available resources are less than the demanded resources.

Similarly, the SINR of the received signal in case of IB-FD system for the 0-th PS UE can be calculated as

$$\gamma_0^{\text{FD}}(j, d) = \frac{P_s^t(j, d)|H_s(j, d)|^2}{P_0^t(j, d)|H_0(j, d)|^2 + \sum_{k=1, k \neq s}^{K-M} P_k^t(j, d)|H_k(j, d)|^2 + \sigma^2}. \quad (2)$$

where $\overline{H_0} = \beta H_0$, $\overline{x_0}$ and H_0 is the transmitting data causing SI and channel coefficient from 0-th user transmit antenna to its own receive antenna, respectively. The factor $\beta (0 \leq \beta \leq 1)$ is self-interference cancellation factor at the 0-th UE where $\beta = 0$ indicates perfect SI cancellation.

3 Proposed Time Efficient Discovery Resource Allocation Scheme

The discovery of more users in less time can be achieved by decreasing the number of collisions among the users transmitting beacons simultaneously. In the proposed TE-DDRA, the available discovery resources are split into two portions: dedicated resources for PS users and a pool of resources for NPS users, thereby completely avoiding contention among two categories. The contention can be further reduced for PS users by using multi-channel ALOHA with energy sensing (MCALOHA-ES) after a specified time frame. The MCALEHA-ES scheme senses the collision first before transmitting the beacon which reduces the chances of collisions. The MCALEHA-ES selects the discovery resource block where the received energy on d -th resource block is minimum, implying that no other user is transmitting the beacon on that RB. We summarize the major steps of the proposed TE-DDRA schemes in Algorithm 1.

4 Simulation Results

Simulation Environment: System-level simulations are performed to check the validity of the proposed TE-DDRA scheme. The key simulation parameters are summarized in Table 1.

Simulation Scenarios: We consider two main scenarios; (1) conventional random HD/FD scenario, and (2) proposed TE-DDRA HD/FD scenario. In conventional random HD/FD scenario, we consider the existing D2D discovery frame structure and treat all users equally, in sense of accessing D2D discovery resource blocks. Moreover, HD/FD users only use MCALEHA scheme to access the discovery resources. Contrary to that, the proposed TE-DDRA HD/FD scheme uses the IB-FD frame structure with dedicated bands for PS users during the discovery phase to reduce the contention among users. Furthermore, this scheme has capability to switch the channel access protocol from MCALEHA to MCALEHA-ES after a predefined time duration.

Discovery time plays a critical role especially for PS situation. We evaluate the discovery time versus the number of users discovered conventional HD/FD mode without prioritizing PS users, and the proposed TE-DDRA with IB-FD mode and prioritization to PS users. In Fig. 2, we compare the performance of conventional random HD/FD with the proposed TE-DDRA scheme. This gain is obtained in IB-FD mode because there is no constraint of receiving the discovery beacon during the beacon transmitting period. Hence, more users can

Algorithm 1. Proposed TE-DDRA Scheme

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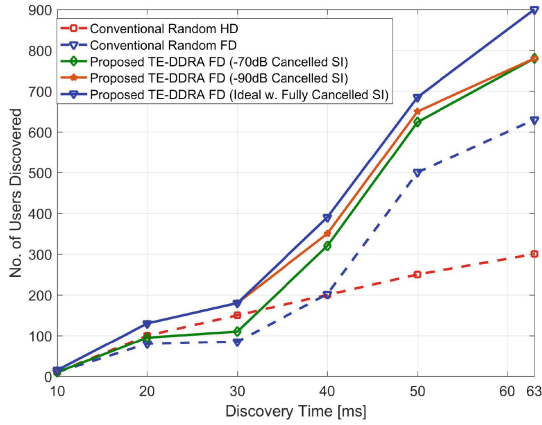
1 Initialization:  $T = 1$ ,  $U = \{1, 2, \dots, K\}$ ,  $M$  PS users,  $N$  NPS users,
 $\gamma^{\text{th}} = 4.5$  dB,  $P^{\text{max}} = 23$  dBm,  $j = 1$ 
2 Assumptions: All users are initially connected in HD mode, and will always
transmit with power  $P^{\text{max}}$ 
3 Discovery resource request: During current discovery period  $T$ ,  $K$  users
send resource request to eNB
4 while  $K$  users discovered do
5   if No. of RB  $\leq K$  user sending request for RB then
6     Switch  $M$  PS users to IB-FD mode
7     Continue using HD mode for  $N$  NPS users
8     if  $j \leq W$  then
9       Allocate resources among  $M$  PS users and  $N$  NPS users using
       MCALOHA
10    else
11      Allocate resources among  $N$  NPS users using MCALOHA
12      Use MCALOHA-ES for  $M$  PS users resource allocation
13    end
14    if  $\gamma_k \geq \gamma^{\text{th}}$  then
15      Neighbor user are successfully discovered by the user sending
      beacon
16    else
17      Undiscovered user will wait for upcoming  $j$ -th subframe to receive
      the beacon
18    end
19     $j = j + 1$ 
20  else
21    Continue as HD mode for  $K$  users
22    Allocate resources among  $K$  users using MCALOHA
23    if  $\gamma_k \geq \gamma^{\text{th}}$  then
24      Neighbor user are successfully discovered by the user sending
      beacon
25    else
26      Undiscovered user will wait for upcoming  $j$ -th subframe to receive
      the beacon
27    end
28     $j = j + 1$ 
29  end
30   $T = T + 1$ 
31 end

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be discovered within less time frame. It can be seen that the proposed method discover more number of users at varying at varying SI cancellation values as shown in Fig. 2.

Table 1. Simulation parameters.

Parameters	Values
LTE layout	1 site (3 cells)
System bandwidth, RBs	10 MHz, 50 RBs
Carrier frequency	2 GHz
UE parameters	max Tx power: 23 dBm, noise figure: 9 dB
Threshold values	$\gamma^{\text{th}} = 4.5$ dB, $W = 3$
Discovery resource selection schedulers	PS user: MCALOHA or MCALOHA-ES NPS user: MCALOHA
PL model	WINNER + B1
Fast fading	PedB

**Fig. 2.** Discovery time vs. number of discovered users.

5 Conclusion

In this paper, concept of switching the duplex mode from half-duplex to IB-FD is implemented that considerably reduces the discovery time for PS users. From simulation results, we proved the validity of the proposed scheme as it saves around 37% of discovery time as compared to conventional random access system.

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