Resource Allocation for Network-assisted Device-to-Device Discovery

Liang Hu
DOCOMO Euro-Labs Landsberger Strasse 312 80687 Munich, Germany
hu@docomolab-euro.com

Abstract— **we study the resource allocation schemes for device-to-device discovery, which is a key enabler for a wide range of mobile proximity services and safety related applications. The design goals are long-range, high energy efficiency, and resource-efficiency. In particular, we study the performance of device-centric and network-centric resource allocation schemes with different levels of network assistance in single and multi-cell environments by means of system level simulations. We also propose a novel location-based resource allocation scheme that achieves the best performance among all the evaluated schemes. The gain by the location-based scheme is large in single-cell environments, but it is rather limited in multi-cell environments where a simple uniform-random device-centric scheme is shown to perform well requiring only limited network assistance.**

Keywords—device-to-device discovery, proximity service, resource allocation

I. Introduction

Device-to-device (D2D) discovery and communication is a key enabler for diverse mobile proximity services such as proximity social networking, advertising, and wireless home automation [1], [2], [3]. Another type of D2D use cases is related to safety applications: vehicle safety communications [4] and public safety communications [5], where devices are required to discover and communicate each other with low-latency and high reliability, even when network coverage does not exist, e.g., in a disaster scenario or in a rural area.

Most of D2D use cases require a D2D discovery phase where each device discovers neighboring devices prior to have direct communications. In this paper we focus on the D2D discovery design defined as: mobile device advertises its own "presence" and discovers its neighboring devices' "presence" in an *autonomous* and *continuous* manner.

The D2D discovery schemes considered in this paper take place at radio layer, i.e., at layer 2, similar to the concept introduced in [1], with the assistance of cellular network, e.g., providing the synchronization reference. Our goal is to design a new *autonomous* and *continuous* device discovery scheme with *high power efficiency*, *long discovery range*, *low-latency* and *high resource-efficiency*. The ultimate objective is to accommodate the future requirements of 5G system [6], [7].

One of the design challenges for D2D discovery lies in the radio resource allocation, where each device selects one discovery resource to transmit its discovery signal either with or without network assistance. We focus on the case where the D2D discovery is assisted by the cellular network at different levels, e.g., from a simple assist of device synchronization to a more support of providing radio resource allocation. As concluded from [8], network-assisted D2D discovery has advantages of providing high discovery range, low latency, and high power-efficiency, compared with non-network assisted one such as Wi-Fi direct. There are a few state-of-the-art (SoA) schemes for network-assisted D2D discovery such as [8], [9], [10] where the focus has been on the device-based resource selection with limited network assistance. In [11], the authors studied clustering-based device-centric resource selection scheme with partial or no network coverage. In [12], [13], the authors provided an overview of the technical design challenges on D2D discovery and communications. It is noted that there have been the on-going 3GPP Rel-12 standardization activities studying the resource allocation for D2D discovery in the proximity service (ProSe) where the focus is on device-centric resource allocation [14].

In this paper, our contributions lie in two aspects: 1) we propose a network-centric resource allocation scheme namely "Location-based"; 2) we compare network-centric and device-centric schemes in two typical deployment scenarios "single cell" and "multi-cell" scenarios; in the end, we also compare the overhead cost for various schemes.

The rest of the paper is organized as follows: Section II focuses on the description of D2D discovery challenges in general, and resource allocation problem in particular; Section III describes the new network-centric schemes by exploring the location information and the SoA device-centric schemes; Section IV shows the simulation results of the proposed network-centric schemes and the comparisons with SoA schemes; finally, Section V draws the conclusions of the paper.

II. D2D Resource Allocation

A. Problem Definition

We study LTE (Long Term Evolution)-based D2D discovery solutions. Fig. 1 illustrates the resource allocation problem for D2D discovery signals. A set of time-frequency resource blocks – namely "discovery resource blocks (DRBs)" – are assumed to be semi-statically reserved from the uplink spectrum band of the cellular network, e.g., in a periodical manner similar to the working assumption in 3GPP Release 12 [11]. It is assumed that a device needs exactly one DRB to transmit the discovery signal.

At each discovery resource pool interval, each device uses one DRB to broadcast its own discovery signal to its neighboring

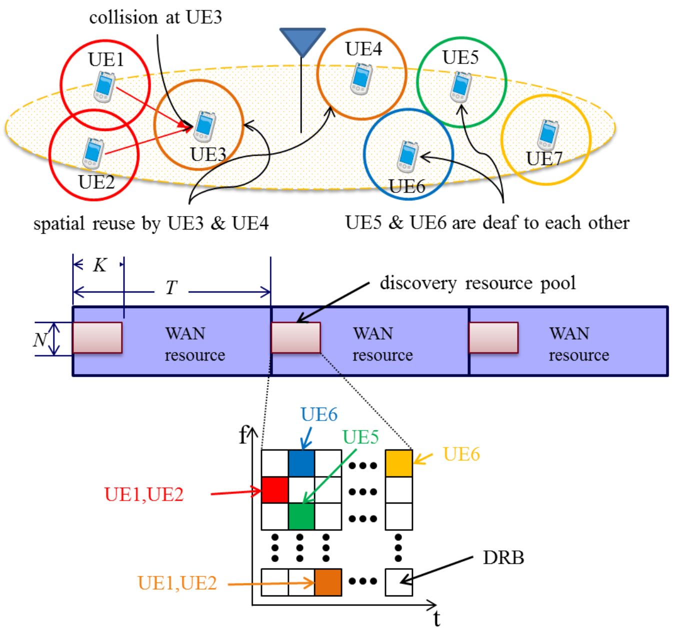

Fig. 1: D2D discovery resource allocation principle and challenges

devices. Each device also monitors and decodes discovery signals from other devices in all the DRBs at each interval.

The design challenge is on how each device smartly selects a DRB to achieve the best discovery performance and resource efficiency. There are several research challenges with respect to the resource allocation (also cf. Fig. 1):

1) *collision* - if two or more devices happen to select the same DRB, then the collisions of multiple discovery signals may take place at the receiving devices;
2) *spatial reuse* – in contrast to 1), the same DRB can be reused by two or more devices if separated far apart;
3) *deafness or half-duplexing* constraint - the device cannot transmit and receive at the same time frame; and
4) *frequency selectivity of the radio channel* - transmitting discovery signals using same DRB may lead to poor discovery performance due to deep fading.

B. *Discovery Resource Assumption*

The details of discovery resource assumption are shown in Fig. 1. It is assumed that: 1) a DRB occupies two physical resource blocks in a sub-frame based on LTE frame structure, which corresponds to a bandwidth of 180 kHz and 14 OFDM symbols; 2) the discovery signal uses QPSK modulation and turbo code with a coding rate of 0.59; and 3) a signal-to-interference-power-ratio (SIR) of 3 dB is required for successful decoding. We assume K×N DRBs are reserved as a discovery resource pool every T sub-frames, which are shared by all devices. At each interval a device selects one DRB out of the discovery resource pool to transmit its discovery signal, and listens to other devices' discovery signals in the other sub-frames of the resource pool. It is assumed that K, N, and T are all configurable by the network, e.g., K and N may depend on the traffic load of the cell, whereas T may depend on the required D2D discovery latency constraint.

C. *Network-centric vs. Device-centric*

We consider the two types of DRB allocation schemes: network-centric and device-centric. In network-centric schemes, the DRB to be used by each device is selected by the network and explicitly signaled to the transmitting device. With a network-centric scheme, the network has the full control of resource allocation such that a certain degree of performance can be guaranteed. This is especially vital for some D2D discovery applications with strict performance requirements, such as public safety and vehicle-safety under network coverage. However, a network-centric scheme has some disadvantages: 1) it may lead to higher network signaling overhead, e.g., the network needs explicit signaling towards each device to allocate resources; 2) it requires the device to be in "RRC (radio resource control) connected" state to signal the resource allocation.

In contrast, device-centric schemes are more scalable in terms of network signaling overhead, especially when devices are densely located. Both "RRC connected" and "RRC idle" devices can be supported, as long as the discovery resource pools are known by the devices. Device-centric schemes could potentially work with or without network coverage. A drawback is that it may lead to unpredictable discovery performance. At high load conditions, the performance of a device-centric scheme may collapse as a result of its distributed nature.

The summary of the pros and cons of the two types of discovery scheme are summarized in Table 1.

Table 1: Device-centric *vs* Network-centric schemes.

	Principles	Pros	Cons
Device centric	Each UE picks one resource autonomously	• Scalable, self-organized • Spatial re-use • Applicable for out of NW coverage	• Collisions problems • Local sub-optimal due to the lack of NW support
Network centric	Each device is assigned one resource by eNB	• No collisions • Guaranteed latency	• Low resource utilization • High signaling overhead • Not applicable for out of NW coverage

III. D2D Resource Allocation Schemes

This section introduces new schemes as well as state-of-the-art techniques followed by the comparison analysis.

A. *Proposed new schemes*

We introduce two network-centric schemes: "Cell-orthogonal" and "Location-based", where network explicitly allocates the DRB to each UE at each single or multiple discovery periods, i.e., the T as shown in Fig. 1. The "Cell-orthogonal" serves as a benchmark scheme whereas "Location-based" is the new scheme we proposed. Note that we use the term "device" and "UE" interchangeably throughout the paper.

The "Cell-orthogonal" consists of the following two steps:
For each cell, each eNB performs the same procedures for all the associated "RRC connected" UEs:

– Step1: eNB allocates orthogonal DRB to each randomly selected UE within its coverage area;

– Step2: If there are more UEs than available DRBs, the rest of UEs are randomly allocated one DRB

The goal of “Location-based” is to maximize spatial reuse by allocating the same DRB to multiple UEs that ensures to minimize mutual interference. That may be achieved by exploring the UE location information, consisting of the steps:

– Step1: eNB allocates orthogonal DRB to each randomly selected UE until all DRBs are occupied.
– Step2: when the number of DRBs is less than the number of UEs, for each of the remaining UEs: in a random order, eNB selects a UE and allocates the DRB that maximizes the minimum distance to the closest neighboring UE that uses the same DRB.

Essentially, “Location-based” has the same step 1 as “Cell-orthogonal”. In step 2, by considering the distance between UEs, “Location-based” optimizes the DRB allocation to choose the DRB for a UE that minimizes the maximum interference to its neighboring UEs that are already allocated the same DRB. It is a simple graph coloring heuristic that approximates the ideal solution by the Greedy coloring algorithm which is a NP-hard problem. The Location-based resource allocation has been studied in the context of vehicle communications [15]. In contrast to our approach, purely the spatial distance separation is utilized to decide the resource re-use, i.e., no graph coloring optimization is considered.

B. State of the art device centric schemes

In the SoA, different device-centric schemes are proposed:

“Uniform Random” means that each UE individually and randomly picks up one DR from the D2D discovery resource pool at every T discovery period. The idea is to randomize the DRB selection among UEs so as to minimize the potential collisions when UEs select the same DRB.

“Greedy-probabilistic” [8] means UE randomly picks up a DR from X% lowest power DRs in D2D discovery resource pool at every T discovery period. X is a design parameter and it takes values from 0 to 100. The idea is to determine individual DRB based on the locally measured energy level per DRB where certain randomness in the form of randomly picking up one DRB from non-zero X% low energy DRBs for reducing the risk that multiple UEs in the proximity happen to make the same local observation and select same lowest energy DRB.

C. Required nework signalling and additional UE behaviors

The allocation schemes require different level of network assistance and additional UE behaviors summarized in Table 2.

For all the schemes, synchronization reference is assumed to be provided by the network such that all UEs in one cell can transmit and receive discovery signals in a synchronous and energy-efficient manner [8]. In case of device centric schemes, network additionally needs to provide the detailed information of discovery resource pool to all UEs, which includes the parameters of N, K and T as shown in Fig. 1. For network centric schemes, network additionally needs to inform the selected DRB to each UE, e.g., via downlink unicast signaling.

In terms of additional UE behavior, “Uniform random” does not require any measurements, whereas “Greedy probabilistic” requires UEs to perform local measurements of total received signal strength indicator (RSSI) per DRB. “Cell-orthogonal” does not require any additional UE behaviors, whereas “Location-based” requires UEs to send their location information to the network.

IV. PERFORMANCE EVALUATION

In this section, we compare the performance of the network-centric and device-centric schemes through system-level simulations based on 3GPP option 3 scenario [14]. We firstly describe the simulations assumptions and parameters followed by the simulation results in two typical deployment scenarios: “single-cell” and “multi-cell” scenarios.

A. Simulation assumptions and parameters

We assume each UE transmits and receives discovery signals. Each UE is interested in discovering all other UEs in the network, for the simplicity. UE periodically transmits discovery signal to maximize discovery probability at every T. We assume UE does not update the signal content within the simulated time. One UE is sufficient to be discovered once by other UEs; UE is defined to be “discovered” by another UE if it is discovered once. The performance metric is defined as:

$$Discovery\ probability = \frac{number\ of\ discovered\ UEs}{total\ number\ of\ target\ discoverable\ UEs.} \tag{1}$$

Since we assume each UE is interested in all other UEs, the total number of target discoverable UEs in (1) is equal to the total number of UEs in the network. In the following subsections, we show the discovery probability in (1) , given the pathloss value between the discovering UE and the target discoverable UE. We introduce a scalar to calculate the total number of discoverable UEs whose pathloss to the discovery UE is between [pathloss - scalar/2, pathloss + scalar/2]. We count the number of UEs that are discovered whose pathloss is within that range. Then we can calculate the discovery probability vs. pathloss. Furthermore, we show the discovery

Table 2: Overhead of device-centric and network-centric schemes

	Scheme	Required Network-Assistance	Required additional UE behaviors
Device centric	Uniform random	1) Synchronization 2) Inform available discovery resource pool	None
	Greedy-probabilistic		RSSI measurements per DR
Network centric	Cell- orthogonal	1) Synchronization 2) Inform the Selected Discovery Resource (unicast)	None
	Location-based		Location Reporting

Table 3: Simulation Parameters.

Layout	Hexagonal grid 3GPP Option 3 (Urban macro (500m ISD) with all UEs outdoor)	
	Scenario 1 Single cell 200 D2D UE per cell	Scenario 2 7 cell wrap around 100 D2D UE per cell
Carrier Frequency	2 GHz	
System bandwidth	10 MHz, FDD UL	
Network sync.	All eNBs are synchronized	

UE RF parameters	Tx power of 23 dBm, 1 Tx/ 2 Rx antenna, Antenna gain 0 dBi, Noise figure 9 dB
UE distribution	Uniform drop per sector
Pathloss model	ITU-1411-6 LOS and NLOS, p=50, PL_{urban} =6.8 dB for urban
Probability of LOS	ITU-R IMT UMi
Shadowing	7 dB log-normal
SIR threshold	3 dB

performance after four discovery intervals T as defined in Fig. 1, where the discovery performance saturates after four discovery intervals. Table 3 summarizes the detailed system-level simulation parameters.

We study the discovery performance in two typical deployment scenarios: single-cell with 200 UEs per cell and seven-cell wrap-around with 100 UEs per cell. We assume a 3GPP deployment scenario option 3 where all UEs are randomly dropped according to a uniform distribution in an outdoor environment and directly discover each other at different levels of network assistance in Table 2. The discovery resource pool is reserved periodically from the LTE uplink spectrum band at 2GHz. All eNBs are assumed to be perfectly sychronized. The D2D path-loss model employs ITU-1411-6 model [14] with probablity of line of sight (LOS) and non-line-of-sight (NLOS) determined by ITU-R IMT UMi model [14]. In this paper, we assume the uncorrelated shadowing model for direct links between D2D deivces by employing log-nomral distributions with 7 dB deviation, which aligns with the current 3GPP working assuption [14].

B. *Single-cell scenario (Scenario 1)*

We firstly compare the two device-centric schemes "Uniform-random" and "Greedy-probabilistic" under different sizes of the resource pool by varying K value (as defined in Fig. 1) from 5 to 20 while keeping N value equals to 10. The discovery performance is evaluated in terms of discovery probability as a function of D2D path loss, as shown in Fig. 2. The "Upper-bound" performance is defined as the ideal achievable discovery performance without mutual interference and only constrained by the D2D path-loss and thermal noise.

In Fig. 2, the performance of "Uniform-random" and "Greedy-probabilistic" are shown, where X% is set to 10%. Note that X% can be any value between 0% and 100% where the Greedy-probabilistic converges to "Uniform random". When the path loss increases from 70 to 160 dB, the discovery probability of all schemes decreases and diminish at around 150 dB. From the discovery performance, when increasing K from 5 to 20, the discovery performance of all schemes improves significantly, since more DRBs bring less collision among devices that use the same DRB. "Uniform-random" always performs better than "Greedy-probabilistic" under different K values. When the size of the resource pool is sufficiently large, e.g., K=20, "Uniform-random" even achieves the performance close to "Upper-bound".

"Greedy-probabilistic" degrades for small number of DRBs (K=5). The reason is that nearby UEs tend to make correlated decisions on DRB selection. For instance, close-by UEs may have similar measured energy level of all DRBs may select a DRB with lower energy, which is likely to be the same DRB.

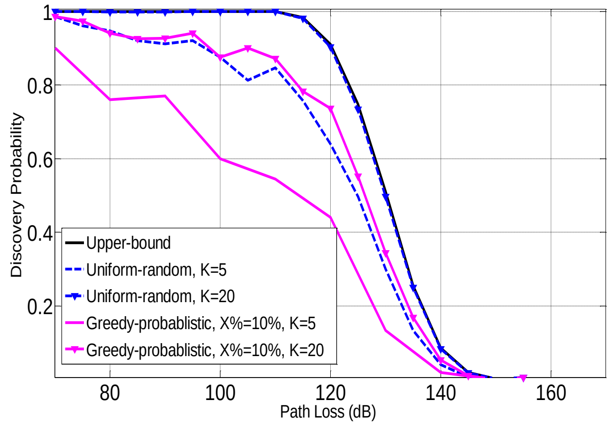

Fig. 2: Discovery probability versus path loss (dB) in Scenario 1 for uniform-random and greedy probabilistic schemes.

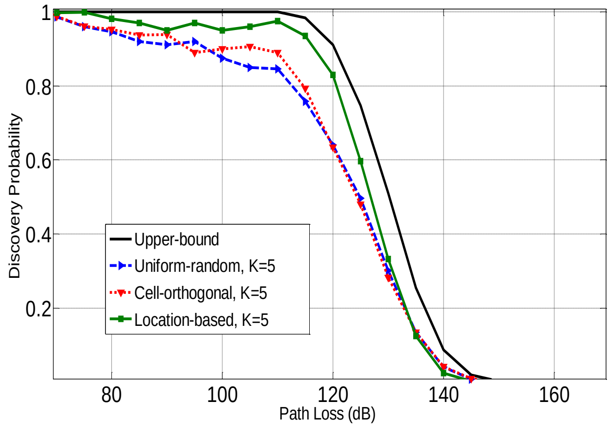

Fig. 3: Discovery probability versus path loss (dB) in Scenario 1

Secondly, we compare two network-centric schemes - "Cell-orthogonal" and "Location-based" with "Uniform random" which is the device-centric scheme that performs better than "Greedy probabilistic". Since "Uniform-random" performs close to "Upper-bound" when K is sufficiently large, we investigate whether the proposed network-centric schemes can provide additional gain over "Uniform-random" when K is small (i.e., the available discovery resources are limited with respect to the number of devices). We fix the size of the resource pool with K=5. As shown in Fig. 3, "Location-based" performs much better than "Cell-orthogonal" and "Uniform-random", whereas "Cell-orthogonal" only slightly outperforms "Uniform-random". "Location-based" scheme shows the clear advantage over the other schemes by exploiting the spatial separation of devices for more efficient resource allocation, at the expense of high signaling overhead as in Table 2.

C. *Multi-cell scenario (Scenario 2)*

In this section we compare "Uniform-random" scheme with network-centric schemes in a 7-cell wrap-around case, where the inter-cell interference is not negligible.

Among the two device-centric schemes in the previous section, "Uniform random" has better discovery performance than "Greedy probabilistic" and thus, it is selected as the baseline for comparing to the network-centric schemes.

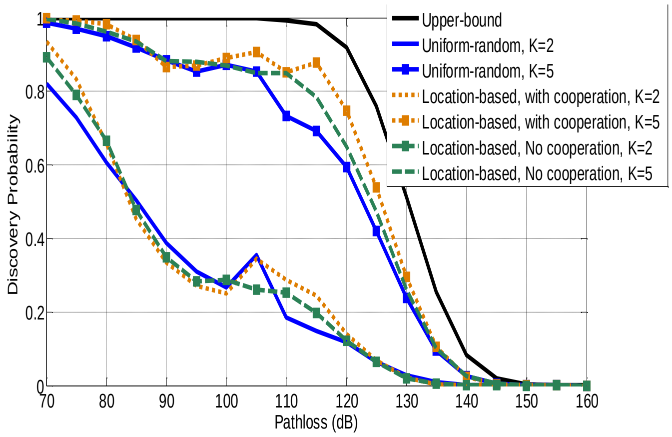

Fig. 4: Uniform-random vs Location-based.

We introduce "Location-based" scheme with and without cell cooperation. "Location-based" scheme in a single cell scenario only optimizes the DRB allocation of devices within a cell, which may lead to poor cell edge performance due to the inter-cell interference. We define "cell cooperation" such that neighbor cells jointly optimize DRB allocation of all devices within the several neighboring cells by employing the same principle as the "Location-based" scheme.

Fig. 4 illustrates that "Location-based" (with/without cell cooperation) performs better than "Uniform-random". Similarly to the single cell scenario, "Location-based" scheme without cell cooperation still performs better than "Uniform random", but the gain is getting limited, due to the inter-cell interference. By introducing inter-cell cooperation for "Location-based" scheme, it further improves the discovery performance, compared to the case of without cooperation.

"Location-based" scheme (with or without cell cooperation) shows clear performance gain over "Uniform-random" scheme in a multi-cell scenario. Yet, interestingly, we observe that, even if "Uniform random" performs worse, but in some cases the performance difference is not so significant. This may motivate the deployment of "Uniform random" scheme in many scenarios, since it is simple and still achieves relatively good performance. Note that the above observation is made under the condition of uniform random UE distribution and non-strict D2D service requirement (e.g., loose latency requirement). Future work is still needed to justify the performance of "Uniform-random" under condition of heterogeneous UE distribution and strict D2D service requirements.

V. Conclusion

We studied device-centric and network-centric resource allocation schemes for D2D discovery. We proposed a new network-centric "Location-based" scheme. When comparing device-centric schemes with network-centric schemes, we observed that in single-cell scenario, "Location-based" scheme performs much better than "Uniform-random"; in seven-cell scenario, the gain of "Location-based" scheme over "Uniform-random" is reduced due to the inter-cell interference. Introducing inter-cell cooperation for "Location-based" only slightly improves the performance. Interestingly, in many cases, "Uniform random" performs close to "Location-based" scheme, with least network-assistance and no UE measurements. Thus, "Uniform-random" can be an attractive baseline scheme at least under uniform UE distribution.

Future work is still needed to justify the performance of "Uniform-random" under condition of heterogeneous UE distribution and strict D2D service requirement, e.g. on latency.

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