UE Grouping and Mode Selection for D2D Communications Underlaying a Multicellular Wireless System

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***Abstract*—Network-assisted Device-to-Device (D2D) communication is a promising technology for next generation wireless systems being seen as a means to improve spectrum utilization and reduce energy consumption. However, D2D communications can generate significant interference to cellular communications when resources are shared by both types of communication. Aiming at the reduction of the intracell interference and spectral efficiency improvement, we formulate and analyze methods to group conventional and D2D-capable User Equipments (UEs) for shared resource usage and to decide if D2D-capable UEs should communicate directly or via the Evolved Node B (eNB). The results show that D2D communications can improve the spectral efficiency of the system and that most of this improvement can be achieved by suitably grouping the UEs for sharing resources.**

I. INTRODUCTION

D2D communications underlaying a cellular system offers improved spectrum and energy efficiency by exploiting resource reuse and proximity gains [1]. In fact, D2D communications should play an important role in 5th Generation (5G) networks in which many scenarios of interest, such as open-air festivals, game matches in stadiums, and Machine-Type Communication (MTC) / Internet of Things (IoT) scenarios feature large numbers of close-by nodes wanting to exchange data. These are examples of scenarios for which resource reuse and proximity gains can be richly exploited. Moreover, 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) also considers D2D communications for proximity-aware services, national/public security and safety, and MTCs [1], [2].

Considering D2D communications in cellular systems with resource reuse among conventional cellular links and D2D links, new interference arises due to D2D communications. Two relevant problems in this context are how to select which cellular and D2D links should share a resource and to determine if resource sharing by D2D communications would improve the system spectral efficiency or if conventional cellular communication should be preferred. These problems are a *grouping problem* and a *mode selection* problem, respectively.

In [3], [4] the authors show that a proper mode selection procedure ensures a reliable D2D communication with limited interference to the cellular network. The resource allocation with grouping have been recently studied by [5], [6]. In [5], the radio resource will be shared by the cellular User Equipment (UE) with maximum channel gain and the D2D for which channel gain between the UE receiver and D2D transmitter during the DL phase and channel gain between the D2D transmitter and the Evolved Node B (eNB) during the UL phase are the lowest. In [6], a low complexity algorithm is presented to solve the mode selection and resource allocation for a single-cell scenario concluding that the joint usage of power allocation and mode selection can improve the system's performance.

In this work, we formulate simple yet effective grouping and mode selection algorithms for D2D communications underlaying an LTE-like cellular system and evaluate their performance considering a multicellular system scenario. We adopt a two-step approach: firstly, we group cellular and D2D-capable UEs and, secondly, we apply a mode selection rule to determine if the D2D UEs will communicate directly – in D2D mode – or via the eNB – in conventional cellular mode. Both steps are done by the eNB which decides for the best rate arrangement.

Differently from previous works on resource allocation (or grouping) and mode selection for D2D communications, we consider a realistic multi-cell scenario, with wrap-around, and both UL and DL communication links on which the proposed algorithms are applied. We present a grouping algorithm that can cope with the intracell interference created by the resource reuse, and a mode selection algorithm that suitably chooses between cellular or D2D mode. Later, results will show that D2D communications can improve system spectral efficiency of the system and that most of this improvement can be achieved by grouping the UEs for sharing resources adequately. The remainder of this article is organized as follows: in Section III the UE grouping and the mode selection algorithms are described, in Section IV results and analyses are provided for the proposed algorithms and, finally, in Section V some conclusions and perspectives are presented.

II. SYSTEM MODELING

In this work, we consider an LTE-like multicellular wireless system following the urban-micro scenario described in [7]. We consider seven hexagonal cells with an eNB installed at their centers. In each cell, there is a rectangular hotspot area located near the cell-edge within which the D2D-capable UEs

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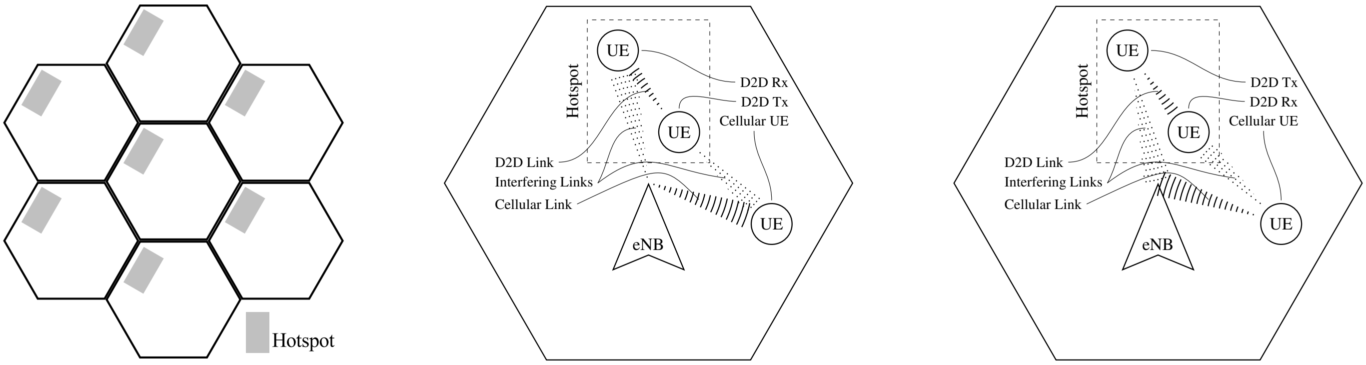


(a) Cellular system (b) Shared-resource communications in DL (c) Shared-resource communications in UL

Figure 1. System scenario and shared-resource cellular and Device-to-Device (D2D) communications within a cell

Table I
SIMULATION PARAMETERS

Parameter	Value
Number of eNBs	7 (with wrap-around)
Inter-site distance	$500\,\mathrm{m}$
Hotspot size	$50 \times 100\,\mathrm{m}$
% of UEs in the hotspot	$50\,\%$
Communication links	DL and UL
Central carrier frequency	$1.9\,\mathrm{GHz}$
System bandwidth for DL / UL	$5\,\mathrm{MHz}$ / $5\,\mathrm{MHz}$
Number of RBs for DL / UL	25 RBs / 25 RBs [7]
Link adaptation	Ideal with 15 MCSs [8]
Required SNR at cell-edge	$-6.2\,\mathrm{dB}$
Traffic model	Full buffer [9]
Number of UEs per cell	16
Power allocation among RBs	Equal Power Allocation
Propagation environment	Urban-micro [9]
eNB transmit power	$38\,\mathrm{dBm}$
UE transmit power	$24\,\mathrm{dBm}$
Path loss model for cellular links	$34.5 + 38\log_{10}(d)\,\mathrm{dB}$ [7]
Path loss model for D2D links	$37 + 30\log_{10}(d)\,\mathrm{dB}$ [7]
Shadowing standard deviation	$10\,\mathrm{dB}$
Short-term fading	3GPP SCM urban-micro [9]
Average user speed	$3\,\mathrm{km/h}$
Noise power per RB	$-116.4\,\mathrm{dBm}$
Antenna configuration	1×1 omni directional [7]
CSI knowledge	Perfect CSI
TTI duration	$1\,\mathrm{ms}$
Number of snapshots	$1{,}000$

are uniformly positioned while conventional cellular UEs are positioned uniformly over the whole cell area. We model both DL and UL and consider a wrap-around model in order to avoid border effects. The considered scenario is illustrated in Figure 1, as well as cellular and D2D communications on shared resources in DL and UL.

The channel modeling encompasses a distance-based path loss (with distance d in meters), log-normal shadow fading, and short-term fading [7]. Herein, the minimum allocable resource unit encompasses 12 adjacent subcarriers of $15\,\mathrm{kHz}$ in frequency domain and two slots of $0.5\,\mathrm{ms}$ each in time domain. Thus each resource unit corresponds to two timely consecutive RBs of 12 subcarries and 7 Orthogonal Frequency Division Multiplexing (OFDM) symbols. The channel response for each resource is represented by the complex channel coefficient associated with its RB middle subcarrier and first OFDM symbol. Resources are allocated to UEs at each TTI (i.e., $1\,\mathrm{ms}$). We assume Equal Power Allocation (EPA) among the RBs and link performance is modeled using the link level results of [8] for the 3GPP LTE MCSs. The most relevant simulation parameters are shown in Table I.

III. UES GROUPING AND MODE SELECTION

As previously mentioned, we adopt a two-step approach regarding grouping and mode selection. For our proposed algorithms, resources are initially assigned according to Maximum Gain (MG) scheduling policy, i.e., each resource is assigned to the cellular UE with highest channel gain on its RB at the current TTI. The MG scheduling will likely assign resources to the UEs closest to the eNB. Then, for each resource, the grouping algorithms of Section III-A, are used to group a D2D pair ($\mathrm{D2D_{Tx}}$ and $\mathrm{D2D_{Rx}}$) together with the cellular UE to whom the resource has been assigned. Then, the mode selection algorithm of Section III-B, is applied.

A. D2D UEs Grouping

The basic idea of D2D grouping is to place in a same group D2D pairs and cellular UEs as to obtain gains through D2D communications and prevent undesired impacts on the performance of cellular communications.

After the MG-based resource assignment to the cellular UEs, one D2D pair among the available ones should be grouped together with the cellular UE on each resource. The D2D pair is chosen based on a grouping metric that should capture the compatibility among the D2D pair and the cellular UE. We consider two grouping algorithms: a random grouping algorithm, described in Section III-A1, and a proposed distance-based grouping algorithm described in Section III-A2, both of which run independently in each cell.

1) Random Grouping Algorithm: In order to have a simple D2D grouping algorithm to serve as a benchmark, on each resource we consider the random selection of one D2D pair inside the hotspot zone to be grouped with the cellular UE to whom a resource has been assigned. This algorithm does not use any channel information and it is presented in Algorithm 1.

Algorithm 1 Random Grouping Algorithm

```
for each TTI do
    for each cell do
        for each resource do
            Select the cellular UE using the MG metric
            Select randomly a non-grouped D2D pair and group it with scheduled cellular UE
        end for
    end for
end for
```

2) Distance-based Grouping Algorithm: As mentioned before, MG scheduling shall improve spectral efficiency by likely scheduling cellular UEs near the eNB. Then, when a D2D_{Tx} is near the cell edge, its harming interference to such cellular UEs should be low and grouping such D2D_{Tx} and cellular UE shall lead to an efficient resource reuse. Thus, in a scenario with multiple D2D pairs, the chosen pair shall be that one whose transmitter presents lowest large-scale fading gains (larger distance) with respect to the eNB. Therefore, the distance-based grouping algorithm will group the cellular UE and D2D pair whose D2D_{Tx} is most distant from the eNB (i.e., with lowest large-scale fading gain), as shown in Algorithm 2.

Algorithm 2 Distance-based Grouping Algorithm

```
for each TTI do
    for each cell do
        for each resource do
            Select the cellular UE using the MG metric
            Select the D2D pair whose $\text{D2D}_{\text{Tx}}$ has the lowest large-scale fading gain to the eNB and group it with scheduled cellular UE
        end for
    end for
end for
```

B. Mode Selection Algorithm

Herein, the basic idea of mode selection is letting the eNB determine if higher rate (spectral efficiency) is obtained when D2D-capable UEs communicate directly – i.e., in D2D mode –, or via the eNB – i.e., in cellular mode. Figures 1(b) and 1(c) illustrate a cell with one eNB, one cellular UE – UE_1 –, and one D2D pair – D2D_{Tx} and D2D_{Rx} as UE_2 and UE_3 – at the cell edge. As the D2D_{Tx} is close to the D2D_{Rx} and far from the eNB, D2D communications can exploit proximity and reuse gains to improve system performance.

In this work, three modes are analyzed: *cellular mode*, which sets all the D2D-capable UEs to communicate via the eNB in spite of potential gains achievable from direct communication; *D2D mode*, which forces the UEs in D2D pairs to communicate directly disregarding potential interference created to cellular communications; and *rate-based mode selection*, which estimates rate values for D2D and cellular communications to select either cellular or D2D mode.

The rate-based mode selection estimates rates applying Shannon's capacity formula on Signal to Interference-plus-Noise Ratio (SINR) values calculated using only long-term fading information and verifies if the estimated rate using D2D communication is larger than the one using cellular communication and orthogonal resources [10]. Thus, we assume that the large-scale fading measurements for the link between the nodes are available (e.g., provided by the eNB) and use these measurements as a representative of the signal strength.

For D2D communication in UL, UE_1 transmits to its serving eNB, this corresponding to the link 1, and the D2D_{Tx} transmits to the D2D_{Rx}, this corresponding the link 2. For links 1 and 2, D2D_{Tx} and UE_1 are the interfering devices, respectively. For link 1, the closer the UE_1 is to the eNB and the farther D2D_{Tx} is from the eNB, the higher its rate (see Figure 1(c)). For link 2, the closer the D2D_{Tx} is to D2D_{Rx} and the farther UE_1 is from D2D_{Rx}, the higher its rate.

For cellular communication in UL, all nodes use orthogonal resources and there are two phases: in phase 1, UE_1 transmits to its serving eNB while D2D_{Tx} is off; in phase 2, D2D_{Tx} transmits to its serving eNB while UE_1 is off. We consider that the sum rate in the cellular mode is (roughly) half the sum of the rate obtained in each phase since it uses two resources (in time) [10].

For communications in DL, cellular and D2D communications work in similar manner with eNB and UE_1 being transmitter and receiver, respectively (see Figure 1(b)).

In the following, we describe the rate-based mode selection in more details considering the UL. The rate-based mode selection decides which mode to use – cellular or D2D mode – for each TTI, resource and cell based on the rate estimates

$$R_1^{\text{D2D}} = \log_2\left(1 + \frac{p_{\text{UE}_1}\alpha_1\chi_1}{p_{\text{D2D}_{\text{Tx}}}\alpha_3\chi_3 + \sigma^2}\right), \tag{1a}$$

$$R_2^{\text{D2D}} = \log_2\left(1 + \frac{p_{\text{D2D}_{\text{Tx}}}\alpha_2\chi_2}{p_{\text{UE}_1}\alpha_4\chi_4 + \sigma^2}\right), \tag{1b}$$

$$R_1^{\text{cell}} = \log_2\left(1 + \frac{p_{\text{UE}_1}\alpha_1\chi_1}{\sigma^2}\right), \tag{1c}$$

$$R_2^{\text{cell}} = \log_2\left(1 + \frac{p_{\text{D2D}_{\text{Tx}}}\alpha_3\chi_3}{\sigma^2}\right), \tag{1d}$$

where R_1^{D2D} is the rate calculated for the link 1, R_2^{D2D} is the rate calculated for in the link 2, R_1^{cell} is the rate calculated in the link 1 when D2D_{Tx} is off, and R_2^{cell} is the rate calculated in the link 3 between D2D_{Tx} and eNB when UE_1 is off. In Equation 1, $p_{(\cdot)}$ is the transmit power of a specific node, σ^2 is the average noise power, and α and χ are the path loss attenuation and shadowing of the previously described links and for the link 4 between D2D_{Tx} to UE_1, which are all assumed to be known.

Hence, the rate-based mode selection scheme will decide to use direct D2D communication if the inequality

$$R_1^{\text{D2D}} + R_2^{\text{D2D}} \geq \frac{1}{2}\left(R_1^{\text{cell}} + R_2^{\text{cell}}\right) \tag{2}$$

is satisfied, otherwise cellular communication is selected. The rate-based mode selection is presented in Algorithm 3, where we consider intercell interference but we do not account for it to estimate rates, since we do not assume any kind of knowledge related to it in the system. However, (long-term) estimates of the interference could be easily incorporated as part of noise power, this topic being left for future investigations.

Algorithm 3 Rate-based Mode Selection Algorithm

```
for each TTI do
    for each resource do
        for each cell do
            Calculate the rate estimates $R_1^{\text{D2D}}$, $R_2^{\text{D2D}}$, $R_1^{\text{cell}}$, and $R_2^{\text{cell}}$
            if $R_1^{\text{D2D}} + R_2^{\text{D2D}} \geq \frac{1}{2}\left(R_1^{\text{cell}} + R_2^{\text{cell}}\right)$ then
                Choose D2D communications
            end if
        end for
    end for
end for
```

IV. NUMERICAL RESULTS AND DISCUSSION

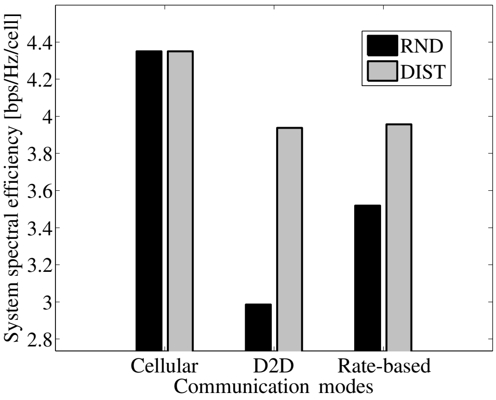
The described methods have been evaluated by means of simulations considering the parameters described in Table I. The system spectral efficiency is used as metric to compare the performance of cellular and D2D UEs. In order to understand and quantify the effect of both Radio Resource Management (RRM) techniques in the system, the two grouping algorithms of Section III-A are combined with the different communication modes described in Section III-B. In Table II, results for UL and DL are presented for cellular and D2D UEs as well as for the random grouping, termed RND, and the distance-based grouping, termed DIST.

Table II
SYSTEM SPECTRAL EFFICIENCY

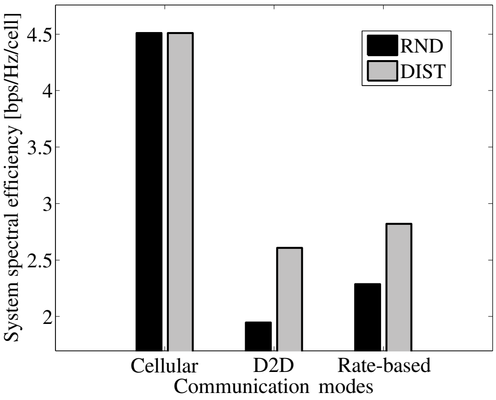
Mode	Cellular UEs			D2D UEs			Total
	DL	UL	UL+DL	DL	UL	UL+DL	
Random Grouping							
Cell.	4.51	4.35	8.86	0.00	0.00	0.00	8.86
D2D	1.95	2.99	4.94	3.13	2.51	5.64	10.58
Mode Sel.	2.29	3.52	5.81	3.04	1.98	5.02	10.83
Distance-based Grouping							
Cell.	4.51	4.35	8.86	0.00	0.00	0.00	8.86
D2D	2.61	3.94	6.55	2.81	2.10	4.91	11.46
Mode Sel.	2.82	3.96	6.78	2.81	2.08	4.89	11.67

In Figure 2[1] we have the results for cellular users for both UL and DL. In Figure 2(a) with random grouping, we notice that the spectral efficiency of the cellular mode is reduced when considering the other modes. Moreover, since there is no D2D communication in the cellular mode, both grouping algorithms have the same performance. For the D2D mode, this reduction is of approximately 31 %, while for the rate-based it is only 9 %. Thus, the rate-based mode selection is capable of choosing between cellular and D2D modes avoid high spectral efficiency losses. With the distance-based grouping, the losses due D2D communications are still present, but only about 9 %. The performance difference expected for the rate-based and D2D modes is not present here, which shows that distance-based grouping is in most of the cases a correct choice for D2D communications in UL.

In Figure 2(b) with random grouping, we notice that the spectral efficiency of cellular mode suffers higher spectral efficiency losses: approximately 57 % for the D2D mode and 46 % for the rate-based mode. However, the gains brought by D2D communications are also high, compensating for the losses and improving the total spectral efficiency. Thus, although the gain from the usage of the rate-based mode selection is not high, it is still capable of choosing cellular mode for situations where D2D communications are not suitable, thus preserving better the rates achieved by the cellular UEs. With the distance-based grouping, the losses due D2D communications are still present, but reduced to about 42 %. Again, the performance difference between rate-based mode and D2D mode remains small in this case, but is more visible here, showing that the forced usage of D2D communications in DL may be a wrong choice for some cases. Nevertheless, distance-based grouping remains in most of the cases a correct choice for D2D communications.



(a) Uplink



(b) Downlink

Figure 2. System spectral efficiency for cellular UEs for both UL and DL

In Figure 3 we have the results for D2D users for both UL and DL. With random grouping in Figure 3(a), we notice spectral efficiency reductions of about 21 % when using the rate-based instead of D2D mode. The higher spectral efficiency of D2D mode comes at the expenses of the degradation of the cellular links, as it can be noted in Figure 2(a). For the distance-based grouping, the difference between the modes is only about 1 %, which shows again that almost all the D2D grouped are indeed good choices for D2D communications. The losses suffered by the D2D UEs due the usage of distance-based are expected, since it chooses the D2D UEs that also minimize the interference to the cellular communications, and not the ones leading to highest rates for D2D communication.

In Figure 3(b) for random grouping, the spectral efficiency

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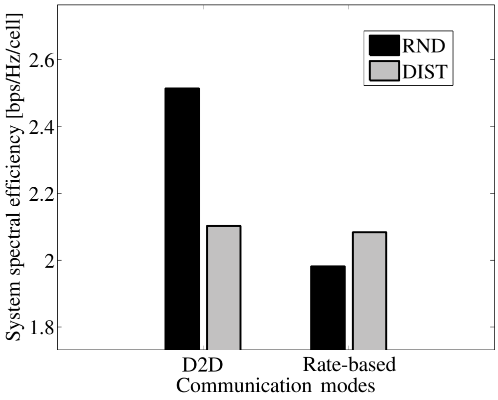
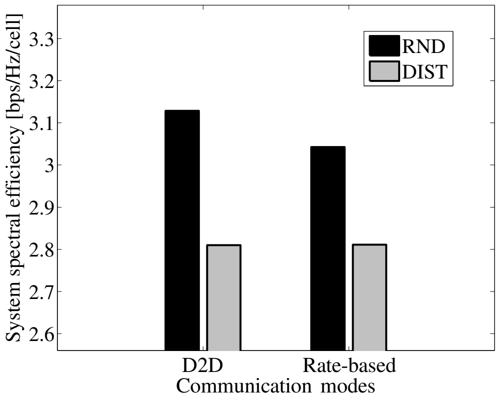
[1] Please, notice that y-axes in our figures do not start at zero.



(a) Uplink

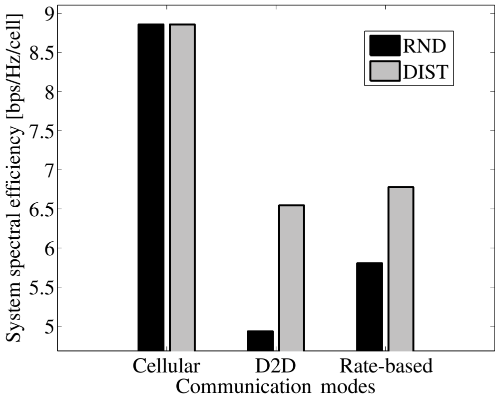


(b) Downlink

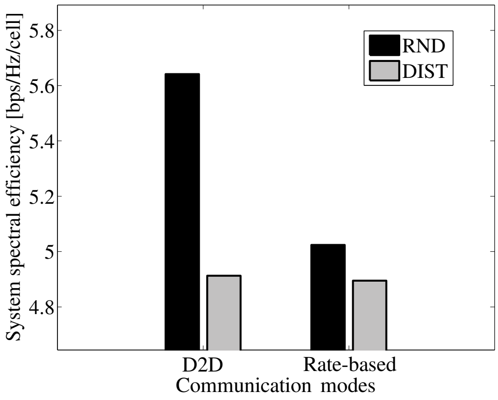
Figure 3. System spectral efficiency for D2D UEs for both UL and DL

reduction for the D2D mode compared to the rate-based mode is approximately 2 %, which is explained since cellular communications in DL use higher power than in UL. For the distance-based grouping, both modes have almost the same spectral efficiency. Again, distance-based grouping has lower spectral efficiency compared to random grouping, which is expected, since the distance-based grouping chooses the D2D UEs taking into account the interference they cause to cellular UEs. Nonetheless, pure D2D communications on the DL might be a good choice from the point of view of D2D UEs, thus avoiding unnecessary calculations performed by mode selection.

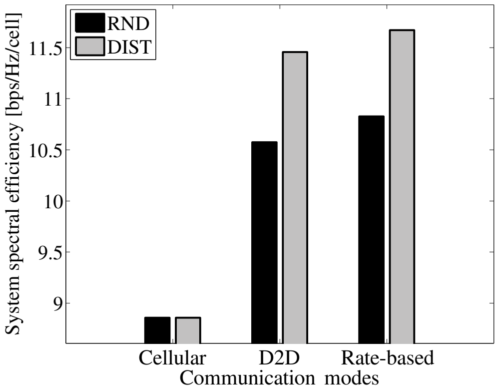
In Figure 4 we concentrate our analyses on the aggregate spectral efficiency values (UL+DL) achieved with each mode, for the cellular and D2D UEs and for the random grouping and the distance-based grouping. Regarding the cellular UEs with random grouping in Figure 4(a), the cellular mode presents the highest spectral efficiency with gains above 50 % compared to the other modes. Its good performance is expected since there is no D2D communications and, consequently, no additional D2D interference to harm cellular communications. With the distance-based grouping, the performance of the cellular mode has not changed, since D2D-capable UEs operate as conventional cellular UEs.



(a) Cellular UEs



(b) D2D UEs



(c) Total system spectral efficiency

Figure 4. System spectral efficiency for cellular and D2D UEs

For the D2D UEs with random grouping in Figure 4(b), the cellular mode is not presented, since there is no D2D communications in that mode. For the D2D users, the D2D mode presents a better performance than the rate-based one, with a relative gain of approximately 12 %. This gain comes at the expenses of the degradation of the cellular links, as it can be noted in Figure 4(a). For D2D users, comparing the usage of random grouping and distance-based grouping in D2D mode and rate-based mode, we can see that the performance with the distance-based grouping algorithm is worse than that of random grouping algorithm. This occurs because the distance-based grouping limits the D2D pairs that can be selected by taking into account the scheduled cellular UE thus leaving out D2D pairs that that would attain high rates but that would do more harm to cellular communications. This does not happen with the random grouping, which does not limit neither the selection of D2D pairs nor their impact on the cellular communications, as it can be verified in Figure 4(a). The distance-based grouping does not only intend to increase spectral efficiency of D2D UEs, but also to limit interference caused by D2D communications to the cellular UEs.

Considering the rate-based mode selection with distance-based grouping, we can see that both D2D and rate-based modes have achieved almost the same spectral efficiency. Thus, the rate-based mode selection offers protection to the cellular UEs, which have higher spectral efficiency considering both random grouping and distance-based grouping algorithms, as shown in Figure 4(a).

Figure 4(c) shows the total system spectral efficiency, i.e., the sum of the spectral efficiencies of cellular and D2D UEs shown in Figure 4(a) and Figure 4(b). In Figure 4(c), it can be seen that the rate-based mode selection achieves results approximately 17 % better than the D2D mode. Conversely, D2D and rate-based modes achieved gains in the spectral efficiency of about 16 % and 32 %, respectively, compared to the cellular mode. Thus, the results show that D2D communications, be it with D2D or rate-based modes, causes a decrease in the spectral efficiency of cellular UEs, due to the interference created by D2D communications, but improved the overall spectral efficiency of the system. Moreover, the rate-based mode achieved better performance than the D2D mode in which all the D2D-capable UEs communicate directly disregarding the interference caused to cellular communications.

Considering again the total spectral efficiency in Figure 4(c), the cellular mode has the worst performance and other two modes have almost the same spectral efficiency, where the gains relative to the performance of the cellular mode are about 19 %. In spite of the fact that the rate-based achieved the best results, its relative gain to the D2D mode is only about 2 %. Regarding the usage of distance-based grouping, there is a marginal gain compared to the random grouping in the D2D and rate-based modes, about 7 %, while the relative gain between the D2D and rate-based modes is only about 1 %.

Hence, although the cellular mode reached the highest spectral efficiency for the cellular UEs, its total spectral efficiency was the lowest, which shows that the usage of D2D communication and a proper mode selection can improve system performance. The D2D and rate-based presented almost the same spectral efficiency, which implies that the usage of the D2D mode, where all the D2D-capable users are underlaid by the cellular network, can be recommended for cases where the complexity is a key parameter. Moreover, most of the performance gains came from usage of a suitable D2D grouping strategy, which might be sufficient for a scheme that aims at suitably increasing spectral efficiency and might dispense the usage of a mode selection scheme.

V. CONCLUSIONS AND PERSPECTIVES

In this work, we formulated simple yet effective grouping and mode selection algorithms for D2D communications underlaying an LTE-like cellular system and evaluate their performance considering a multicellular system scenario.

The presented results have shown that the usage of D2D communications, either using forcedly the D2D mode or employing the rate-based mode selection, can improve the spectral efficiency of the system. This spectral efficiency gain comes at the cost of a reduction in the spectral efficiency of cellular communications.

For the D2D-capable UEs, the rate-based mode achieved a slightly worse performance than the D2D mode, but provided higher protection to the cellular communications.

Although the rate-based presented the highest spectral efficiency values among the three considered modes, its gain compared to the D2D mode was marginal, which implies that most of the spectral efficiency improvement can be achieved by employing a suitable grouping algorithm, such as the proposed distance-based grouping.

As future perspectives, we intend to study a D2D multi-hop scenario, where mode selection would be a challenge as well as its usage with other RRM techniques, such as power control and resource allocation.

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] 3GPP, "Feasibility study for Proximity Services (ProSe)," 3rd Generation Partnership Project (3GPP), TR 22.803, Dec. 2012. [Online]. Available: http://www.3gpp.org/ftp/Specs/html-info/22803.htm

[3] K. Doppler, C.-H. Yu, C. B. Ribeiro, and P. Janis, "Mode Selection for Device-to-Device Communication Underlaying an LTE-Advanced Network," in *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC)*, Apr. 2010, pp. 1 –6.

[4] S. Hakola, T. Chen, J. Lehtomaki, and T. Koskela, "Device-to-Device (D2D) Communication in Cellular Network - Performance Analysis of Optimum and Practical Communication Mode Selection," in *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC)*, Apr. 2010, pp. 1 –6.

[5] M. Zulhasnine, C. Huang, and A. Srinivasan, "Efficient Resource Allocation for Device-to-Device Communication Underlaying LTE Network," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2010 IEEE 6th International Conference on*, Oct 2010, pp. 368–375.

[6] C.-P. Chien, Y.-C. Chen, and H.-Y. Hsieh, "Exploiting spatial reuse gain through joint mode selection and resource allocation for underlay device-to-device communications," in *Wireless Personal Multimedia Communications (WPMC), 2012 15th International Symposium on*, 2012, pp. 80–84.

[7] 3GPP, "Further advancements for E-UTRA physical layer aspects," Third Generation Partnership Project, Tech. Rep. TR 36.814 V9.0.0, Mar. 2009.

[8] 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.

[9] 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.

[10] 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.