Design and Evaluation of a Hybrid D2D Discovery Mechanism in 5G Cellular Networks

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***Abstract*—Device-to-device (D2D) communications allow devices to communicate directly without using base stations for relaying, yielding several merits such as increasing the spectral efficiency and system capacity, reducing network latency and power consumption of UEs, offloading the 5G cellular networks, and extending the network coverage. However, to realize D2D communications, the first challenging issue is how to efficiently find target devices in proximity for communications. Therefore, in this paper we intend to design a hybrid D2D discovery mechanism and evaluate its performance. Simulation results demonstrate that the proposed D2D discovery mechanism achieves better performance in terms of power consumption and discovery time, compared with the direct discovery scheme that purely utilizes the contention-based transmission scheme and operates in the unlicensed band.**

***Index Terms*—5G wireless cellular networks, device-to-device (D2D) communication, device discovery, Internet of Things (IoTs).**

I. Introduction

The high transmission rate of 5G cellular networks can strongly promote the realization of Internet of Things (IoTs) and smart cities. However, the big data resulting from IoTs and smart cities may overload the 5G cellular networks because of the limited spectrum resources. To tackle this problem, device-to-device (D2D) communications have been proposed recently. D2D communications allow devices to communicate directly without using base stations for relaying. Thus, D2D communications yield several merits such as increasing the spectral efficiency and system capacity, reducing network latency and power consumption of UEs, offloading the 5G cellular networks, and extending the network coverage [1], [2].

The possible use cases of D2D include machine-to-machine (M2M), vehicle-to-vehicle (V2V), content distribution, location-aware services in smart cities, social networking, proximity online gaming, e-health caring, and public safety services [1]. However, to realize D2D communications, several challenging issues such as the device discovery, spectrum resource allocation, interference management, power control, and communication security, have to be solved [1], [3], [4]. Among these issues, the first challenge for D2D communications is the device discovery. Therefore, several papers [5]–[12] have studied and designed device discovery mechanisms for D2D communications. D2D discovery can be based on either core network functionalities to estimate proximity, also known as network-assisted D2D discovery [5]–[9], or autonomous actions taken by D2D-enabled devices [10]–[12].

Choi et al. [5] designed a D2D discovery scheme for proximity services based on the random access procedure in the LTE-A system. The proposed random-access-based D2D discovery scheme is based on the network-assisted approach which enables the access or core network to centrally control the formation of D2D communication networks. The work [6] presented a signature-based discovery design as a conceptual example for cellular applications. In [7], Lin et al. presented two types of device discovery and access procedures and then analyzed the performance of proposed schemes based on the Markov process model. The paper [8] analyzed the performance of network-assisted D2D discovery in random spatial networks. In [9], the authors proposed a centralized D2D discovery scheme by employing a signaling algorithm to exchange D2D discovery messages between network entities. In this system, potential D2D pairs share uplink cellular users resources with collision detection to initiate D2D links. As to the paper [10], the authors proposed a social-aware peer discovery scheme, which exploits social network characteristics for assisting the ad hoc peer discovery for D2D communications. In this scheme, the D2D users are first divided into groups according to their social metrics of community and centralities, and then the optimal beaconing rate is decided for each group of users. Since several proximity devices may transmit discovery beacons at the same time, collisions may occur, yielding device discovery failures. Hence, to enhance the discovery probability and reduce the discovery delay, Zhang et al. proposed a random backoff procedure to retransmit beacons in [11]. In [12], Sun et al. proposed a simple and efficient scheme, called listen channel randomization (LCR), to expedite device discovery in Wi-Fi Direct.

There exist two types of D2D discovery mechanisms: direct and network-assisted. In the direct discovery scheme, D2D devices autonomously and distributedly discover, or indicate their presence to, other devices in proximity. In the network-assisted discovery mechanism, the evolved packet core (EPC) and the base station use the location information of UEs to trigger the D2D discovery process which can be centralized or distributed. The advantages of network-assisted D2D discovery include reducing the energy, signaling, and interference in D2D discovery, by exploiting knowledge of the network layout. On the other hand, the majority of literatures in D2D discovery designed schemes for proximity services [5], [6], [10], [11]. Few papers have studied the D2D discovery mechanism for finding a specific target device [8]. Additionally, most of D2D discovery schemes in the literature are either fully distributed or fully centralized and thus maybe are not optimal. Consequently, in this paper we intend to design a hybrid mechanism combining network-assisted and direct D2D discovery schemes to find a specific target device in proximity and evaluate its performance by simulations.

The rest of this paper is organized as follows. Section II describes the proposed hybrid mechanism which combines the network-assisted and direct D2D discovery schemes. Section III conducts simulations to evaluate the performance of the proposed D2D discovery mechanism. Finally, the concluding remarks are given in Section IV.

II. Proposed Hybrid D2D Discovery Mechanism

In this paper, we intend to design a hybrid D2D discovery mechanism for finding a specific target device in proximity. The proposed D2D discovery mechanism consists of two phases. In the first phase, the cellular network has to judge whether a UE pair is able to establish a D2D link. When two UEs of a pair are close enough to initiate D2D communications, the eNB notifies them of opening the Wi-Fi Direct engine for D2D discovery and communication purposes. The second phase is designed for a source UE to discover the target UE to communicate with. The details of the proposed hybrid D2D discovery mechanism in Phases 1 and 2 are described as follows.

Phase 1:

1a) When a UE initiates a request to contact a remote one, its request is sent to the eNB and the EPC. The request message must include the full, unique device identity, e.g., the 15-bit International Mobile Subsrciber Identity (IMSI), and other related information.

1b) EPC judges whether a pair of UEs is close enough to initiate a D2D link based on the UEs' IPs, IDs, or location information. If two UEs are located in the same cell (the pair A-A′ in Fig. 1) or adjacent cells (the pair B-B′ in Fig. 1), then the EPC or eNB informs these two UEs of starting the D2D device discovery procedure in Phase 2; otherwise, these two UEs use the cellular service to communicate.

In this paper, we use the Wi-Fi Direct protocol [6], [12] to realize the D2D discovery and communications. Considering two UEs denoted by A and A′, UE A is the source which initiates the request and UE A′ is the target device to be discovered. UE A starts in the Wi-Fi Direct search state, while the target UE A′ starts in the Wi-Fi Direct listen state. The D2D discovery procedure in Phase 2 is described as follows.

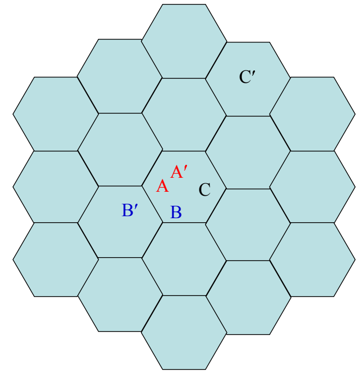

Fig. 1. Some cases of locations of UE pairs.

Phase 2:

2a) UE A sends a beacon to discover UE A′. If UE A′ receives the beacon correctly, it responds a message to UE A.

2b) If UE A receives the response correctly, it sends an acknowledgment to UE A′ and then the D2D communication starts; otherwise, go to step 2c).

2c) If the number of retransmissions exceeds a pre-defined number R, named the retry limit, the discovery procedure stops and these two UEs use the cellular service to communicate; otherwise, go to step 2a) after a random time which is determined using the binary exponential backoff algorithm.

To summarize, the proposed hybrid D2D device discovery mechanism includes two phases. Phase 1 operates over the underlay cellular network to avoid unnecessary contentions and collisions of D2D discovery messages in Phase 2. Phase 2 operates over the unlicensed band to discover D2D devices to save the spectrum resources of the cellular network.

III. Numerical Results

In this section, we employ simulations to evaluate the performance of the proposed D2D discovery mechanism. The simulation program is developed by ourselves using the C++ Builder. The radius D of the considered cell is 200m. We assume that there are N = 200 UEs which are uniformly distributed over the considered cell, i.e., follows the Poisson point process. Among these UEs, only the ratio r of UEs whose target UEs to communicate with are within the same cell. In Wi-Fi Direct, the maximum probe distance of the beacon signal is assumed to be 100m and the retry limit R is set to 10. The power consumption (in number of transmitted beacons) and discovery time (in slots) of D2D discovery mechanisms, including direct D2D discovery and the proposed hybrid D2D discovery, are evaluated and compared. In the direct D2D discovery scheme, all UEs in the considered cell directly initiate D2D discovery procedure in Phase 2. While in the proposed hybrid D2D discovery mechanism, only the ratio

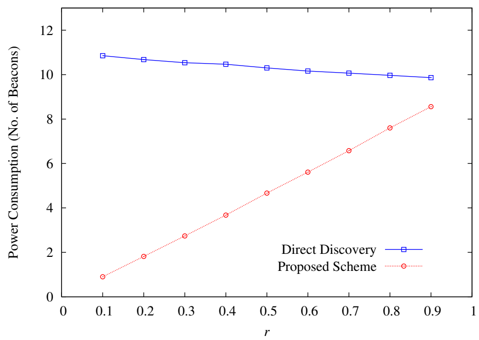

Fig. 2. Comparison of power consumption.

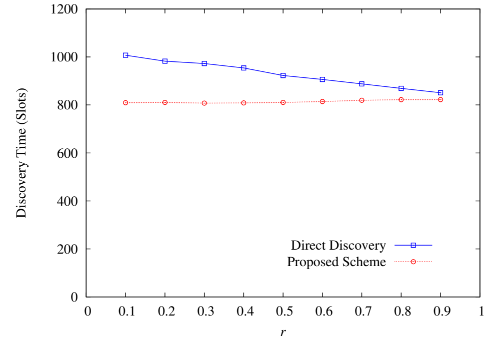

Fig. 3. Comparison of discovery time.

r of UEs will trigger the D2D discovery procedure in Phase 2. When a transmitter does not receive any response within a slot time from its target device, the binary exponential backoff algorithm (in slots) is used to retransmit a beacon for both mechanisms.

Figure 2 plots the UE's power consumption per discovery cycle under the proposed and direct discovery mechanisms. In the proposed hybrid D2D discovery scheme, when the number of D2D pairs within the same cell (proportional to r) grows, the number of transmitted beacons increases because both the probabilities of initiating the discovery procedure in Phase 2 and collisions increase, yielding the increase of power consumption. In the direct discovery scheme, when the number of D2D pairs within the same cell is small, the probe beacons of the majority of UEs can not reach their target devices, yielding continuous retransmissions. When the number of D2D pairs within the same cell is large, the number of collisions of beacons becomes high and continuous retransmissions are required. Thus, the average power consumption of a UE under the direct discovery scheme always stays at a high level. In Fig. 2, our proposed hybrid D2D discovery mechanism obviously outperforms the direct discovery scheme. Figure 3 shows the average discovery time under the proposed and direct discovery mechanisms. In the proposed hybrid D2D discovery scheme, the discovery time is almost irrelevant to r. In the direct discovery scheme, when the number of D2D pairs within the same cell becomes larger, there are more D2D pairs within the probe range and thus the average discovery time decreases. Similarly, our proposed discovery mechanism also outperforms the direct discovery scheme in terms of the discovery time according to Fig. 3.

IV. Conclusions

In this work, we propose a hybrid D2D discovery mechanism which includes two phases of discovery processes. Phase 1 filters out those UE pairs unable to establish D2D communications to enhance the D2D discovery performance. Phase 2 uses the Wi-Fi Direct to discover the target UEs for D2D communications. Only those pairs of UEs within the same cell or adjacent cells can trigger the D2D discovery procedure in Phase 2. Simulation results demonstrate that the proposed hybrid D2D discovery mechanism significantly outperforms the conventional direct D2D discovery scheme in terms of power consumption and discovery time.

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