Computer Networks 88 (2015) 149–160

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Enabling device discovery transmissions in LTE networks with fractional frequency reuse

Dimitris Tsolkas*, Nikos Passas, Lazaros Merakos

University of Athens, Department of Informatics & Telecommunications, Panepistimiopolis, Ilisia 15784, Athens, Greece

ARTICLE INFO

Article history:
Received 15 January 2015
Revised 22 May 2015
Accepted 19 June 2015
Available online 25 June 2015

Keywords:
Wireless communication
Device-to-device communications
Device discovery
Spatial spectrum reuse

ABSTRACT

The major challenge in device-to-device (D2D) communications is the device discovery problem, i.e., the problem of meeting the communication peers in time, frequency and space. This requires frequent transmission of discovery signals, consuming expensive and scarce radio resources. To mitigate this consumption, we propose a coordination scheme that reuses uplink (UL) spectrum opportunities under a “blind” spatial spectrum reuse approach. Based on the low transmission demands of the discovery transmissions (low range and power, limited quality requirements, etc.), the scheme enables a number of discovery transmissions without continuously gathering and processing the actual interferences in the network. The focus is on a long term evolution (LTE) network that adopts the fractional frequency reuse (FFR) inter-cell interference coordination technique. In this case, the “blind” spatial spectrum reuse approach is endorsed by the spatial constraints provided by the FFR technique to the UL cellular transmissions (each cell is divided into the cell-center and cell-edge areas, while different spectrum portion is allocated to each area). The proposed scheme introduces a D2D coordinator that exploits spatial distribution analysis and approximations for the wireless environment to adjust the number of the underlay discovery transmissions, and hence, control the introduced interferences. Evaluation results show that the proposed scheme can enable an adequate number of discovery transmissions, with limited and controlled impact on the cellular UL transmissions.

1. Introduction

The term *device-to-device (D2D) communications* in long term evolution (LTE) networks [1] refers to direct short-range transmissions between user equipments (UEs), without intervention of an evolved Node B (eNB). In contrast to other direct communication technologies, such as Bluetooth and WiFi Direct, D2D communications utilize licensed spectrum with quality of service (QoS) guarantees for both data and voice communications, while no manual network detection/selection is required. Compared to the very appealing cognitive radio communications, where secondary transmitters detect spectrum holes in spectrum used by cellular (primary) users, D2D communications refer to transmissions coordinated by the cellular network, reaping the benefits of being synchronized and controlled by the eNB.

The introduction of D2D communications in cellular networks is expected to be beneficial from a variety of perspectives, shifting the current cellular communication paradigm to a more flexible and dynamic state. The short distance between D2D peers provides better link conditions and, thus, more efficient connection with lower energy consumption. Higher overall spectral efficiency can be achieved, since the intermediate transmissions to an eNB are avoided, while the coexistence of cellular and D2D transmissions in shared spectrum can lead to improved utilization of the radio

* Corresponding author. Tel.: +30 210 7275143.
E-mail addresses: dtsolkas@di.uoa.gr (D. Tsolkas), passas@di.uoa.gr (N. Passas), merakos@di.uoa.gr (L. Merakos).

http://dx.doi.org/10.1016/j.comnet.2015.06.010
1389-1286/

and network resources. From the operators' point of view, new business models may be designed, while new types of services may be launched for commercial and public safety scenarios. In this concept, the device discovery problem, i.e., the need of a potential D2D transmitter to know whether the target receiver is in its vicinity and, thus, within range to start direct communication, has been identified as one of the major challenges. Taking into account the wide range of new D2D services that can be designed, the need for discovery transmissions will increase rapidly, consuming radio resources in a more intense and massive way. The issue that emerges is whether we can mitigate this consumption by allowing discovery transmissions to spatially reuse the cellular spectrum. In this paper, we examine the case where the discovery transmissions spatially reuse the uplink (UL) cellular spectrum. Our focus is on a long term evolution (LTE) network that adopts the fractional frequency reuse (FFR) intercell interference coordination technique. Motivated by the spatial constraints provided by the FFR technique in the UL direction and the low demands of the discovery transmissions, we propose a "*blind" spatial spectrum reuse* approach, i.e., an approach that enables a number of discovery transmissions without continuously gathering and processing the actual interferences in the network.

The remainder of the paper is organized as follows. Related work and our major contributions are presented in Section 2. The system model adopted is introduced in Section 3, while the proposed scheme is described in Section 4. Section 5 includes the evaluation results, and, finally, Section 6 contains our conclusions.

2. Related work

D2D standardization efforts have already begun in Release 12 of the LTE system, in which the issue is examined under the perspective of enabling *proximity services (ProSe)* for in-coverage and out-of-coverage UEs [2]. Towards enabling ProSe communications, many solutions have been designed to deal with different direct communication challenges, recognizing the device discovery as a fundamental procedure [3–6]. 3GPP (3rd Generation Partnership Project) has already defined the basic types and scenarios for discovery transmissions ([2,7]). According to these, the radio resource allocation for device discovery can follow either a procedure where a spectrum portion is allocated to all or a group of UEs (discovery Type 1 in [7]), or a procedure where radio resources are allocated on a per UE basis (discovery Type 2 in [7]). The vast majority of the approaches in the literature deal with the first procedure, proposing radio access and resource allocation schemes where a set of radio resources is semi-statically reserved from the UL spectrum band of the cellular network for the device discovery transmissions (e.g., [8–12]). The second approach refers to the case where the aim is to find a specific discovery target, defining the last step before the establishment of the D2D communication. Practically, this procedure validates the proximity of the D2D peers just before the communication, even if a discovery procedure in dedicated spectrum has been applied. For this procedure, also known as eNB-directed discovery [13], we have defined in [14] the signaling flow that can be used for allocating radio resources to the discovery transmitter, while in this paper we examine the case where the discovery transmissions spatially reuse the UL cellular spectrum.

The spatial spectrum reuse for direct transmissions in cellular networks has been well studied in the literature revealing the interference management as a main challenge. Two basic approaches have been defined: (i) the spectrum underlay, where direct transmissions reuse spectrum portions utilized by cellular transmitters, and (ii) the spectrum overlay, where direct transmissions use temporarily empty spectrum portions. A comparison of the two approaches can be found in [15] and [16], in terms of transmission capacity and throughput, respectively. In both cases, a widely accepted choice is the exploitation of the UL cellular period for the mitigation of the generated interferences, where the cellular interference victims are the immobile eNBs, e.g., [17–19]. This approach shifts the major interference problem to the protection of the directly communicating transceivers, which by itself is quite challenging, since, in both the underlay and the overlay approaches, the interferences caused by neighboring transmissions (either cellular or direct) are far from negligible. This is an important concern, considering that the current trend is to reduce the cell size for achieving higher spatial network capacity. A common solution for inter-cell interference protection in conventional cellular networks (with no direct transmissions) is the fractional frequency reuse (FFR) technique [20,21]. According to FFR, neighboring cells utilize the same spectrum in the UL only for transmissions that originate from interior users (i.e., users located close to the center of the cell) providing sufficient isolation from inter-cell interference. However, in cellular networks with FFR where the spectrum is reused by direct transmissions, the interference protection of the direct receivers requires more investigation. Presently, the main approach for controlling the interference from and to direct transmissions is the exploitation of interference-aware resource allocation (RA) and power control (PC) schemes, e.g., [22–25]. An eNB selects appropriate spectrum resources and power levels for the direct transmitters, taking into account information on the interferences among direct and cellular nodes. The important issue here is how the eNB acquires the interference information. To this end, various mechanisms have been proposed, exploiting mainly measurements guided by the eNB, e.g., [23,26,27]. However, the continuous gathering of interference information adds signaling and consumes network resources, while information accuracy is highly dependent on network topology changes. Overall, even if accurate information is available, a very complex and hard to optimize problem has to be resolved.

In contrast to the regular transmissions of data, discovery signals are frequent, low-ranged transmissions, with relaxed demands, and fixed transmission power (defined by the discovery range). These characteristics bring to the surface the idea of "blind" spatial spectrum reuse, where a number of discovery transmissions are enabled based on an estimation of the available interference room in the network. For instance, a basic approach on this idea would be to enable a random number of additional transmissions dedicated to discovery and adjust this number accordingly if performance degradation is observed. Such an approach runs the risk of introducing random performance fluctuation in the system, while there are no guarantees for the discovery