XXXI SIMPÓSIO BRASILEIRO DE TELECOMUNICAÇÕES - SBrT2013, 1-4 DE SETEMBRO DE 2013, FORTALEZA, CE

Impact of Device-to-Device Communications on Cellular Communications in a Multi-Cell Scenario

Rodrigo L. Batista, Carlos F. M. e Silva, José M. B. da Silva, Tarcisio F. Maciel and Francisco R. P. Cavalcanti

Abstract— **Device-to-Device (D2D) communication, while being network-assisted, is seen as promising technology for the next generation of wireless systems as a mean to improve the utilization of cellular spectrum and to reduce the energy consumption of User Equipments (UEs). However, D2D communications can generate significant interference to the cellular network when the same Physical Resource Blocks (PRBs) are shared by both systems. The design of an efficient D2D network underlaying the cellular network with minimal impact on cellular communications is the key problem. In this paper, we provide an impact assessment of D2D communications on the performance of cellular communications in a Long Term Evolution (LTE)-like multi-cell scenario through system-level simulations. Simulation results show that the overall system capacity is always improved when D2D communications are enabled. However, the performance loss of cellular communications in Downlink (DL) is highly significant. For Uplink (UL), the impact on cellular performance is less noticed, being almost negligible for the urban-macrocell environment and acceptable for the spatial multiplexing-based multi-antenna configuration scheme.**

Keywords— **Multi-cell scenario, device-to-device communications, D2D, network-assisted, performance assessment.**

I. INTRODUCTION

Device-to-Device (D2D) communications underlaying the cellular network has been a topic of intense research and appears as a relatively new area, that may offer potentially high benefits for future wireless networks in terms of capacity gain. By taking advantage of communicating devices proximity, direct low-power communication permits to offload the cellular network through a direct link with reduced congestion instead of using both Downlink (DL) and Uplink (UL) resources as in traditional network. Being a relatively new area, D2D communications as underlaying cellular networks still present relevant questions for research. Since D2D communications give rise to new types of intercell and specially intracell interference, the efficient interference coordination becomes a major issue in cellular networks supporting D2D communications [1], [2].

An introduction to D2D communications underlaying a 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE)-Advanced network is provided in [2] and key issues related to the potential benefits of implementing D2D networks within cellular systems are identified and discussed. The analysis demonstrates the feasibility of the coexistence of both communication types and shows that D2D communications bring benefits in interference limited scenarios. Also, it is shown that by allowing D2D communications to underlay the cellular network, the overall throughput may increase up to 65 % compared to the case where all D2D traffic is forwarded by the cellular system.

To understand the impact of user locations within the cell on the system performance, a distance-based study for specific scenarios in which D2D communications can increase the overall system capacity is addressed in [3], [4]. Results show that the use of D2D communications may provide considerable performance gains, but strongly depends on the distance among communicating and interfering devices. Cellular communications occurring near the Enhanced Node B (eNB) and D2D communications occurring near the cell-edge provides the most favorable scenario for D2D communications. The best overall throughput depends mainly on the position of the D2D receiver relative to the cellular terminal when reusing DL resources, and to the eNB when reusing UL resources [1], [3], [4]. Thus, D2D communications shall exploit the network topology to limit the interference due to the undesired proximity of D2D and cellular transmitters (Tx) and receivers (Rx).

In most of the previous works [2]–[4], the overall capacity of the cellular network supporting D2D communications always outperforms the pure cellular network when cellular spectrum resources are reused by D2D communications in favorable hotspot positions within the cell. The main contribution of this paper is to evaluate the impact on the performance of cellular communications in favorable conditions for D2D communications, in a multi-cell scenario, with urban-macrocell and urban-microcell environments, and considering single-antenna and multi-antenna configurations, by means of system-level simulations.

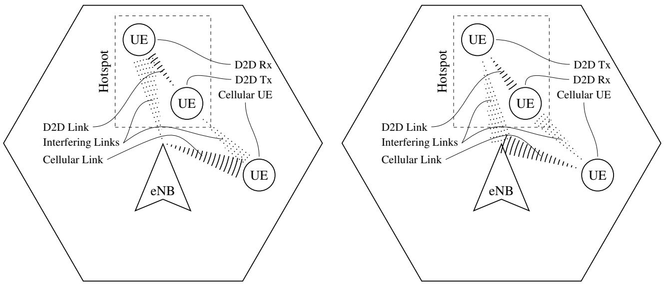
In the remainder sections, the paper is organized as follows. In Section II, the system model is addressed. In Section III, Radio Resource Allocation (RRA) procedures used for D2D communications underlaying a LTE-like cellular network are introduced and explained. In Section IV, the main simulation results are presented and discussed. Finally, conclusions and perspectives are drawn in Section V.

II. SYSTEM MODEL

In this section, the models adopted to evaluate the system performance are presented. Let us assume that each eNB is placed at the center of site, which is represented by a regular hexagon. The considered scenario corresponds to a multi-cell network with eNBs uniformly distributed over its coverage area. Two propagation environments are considered: urban-macrocell and urban-microcell. In the urban-macrocell environment, the site comprises three cells, while in the urban-microcell environment it has only a single-cell [5].

The authors are with Wireless Telecommunications Research Group (GTEL) at Federal University of Ceará, Fortaleza, Cerá, Brazil. E-mails: {rodrigobatista, cfms, mairton, maciel, rodrigo}@gtel.ufc.br. This work was supported by the Innovation Center, Ericsson Telecomunicações S.A., Brazil, under EDB/UFC.33 Technical Cooperation Contract.

The scenario is also composed with hotspots, which are located near the cell-edge in order to evaluate D2D communications in a scenario where they are likely to happen. Hotspots have rectangular shape and different loads of User Equipments (UEs) inside them. Herein, a percentage of total UEs within the cell are clustered inside the hotspot zone. Fig. 1 exemplifies cellular and D2D communications in one of such hotspot zones in the urban-microcell environment for both DL and UL communication phases.



(a) DL. (b) UL.

Fig. 1. Cellular and D2D communications in the urban-microcell environment with hotspot located near the cell-edge for both DL and UL phases.

The modeling of the complex channel coefficients includes propagation effects on the wireless channel, namely, pathloss, shadowing, short-term fading and antenna gains. The distance dependent Non-Line Of Sight (NLOS) pathloss in the microcell environment is based on the COST 231 Walfish-Ikegami NLOS model, whereas the pathloss in the macrocell environment is based on the modified COST 231 Hata urban propagation model. Slow channel variations due to shadowing are modeled with a lognormal distribution of zero mean and standard deviation σ_{sh}. Particular aspects of the large-scale fading model for both urban-macrocell and urban-microcell environments are described in [5], [6] and their basic parameters are presented in Table I.

TABLE I

PARAMETERS OF THE LARGE-SCALE FADING MODEL FOR CELLULAR LINKS IN URBAN-MACROCELL AND URBAN-MICROCELL ENVIRONMENTS.

Cell environment	**Urban-macrocell**	**Urban-microcell**
Inter-site distance	3 000 m	500 m
eNB transmit power	43 dBm	38 dBm
UE transmit power	24 dBm	24 dBm
Pathloss model	$34.5 + 35\log_{10}(\mathrm{d})$	$34.5 + 38\log_{10}(\mathrm{d})$
Shadowing std. dev.	8 dB	10 dB

For D2D communications, the shadowing is defined according to environment and the pathloss model employed for both environments is given by

$$\mathrm{PL} = 37 + 30\log_{10}(\mathrm{d}),$$

where d is the distance in meters [7].

Usually, due to signaling constraints, subcarriers are not allocated individually, but in blocks of adjacent subcarriers, which represent the Physical Resource Block (PRB) [6]. For both DL and UL links, each frame composes $\mathrm{N_{PRB}}$ PRBs, which has dimensions of frequency and time. In the frequency domain, the PRB is defined as 12 contiguous Orthogonal Frequency Division Multiplexing (OFDM) subcarriers spaced of 15 kHz, which gives a bandwidth of 180 kHz. In our model, for a given PRB, the complex channel coefficients correspond to those associated with the middle subcarrier of the considered PRB, and channel coherence bandwidth is assumed larger than the bandwidth of a PRB, leading to flat fading channel over each PRB. In the time domain, the PRB is composed by 14 OFDM symbols, whose duration has 1 ms, or one Transmission Time Interval (TTI), and it is totally dedicated for data. The PRB is the minimum allocable resource that can be scheduled by an RRA procedure at each eNB in LTE systems.

In the considered notation, it is assumed that the multi-cell scenario is composed of $\mathrm{N_{CELL}}$ cells and each one serves $\mathrm{N_{UE}}$ UEs uniformly distributed over its coverage area. Also, it is assumed that frequency resources can be fully reused in all cells. Within the cell, a number of $\mathrm{G} \leq \mathrm{N_{UE}}$ UEs are selected by the cellular scheduling while only one pair of UEs is grouped within the hotspot for D2D communications. Furthermore, each cell is equipped with co-located multi-antennas, which are omnidirectional in the urban-microcell environment and directional in the urban-macrocell environment. Each UE is equipped with omnidirectional co-located multi-antennas. In the Multiple Input Multiple Output (MIMO) scenario, preprocessing and post-processing are performed at each side and the number of streams transmitted is denoted by S.

III. RADIO RESOURCE ALLOCATION PROCEDURE

Since the number of UEs is typically larger than the number of available resources, UEs have to be scheduled by the RRA procedure. In this section, the cellular scheduling and the D2D pair grouping are described to assign the available resources to UEs for both cellular and D2D communications, respectively.

Cellular scheduling is the process of dynamically allocate the available PRBs among the UEs for data transmission, based on some set of rules. For the cellular system, the assignment decisions are taken independently for each cell, TTI, and PRB. We consider the Maximum Gain (MG) criterion, whereby the system throughput is maximized by assigning in each cell, for that TTI, the PRB to the UE with the highest channel gain.

The fundamental idea behind D2D pair grouping is to form D2D pairs of favorable UEs to obtain gains through D2D communications and prevent impact on performance of cellular communications. Considering that, the cellular scheduling algorithm will choose the UE with highest channel gain to eNB and candidate UEs to D2D communication inside the hotspot zone that are much close to each other and far away from the selected cellular UE; a simple D2D pair grouping algorithm which selects randomly one D2D pair inside hotspot zone is considered. The grouping is performed inside each cell, for each PRB and TTI, and does not include any knowledge about the cellular UE previously scheduled.

In the following, Algorithm 1 presents both cellular scheduling and D2D pair grouping in the algorithmic form for a better description of RRA procedure.

Algorithm 1 RRA procedure: cellular scheduling (MG metric) and D2D pair grouping (random metric).

```
for each TTI do
  for each PRB do
    for each cell do
      Selects the cellular UE with the highest channel gain
      Selects randomly one D2D pair of UEs inside the hotspot
      Performs link adaptation of selected UEs
    end for
  end for
end for
```

IV. RESULTS

This section provides a performance assessment of D2D communications in a multi-cell scenario through system-level simulations. The simulations are aligned with the 3GPP LTE architecture [5], [6], [8]. The main parameters considered in the simulations are summarized in Table II.

TABLE II
SIMULATION PARAMETERS.

Parameter	**Value**
Number of eNBs (N_{CELL})	7 (Wrap-around)
Hotspot size	50 × 100 m
Percentage of hotspot UEs	50 %
Communication links	DL/UL
Central carrier frequency	1.9 GHz
System bandwidth	5 MHz
Number of PRBs	25 [6]
Noise power	–116.4 dBm
Average user speed	3 km/h [6]
Channel model	3GPP Spatial Channel Model (SCM) [5]
Antenna pattern	$-\min\left\{12\left[\frac{\theta}{70^\circ}\right]^2, 20\right\}$ dB [5]
CSI knowledge	Ideal
Link adaptation	15 Modulation and Coding Schemes (MCSs) [8], [9]
Required SNR at cell-edge	–6.2 dB
Spatial precoding	Zero-Forcing (ZF)
Power allocation among PRBs	Equal Power Allocation (EPA)
Traffic model	Full buffer [5]
Number of UEs per cell (N_{UE})	4, 8, 12, 16
Antenna configuration	1 × 1, 2 × 2
Effective TTI duration	1 ms
Monte Carlo realizations	1 000
Snapshot duration	1 s

Basically, the simulation events are organized in snapshots, during which pathloss and shadowing are assumed to remain constant for all the UEs while the time variations of fast fading is considered. The dynamics of fast fading can be captured by assuring that each snapshot takes at least 1 s, which is around 10 times longer than the channel coherence time for the simulation parameters. In order to capture the impact of long term propagation effects on the system performance, several snapshots are simulated.

In the following, the impact of D2D communications on cellular communications is evaluated in single-antenna and multi-antenna configurations, and in urban-macrocell and urban-microcell environments. Moreover, this impact is evaluated in the scenario more favorable for D2D communications, where D2D pairs are grouped within hotspot zones located near the cell-edge, as depicted in Fig. 1, and cellular users are scheduled near to eNB, as described in Section III.

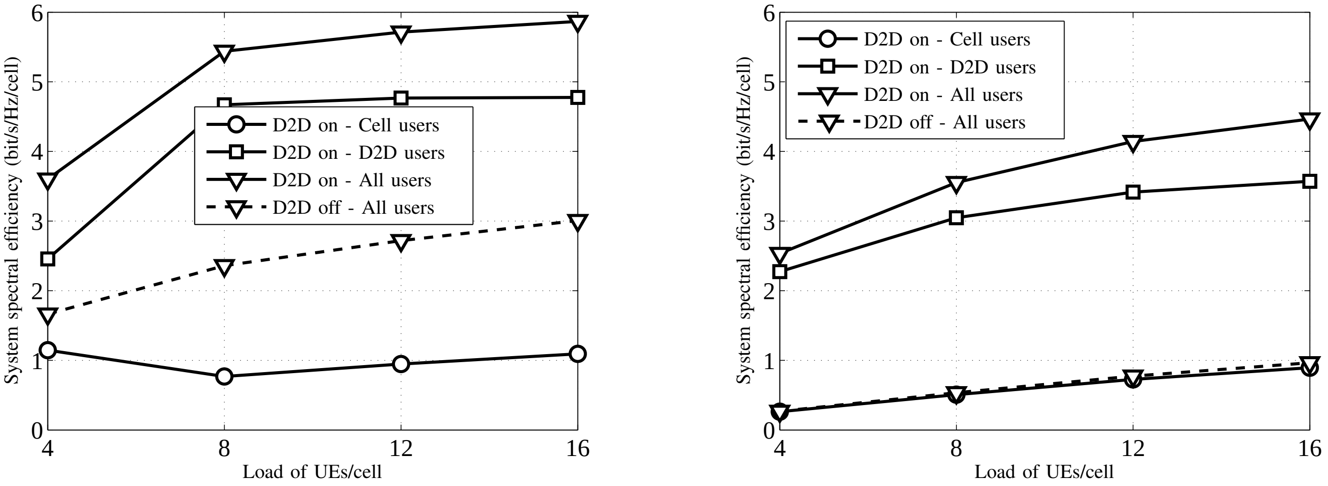
The results are presented in terms of system spectral efficiency achieved by users employing cellular communications, users employing D2D communications, and all users together in the system. In a network employing D2D communications, while the impact on cellular communications is measured by the decrease, the performance of D2D communications is evaluated by the gain in system spectral efficiency, both measured in comparison to the pure cellular network. The nomenclatures *D2D on* and *D2D off* are exhaustively used in figure legends to refer, respectively, the cellular network with and without D2D communications occurring in parallel.

First, the single-antenna configuration, where the cellular scheduling algorithm selects G = 1 UE and S = 1 stream per UE, is evaluated. Fig. 2 shows the system spectral efficiency in the urban-macrocell environment for both DL and UL communication phases. As seen in Fig. 2(a), the total performance, which is the sum of all users, is greatly increased when compared to the pure cellular scenario. The gain achieved with D2D communications represents 159 % for the highest load. However, cellular communications have their performance reduced due to interference introduced by D2D communications, which act as interfering sources close to cellular users. For the highest load, the performance loss in the system is around 64 %.

Contrary, in UL, the D2D communications do not affect substantially the performance of cellular users and still provide very high gains, as shown in Fig. 2(b). The total gain achieved with D2D communications represents 370 % for the highest load. Additionally, the spectral efficiency in cellular communications is practically maintained in UL because the urban-macro environment is wide (see the inter-site distance defined in Table I) and each eNB is much further away from the D2D interfering UEs.

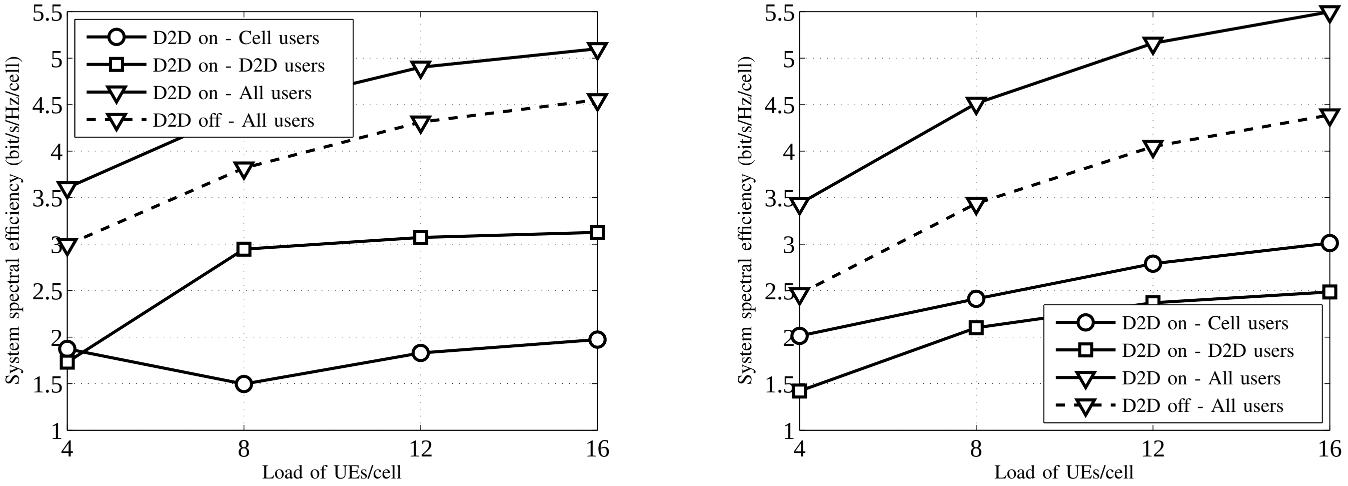
Finally, the absolute gain achieved with D2D communications is higher in DL than UL, even though D2D users have the same transmit power in both communicating links. Indeed, in DL, D2D communications affect much more the performance of cellular UEs than are affected by transmissions coming from the eNB. In the UL, D2D communications do not achieve an higher gain because now D2D users suffer interference coming from closer cellular UEs.

Fig. 3 shows the system spectral efficiency in the urban-microcell environment for both DL and UL communication phases. As seen in Fig. 3(a), when D2D communications are activated, the total system performance is improved and cellular users have their performance decreased, as in the urban-macrocell environment. The gain achieved with D2D communications represents 69 % for the highest load. Herein, the performance loss of cellular communications is also high, being around 57 % for the highest load. Also, as shown



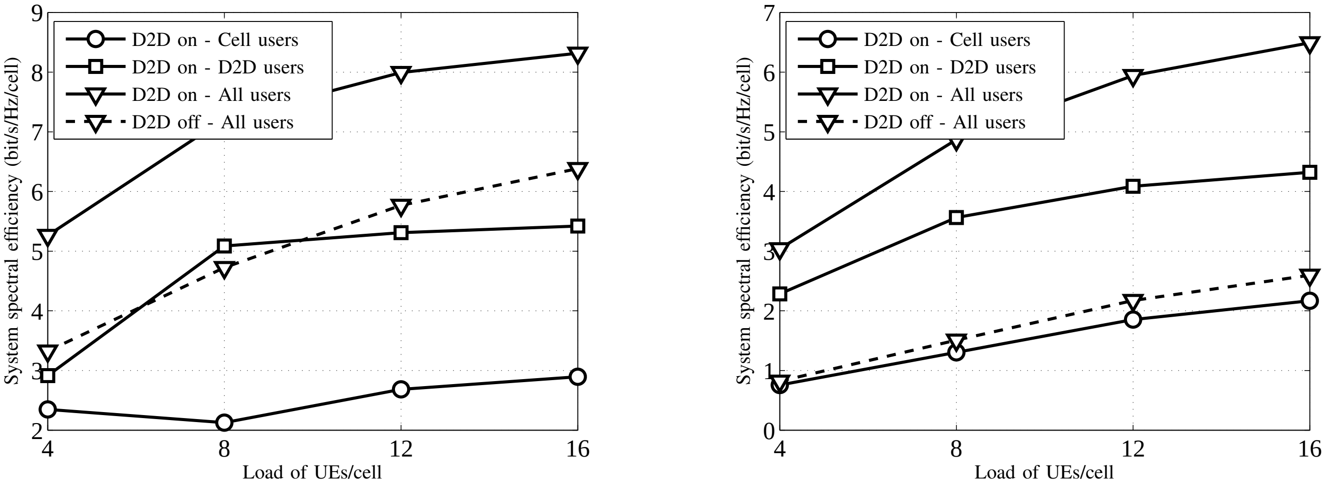
(a) DL. (b) UL.

Fig. 2. System spectral efficiency in the urban-macro environment for both DL and UL communication phases.



(a) DL. (b) UL.

Fig. 3. System spectral efficiency in the urban-microcell environment for both DL and UL communication phases.



(a) DL. (b) UL.

Fig. 4. System spectral efficiency in the urban-microcell environment with the spatial multiplexing-based MIMO 2×2 configuration for both DL and UL communication phases.

in Fig. 3(b), there is a great impact on performance of cellular communications in UL for the urban-microcell environment, differently of what happened in urban-macrocell environment, and for the highest load, the performance loss is around 31 %. Herein, the gain achieved with D2D communications represents 57 % for the highest load. Moreover, when comparing the gains achieved with D2D communications for both urban-macrocell and urban-microcell environments in the DL and UL phases, D2D communications have a worse performance in the urban-microcell because cellular links are closer to D2D receivers than in the urban-macrocell environment.

Next, the MIMO 2×2 configuration is evaluated regarding the more challenging environment for D2D communications, the urban-microcell environment, in which there is a great impact on performance of cellular communications in UL and D2D communications do not get high gains as in the urban-macrocell environment. Herein, only the Single-User (SU)-MIMO with multiple-stream transmissions is considered. Thus, $G = 1$ UE is scheduled and $S = 2$ streams are transmitted. Fig. 4 shows the system spectral efficiency for the urban-microcell environment with the spatial multiplexing-based MIMO 2×2 configuration for both DL and UL phases.

As seen in Fig. 4(a), the performance achieved by using multi-antennas in DL is somehow improved in comparison to that obtained in the single-antenna configuration, being the performance loss of cellular communications about 55 % and the total gain achieved with D2D communications around 65 % for the highest load. Furthermore, the performance achieved by using a multi-antenna configuration scheme in UL is also improved, as shown in Fig. 4(b). In comparison to single-antenna configuration, with MIMO 2×2 the performance loss is reduced from 31 % to 17 % and the gain achieved with D2D communications is increased from 57 % to 166 % for the highest load. Also, by comparing the absolute cellular performance of the multi-antenna in comparison to the single-antenna configuration in the UL phase, as seen in Fig. 3(b) and Fig. 4(b), the cellular performance with MIMO 2×2 is degraded, which happens because an UE already was usually scheduled in all PRBs of the system in the single-antenna configuration and now the lower power at the UE is divided between two streams. However, D2D communications were able to achieve an higher system spectral efficiency, which happens because your proximity.

In the following, the gain introduced with D2D communications and the performance loss of cellular communications in comparison to the performance achieved in the pure cellular scenario for both DL and UL communication phases with 16 UEs/cell are summarized in Table III.

TABLE III

GAIN OF D2D COMMUNICATIONS AND IMPACT ON CELLULAR COMMUNICATIONS FOR BOTH DL AND UL PHASES WITH 16 UES/CELL.

Environ.	**Antenna**	**D2D gain**		**Cell. impact**	
		DL	UL	DL	UL
U-macrocell	SISO	159 %	370 %	64 %	–
U-microcell	SISO	69 %	57 %	57 %	31 %
U-microcell	MIMO 2×2	85 %	166 %	55 %	17 %

V. CONCLUSIONS

The main objective of this paper was to study the impact of D2D communications on cellular communications in a multi-cell scenario. Results showed that the overall system capacity is always improved in both DL and UL phases, urban-macrocell and urban-microcell environments, and with single-antenna and multi-antenna configurations. However, the improvements were registered because D2D communications achieve high gains, that compensates the performance losses in cellular communications. Even in favorable conditions for the use of D2D communications, i.e., when hotspots are located near the cell-edge, there is a strong impact on cellular performance. In fact, the performance of cellular communications is greatly reduced in DL. In UL, a lower impact on cellular performance was observed, being almost negligible in the urban-macrocell environment. Also, D2D communications achieved an higher performance gain in UL. However, in terms of absolute values of system spectral efficiency, D2D communications have shown better system spectral efficiency in DL than UL. We have also seen that the benefits from spatial multiplexing are promising for D2D communications in UL, by reduction the impact on cellular communications, and at the same time, still providing high gain in a challenging environment such as the urban-microcell environment.

Since the problem of mitigating the co-channel interference is the biggest challenge in a multi-cell scenario, in the future we intend to investigate the problem of grouping dynamically D2D communicating pairs sharing the same resources with cellular users in order to avoid interference. As such, D2D communications will not be enabled in all PRBs, as done in the paper, but only when the impact on cellular communications is minimum. Besides that, further gains can be achieved with multiple D2D pairs in situations of low interference.

REFERENCES

[1] G. Fodor, E. Dahlman, G. Mildh, S. Parkvall, N. Reider, G. Mikló, and Z. Turányi, "Design Aspects of Network Assisted Device-to-Device Communications," *IEEE Communications Magazine*, vol. 50, no. 3, pp. 170–177, Mar. 2012.

[2] K. Doppler, R. Mika, C. Wijting, C. Ribeiro, and K. Hugl, "Device-to-Device Communication as an Underlay to LTE-Advanced Networks," *IEEE Communications Magazine*, vol. 47, no. 12, pp. 42–49, Dec. 2009.

[3] E. O. Lucena, M. G. S. Rêgo, T. F. Maciel, and F. R. P. Cavalcanti, "On the Performance of Device-to-Device Communication: a Distance-based Analysis," in *XXIX Telecommunications Brazilian Symposium - SBrT*, Curitiba, Brazil, Oct. 2011, pp. 1–5.

[4] H. de H. M. Barros, M. G. S. Rêgo, E. O. Lucena, T. F. Maciel, W. C. F. Jr., and F. R. P. Cavalcanti, "A Distance-based Study for Device-to-Device Communication Underlaying a Cellular System," in *XXX Telecommunications Brazilian Symposium - SBrT*, Brasília, Brazil, Sep. 2012, pp. 1–5.

[5] 3GPP, "Spatial Channel Model for Multiple Input Multiple Output (MIMO) simulations," Third Generation Partnership Project, Tech. Rep. TR 25.996 V7.0.0, Jun. 2007.

[6] ——, "Physical Layer Aspects for Evolved Universal Terrestrial Radio Access (UTRA)," Third Generation Partnership Project, Tech. Rep. TR 25.814 V7.1.0, Sep. 2006.

[7] ——, "Further advancements for E-UTRA physical layer aspects," Third Generation Partnership Project, Tech. Rep. TR 36.814 V9.0.0, Mar. 2009.

[8] ——, "Evolved Universal Terrestrial Radio Access (E-UTRA); physical layer procedures," Third Generation Partnership Project, Tech. Rep. TR 36.213 V8.6.0, Mar. 2009.

[9] J. C. Ikuno, M. Wrulich, and M. Rupp, "System Level Simulation of LTE Networks," in *Proc. IEEE Vehicular Technology Conference*, May 2010, pp. 1–5.