Uplink Power Control with Variable Target SINR for D2D Communications Underlying Cellular Networks

Yuri V. L. de Melo, Rodrigo L. Batista, Carlos F. M. e Silva,
Tarcisio F. Maciel, José Mairton B. da Silva Jr., and Francisco R. P. Cavalcanti
Wireless Telecommunications Research Group (GTEL)
Federal University of Ceará (UFC), Fortaleza, Brazil
E-mails: {yurivictor, rodrigobatista, cfms, maciel, mairton, rodrigo}@gtel.ufc.br

Abstract—**Researches in Power Control (PC) schemes are fundamental to provide efficient algorithms and understand their behavior in Device-to-Device (D2D) scenario. The aim of the current study is to investigate Open Loop Power Control (OLPC), Closed Loop Power Control (CLPC) and indicate Soft Dropping Power Control (SDPC) like an alternative PC scheme to D2D communications underlaying a cellular network. We briefly review PC schemes, suggest a new point of dynamic offset compensation factor σ setting the issue in CLPC and evaluate its performance in terms of spectral and power efficiency. Results demonstrate that SDPC keeps a reasonable spectral efficiency and provides a gain of $70\,\%$ in power efficiency in relation Long Term Evolution (LTE) PC schemes for cellular communications, and the factor $\sigma = 0.8$ can modify the behavior of CLPC because increases the Signal to Interference-plus-Noise Ratio (SINR) of the worst users.**

I. INTRODUCTION

Currently, energy efficiency in wireless networks is seen as an essencial requirement, in order to extend the battery lifetime of User Equipments (UEs). New technologies, such as Device-to-Device (D2D) communications underlaying a cellular network, are used to improve resource utilization and potentially reduce power consumption. Nevertheless, a possible impairment may happen in the quality of cellular communications due to increased co-channel interference [1]. Therefore, Power Control (PC) schemes are required to keep interference under control, protect cellular communications and achieve energy-efficient transmissions.

Many research papers found in literature show a comparative between PC schemes in D2D communications. In [2], [3], Uplink (UL) PC schemes have been studied for D2D communications, such as fixed power scheme, fixed Signal to Noise Ratio (SNR) target scheme, and Long Term Evolution (LTE) PC schemes—Open Loop Power Control (OLPC) and Closed Loop Power Control (CLPC). In [3], the authors use the LTE OLPC for cellular links and study other PC schemes for D2D links. The authors conclude that the LTE PC schemes get close in terms of transmit power and Signal to Interference-plus-Noise Ratio (SINR) levels to an optimization-based approach aiming to increase spectrum usage efficiency and reduce sum power consumption, especially for cellular UEs.

In [4], the Soft Dropping Power Control (SDPC) scheme adjusts the transmit power to meet a variable target SINR in an UL single-carrier system. In [5], the SDPC scheme was used to protect cellular and D2D communications from mutual interference in a Downlink (DL) Orthogonal Frequency Division Multiple Access (OFDMA) system. It improved the spectral efficiency of cellular UEs in $14\,\%$ and still significantly reduced the power of D2D transmitters in about $49\,\%$ without harm the spectral efficiency achieved by D2D receivers. Thus, SDPC scheme appears as a promising solution to protect cellular UEs from the interference generated by D2D communications.

The main contribution of this paper is to provide system-level analyzes for energy efficiency of cellular and D2D communications achieved by PC schemes in multi-cell UL OFDMA systems, as described in the following:

- Compare the LTE PC schemes;
- Suggest and analyze the parameters for CLPC scheme;
- Show SDPC like an alternative of PC scheme.

The remaining sections are organized as follows: in Section II, the system model is addressed; Section III describes the considered PC schemes; Section IV presents the simulation results; and finally, in Section V conclusions are drawn.

II. SYSTEM MODEL

The considered scenario corresponds to seven hexagonal cells with an Evolved Node B (eNB) placed at the center of each cell, see Fig. 1. All UEs and eNBs are equipped with a single omnidirectional antenna. Each cell comprises a hotspot zone located near the cell-edge in order to model situations in which D2D communications are likely to happen [1]. Herein, $50\,\%$ of the total number of UEs within the cell are clustered inside a $50 \times 120\,\mathrm{m}$ hotspot zone while the remaining UEs are uniformly distributed over the cell area. Considering that UEs inside the hotspot are close to each other and far from most cellular UEs, pairs of D2D-capable UEs are obtained by a simple random pairing procedure [1].

Due to practical reasons, subcarriers are grouped in blocks of 12 adjacent subcarriers spaced by $15\,\mathrm{kHz}$, which gives a total bandwidth of $180\,\mathrm{kHz}$ per block. Then, the information is conveyed on that bandwidth over a slot with duration of $0.5\,\mathrm{ms}$ and 7 Orthogonal Frequency Division Multiplexing (OFDM) symbols. This frequency-time block is designated as Physical Resource Block (PRB) and is the minimum allocable unit that can be scheduled in OFDMA LTE systems. Nevertheless, and

978-1-4799-8088-8/15/$31.00 ©2015 IEEE

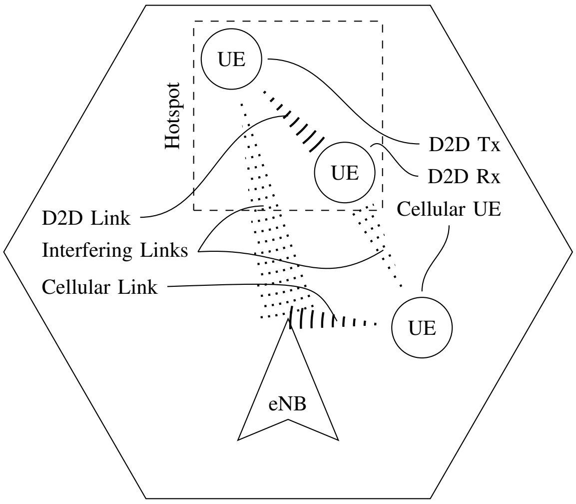


Fig. 1. Cellular and D2D communications in UL direction

due to scheduling constraints, a UE when scheduled takes two slots (per Transmission Time Interval (TTI) or $1\,\mathrm{ms}$) [6]–[8].

In our model, the total number of PRBs available N_{PRB} at each cell can be fully reused in all other cells. Moreover, the channel response for each PRB is represented by the complex channel coefficient associated with its middle subcarrier and first OFDM symbol; and the channel coherence bandwidth is assumed larger than the bandwidth of a PRB, leading to a flat fading channel over each one of them.

The modeling of the complex channel coefficients includes propagation effects on the wireless channel, namely, pathloss, shadowing, fast fading and antenna gains. Particular aspects of the fading model for the considered urban-microcell propagation environment are described in [6], [9] and the basic parameters for cellular and D2D links are presented in Table I.

TABLE I
BASIC PARAMETERS IN THE URBAN-MICROCELL PROPAGATION ENVIRONMENT FOR THE CHANNEL MODEL OF CELLULAR AND D2D LINKS

Parameter	Value	Ref.
Inter-site distance	$500\,\mathrm{m}$	[9]
UE transmit power (P_{UE})	$24\,\mathrm{dBm}$	[6]
Horizontal antenna pattern	$A(\theta) = 1$ (omnidirectional)	[6]
Cellular pathloss model†	$34.5 + 38\log_{10}(d)\,\mathrm{dB}$	[6]
D2D pathloss model†	$37 + 30\log_{10}(d)\,\mathrm{dB}$	[7]
Shadowing std. deviation	$10\,\mathrm{dB}$	[6]
Fast fading model	3GPP SCM	[9]

† d is the distance between communicating devices in meters

The use of Maximum Gain (MG) scheduling policy provides a favorable scenario for sharing resources, since scheduled cellular UEs are usually close to the eNB and D2D pairs are within hotspot zones located near the cell-edge. After one cellular UE is selected by the cellular scheduling policy, a D2D pair inside the hotspot zone is grouped with the former UE to share the same PRB [1].

Hence, the link adaptation procedure selects the Modulation and Coding Scheme (MCS) that yields the maximum SINR threshold [8], [10], and all packets are successfully received.

III. Power Control Schemes

A. LTE Power Control

OLPC and CLPC are the standard LTE power control with fractional pathloss compensating [8]. The total transmit power p_k of a cellular or D2D UE k is given as

$$p_k = \min\{P_{\mathrm{UE}}, P_0 - \alpha G + 10\log_{10} N_k + \triangle\}, \tag{1}$$

where P_{UE} is the maximum UE power, $0 \leq \alpha \leq 1$ is the pathloss compensation factor, G denotes the path gain of the channel, N_k is the number of PRBs scheduled to the UE k and $\triangle$ is dynamic offset. Dynamic offset is what differentiates OLPC from CLPC, because OLPC does not have feedback, therefore $\triangle = 0$ and CLPC has it, which can be computed as

$$\triangle = \begin{cases} (\Gamma_k - \gamma_k)\sigma, & \text{if } (\Gamma_k - \gamma_k)\sigma > 1, \\ 1, & \text{if } (\Gamma_k - \gamma_k)\sigma \leq 1, \end{cases} \tag{2}$$

where γ_k is the current SINR of UE k and $0 < \sigma \leq 1$ is the dynamic offset compensation factor. P_0 is power level used to control the target SINR Γ_k, which is given according to [3] as

$$P_0 = \alpha(\Gamma_k + P_{\mathrm{N}}) + (1-\alpha)(P_{\mathrm{UE}} - 10\log_{10} N_k), \tag{3}$$

where, for simplicity, P_{N} is the thermal noise power at the cellular or D2D receiver, respectively, eNB or UE. After total transmit power is updated, the Equal Power Allocation (EPA) scheme obtains the power $p_{k,n}$ in each PRB n as

$$p_{k,n} = p_k / N_k. \tag{4}$$

B. Soft Dropping Power Control (SDPC)

The SDPC gradually decreases the target SINR as the required transmit power rises and thus it increases the probability of configuring a feasible solution for the PC problem—in which the target SINR values of all co-channel links can be reached [4]. Hence, links with worse quality, which demand higher power, aim lower SINR values while links with better quality, which demand lower power, aim higher SINR values.

In the SDPC scheme, each UE iteratively adjusts its transmit power per PRB in order to find a power vector $\mathbf{p}$ for all UEs in the system such that the SINR $\gamma_{k,n}$ of each UE k in PRB n must satisfy

$$\gamma_{k,n}(\mathbf{p}) \geq \Gamma_{k,n}(p_{k,n}), \tag{5}$$

where $\Gamma_{k,n}(p_{k,n})$ is the target SINR of the UE k in the PRB n, which varies according to the required transmit power $p_{k,n}$.

The SDPC scheme uses a target SINR varying from a maximum value Γ_{max} to a minimum Γ_{min} as the required transmit power goes from a minimum value P_{min} to a maximum P_{max}. Here, we denote the PC range by $\Delta_P = P_{max} - P_{min}$. For $p_{k,n} \leq P_{min}$, one attempts to maintain a high quality connection by aiming for a target SINR Γ_{max}. For $p_{k,n} \geq P_{max}$, one aims a target SINR Γ_{min} which is relatively easier to reach when channel conditions are bad.

Finally, for $P_{min} < p_{k,n} < P_{max}$, one aims for a target SINR $\Gamma_{k,n}(p_{k,n})$ that linearly (in logarithmic scale) trades SINR for transmit power.

The target SINR $\Gamma_{k,n}(p_{k,n}^{(t)})$ of UE k in the PRB n at TTI t is given according to

$$\Gamma_{k,n}(p_{k,n}^{(t)}) = \begin{cases} \Gamma_{max}, & \text{if } p_{k,n}^{(t)} \leq P_{min}, \\ \Gamma_{max}\left(\dfrac{p_{k,n}^{(t)}}{P_{min}}\right)^{\rho}, & \text{if } P_{min} < p_{k,n}^{(t)} < P_{max}, \\ \Gamma_{min}, & \text{if } p_{k,n}^{(t)} \geq P_{max}, \end{cases} \tag{6}$$

where

$$\rho = \frac{\log_{10}(\Gamma_{min}/\Gamma_{max})}{\log_{10}(P_{max}/P_{min})}. \tag{7}$$

Then, the power per PRB of each UE is updated every transmission as follows

$$p_{k,n}^{(t+1)} = p_{k,n}^{(t)}\left(\frac{\Gamma_{k,n}(p_{k,n}^{(t)})}{\gamma_{k,n}(\mathbf{p}^{(t)})}\right)^{\beta}, \tag{8}$$

where β is a control parameter given by $(1-\rho)^{-1}$ [11].

Finally, whenever the achieved power $p_{k,n}^{(t+1)}$ is over P_{max} or under P_{min}, it is constrained as follows

$$p_{k,n}^{(t+1)} = \min\{P_{max}, \max\{p_{k,n}^{(t+1)}, P_{min}\}\}. \tag{9}$$

In this paper, the maximum power P_{max} is exactly the power that would be obtained in each PRB by employing EPA among the total number of PRBs of the system [5] as follows

$$P_{max} = P_{\text{UE}}/N_{\text{PRB}}. \tag{10}$$

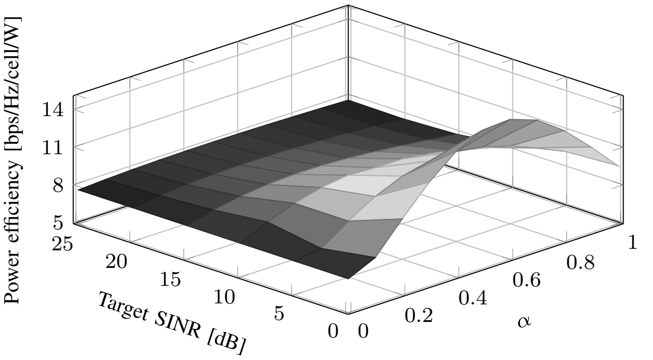
IV. SIMULATION RESULTS

This section provides the performance assessment of PC schemes for cellular and D2D communications in UL OFDMA systems through system-level simulations, which are aligned with LTE architecture [6]–[9]. The main parameters considered in the simulations are summarized in Table II.

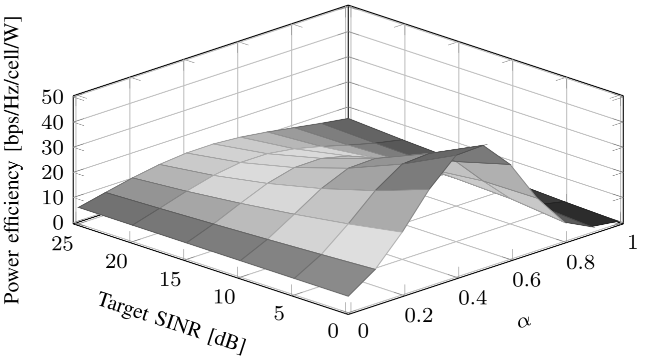
TABLE II
SIMULATION PARAMETERS

Parameter	Value	Ref.
Number of eNBs	7 (with wrap-around)	
Central carrier frequency	1.9 GHz	[9]
System bandwidth	5 MHz ($N_{\text{PRB}} = 25$)	
CSI knowledge	Ideal channel information	
Interference margin	Last measured interference	[1]
Link adaptation	LTE (15 MCSs)	[8]
Thermal noise power	-112.4 dBm	[6]
SINR threshold for lowest MCS	-6.2 dB	[10]
Max. target SINR (Γ_{max})	25 dB	[5]
Average user speed	3 km/h	[6]
Traffic model	Full buffer	
Number of UEs per cell	4	
Effective TTI duration	1 ms	
Snapshot duration	1 s	

For performance evaluation, SDPC is calibrated according to the previous paper [5], which has shown a good power efficiency performance when $\Gamma_{min} = -5$ dB, $\Gamma_{max} = 25$ dB and $\Delta_P = 20$ dB. The parameter $\alpha = 0.5$ is defined as the best value to provide power efficiency at OLPC, see Fig. 2 and the same α is used at CLPC. The CLPC has a parameter σ, which needs to be defined. To understanding the behavior of the σ, for different values of σ the SINR levels were extracted in the 5th and 95th percentiles, and then we computed the diference between those percentiles. Remember if the value is small, the users can achieve the same SINR level. Finally, we set $\sigma = 0.8$, because it has the least value, as shown in Table III.



(a) Cellular Power efficiency (OLPC in cellular and No-PC in D2D links)



(b) D2D Power efficiency (No-PC in cellular and OLPC in D2D links)

Fig. 2. Calibration of the OLPC scheme by applying it to cellular or D2D links. The pathloss compensation factor $\alpha = 0$ gives the No-PC performance

TABLE III
CALIBRATION OF σ FOR CLPC

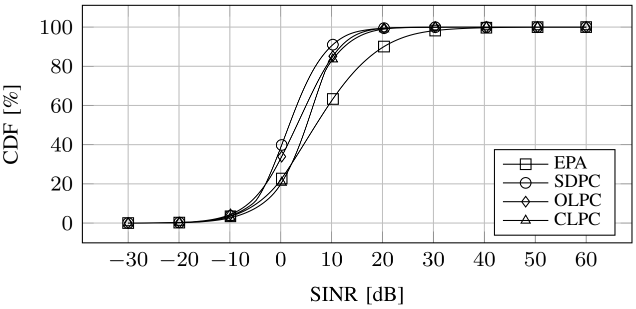
σ	$\text{SINR}_{5\,\%}$	$\text{SINR}_{95\,\%}$	$\text{SINR}_{95\,\%} - \text{SINR}_{5\,\%}$
	Cellular Communication		
0.2	-26.48	-1.34	25.14
0.4	-21.96	0.16	22.12
0.6	-20.45	1.17	21.62
0.8	-15.92	3.18	19.10
1.0	-19.94	9.21	29.10
	D2D Communication		
0.2	-13.41	8.70	22.11
0.4	-10.39	8.21	18.60
0.6	-9.38	8.21	17.59
0.8	-7.87	9.20	17.07
1.0	-10.00	10.73	20.73

The target SINR in OLPC and CLPC is $10\,\mathrm{dB}$ and we consider No-PC approach with EPA among scheduled PRBs, i.e., $p_{k,n} = P_{\mathrm{UE}}/N_k$.

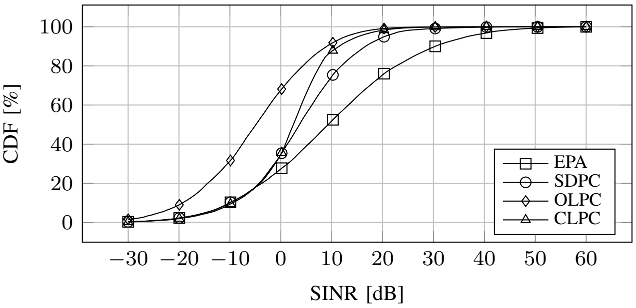
Fig. 3 shows the Cumulative Distribution Functions (CDFs) of SINR for cellular or D2D links. Fig. 3(a) depicts the behavior of SINR levels of cellular links, when EPA is applied to D2D links. Comparing OLPC and CLPC we can perceive that CLPC improves the worst users without compromising the best users.

The SDPC modify the power of users who show SINR between Γ_{max} and Γ_{min} and keeps a fixed power value given by Eq. 10 to user's SINR below Γ_{min}. Comparing EPA with both LTE PC schemes and SDPC, it can be seen a decrease in SINR level of the users with high SINR level, this behavior provides a better power efficiency to cellular communication.

Fig. 3(b) presents SINR levels of D2D links, when EPA is applied to cellular links. We can notice that the SINR has the worst level when OLPC is applied in D2D links. Special attention must be given to the OLPC and CLPC, we can notice a fall of SINR level when OLPC is used. The fall is due high path gain caused by proximity between D2D transmitter (Tx) and receiver (Rx); however, CLPC is not affected, because there is a feedback that adjust transmit power. The SDPC keeps the same SINR to users with low SINR level and improves the users with high SINR level in relation the CLPC.



(a) SINR of cellular communications



(b) SINR of D2D communications

Fig. 3. SINR by applying power control schemes to cellular or D2D links

To further analyze the performance of PC schemes, Fig. 4 shows the behavior of PC schemes in relation to spectral and power efficiency. PC schemes with high spectral efficiency are situated at the top of figure and high power efficiency are situated in the right of the figure. We can notice that EPA has the highest spectral efficiency and the lowest power efficiency among PC schemes. CLPC and OLPC have the same power efficiency, however, CLPC has a feedback, which increases its spectral efficiency. Both LTE PC schemes have a spectral efficiency higher than SDPC, but SDPC keeps a reasonable spectral efficiency and provides a gain of $70\,\%$ in power efficiency in relation LTE PC schemes.

The results can be extended to understand the effects of PC schemes to D2D communications. EPA keeps same behavior of the cellular communications. Both LTE PC schemes have low level of spectral efficiency. CLPC keeps a spectral efficiency similar of CLPC in cellular communications due the feedback. OLPC decreases significantly the spectral efficiency, but it achieved the highest power efficiency. When we compare SDPC and LTE PC schemes, we can notice that SDPC shows better spectral efficiency. However, when power efficiency is compared, SDPC has a gain of $35\,\%$ in relation to CLPC and a loss of $120\,\%$ in relation to OLPC. Other result that can be noted is PC schemes in the middle of the Fig. 4. These schemes can be combined to provide a tradeoff between spectral efficiency and power efficiency.

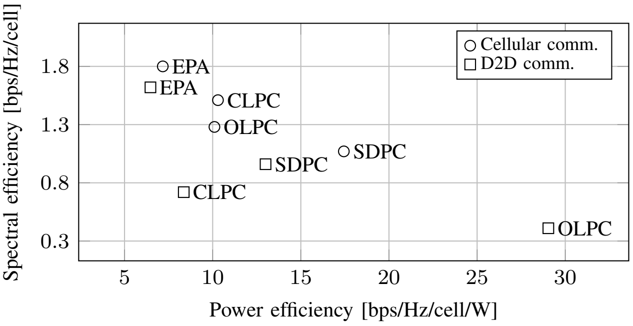


Fig. 4. Performance of PC schemes for cellular and D2D communications

V. CONCLUSIONS

In conclusion, the aim of the studies presented in this paper is to contribute to a better understanding of the role and behavior of PC schemes when D2D communications underlay a cellular network. Indeed, different PC schemes vary greatly in complexity, numbers of parameters, and have different performance levels. We notice that EPA scheme always has the highest spectral efficiency and the lowest power efficiency in both communications. SDPC keeps a reasonable spectral efficiency and provides a gain of $70\,\%$ in power efficiency in relation LTE PC schemes for cellular communications. If the purpose of power control is power efficiency, it would be interesting to use SDPC in cellular communications and OLPC in D2D communications.

We also conclude that for OLPC and CLPC, path gain is an important factor affecting performance of the both communication modes and the factor $\sigma = 0.8$ can modify the behavior of CLPC because it increases the SINR of the worst users. Other conclusion is that SDPC and CLPC can be combined to provide a tradeoff between spectral efficiency and power efficiency.

VI. PROOF OF CONVERGENCE SDPC

By assuming η as the thermal noise at the receiver and $tx(m)$ the transmitter D2D pair $m \in \{0, 1, \ldots, R\}$, the SINR $\gamma_{k,c,n}^{(t)}$ perceived by cellular user k in the cell c and PRB n at TTI t can be written as shown in Eq. 11

$$\gamma_{k,c,n}^{(t)} = \frac{\left|h_{k,c,n}^{(t)}\right|^2 p_{k,c,n}^{(t)}}{I_{\text{Cell}} + I_{\text{D2D}} + \eta^2}, \tag{11}$$

where I_{Cell} and I_{D2D} are the interference from cellular and D2D links, respectively,

$$I_{\text{Cell}} = \sum_{c' \neq c}^{C} \sum_{k'}^{K} \left|h_{k,c',n}^{(t)}\right|^2 p_{k',c',n}^{(t)}, \tag{12}$$

and

$$I_{\text{D2D}} = \sum_{c'}^{C} \sum_{m'}^{M} \left|h_{k,tx(m'),c',n}^{(t)}\right|^2 p_{tx(m'),c',n}^{(t)}. \tag{13}$$

For power value in $P_{min} < p_{k,c,n}^{(t)} < P_{max}$, we can write

$$p_{k,c,n}^{(t+1)} = p_{k,c,n}^{(t)} \left(\frac{\Gamma_{max} \left(\frac{p_{k,c,n}^{(t)}}{P_{min}} \right)^{\rho}}{\frac{\left|h_{k,c,n}^{(t)}\right|^2 p_{k,c,n}^{(t)}}{I_{\text{Cell}} + I_{\text{D2D}} + \eta^2}} \right)^{\beta}, \tag{14}$$

and

$$I(p_{k,n}^{(t)}) = \left(p_{k,c,n}^{(t)}\right)^{1+\rho\beta-\beta} \left(\frac{\Gamma_{max} \left(I_{\text{Cell}} + I_{\text{D2D}} + \eta^2\right)}{\left|h_{k,c,n}^{(t)}\right|^2 P_{min}^{\rho}} \right)^{\beta}. \tag{15}$$

Once all terms in Eq. 15 are positive, $I(p_{k,n}^{(t)})$ satisfies positivity. To verify monotonicity, it is necessary to ensure that $I(p_{k,c,n}^{(t)}) \geq I(p'^{(t)}_{k,c,n})$, for all $p_{k,c,n}^{(t)} \geq p'^{(t)}_{k,c,n}$, then the value of exponent must be positive,

$$\left(p_{k,c,n}^{(t)}\right)^{1+\rho\beta-\beta} \geq \left(p'^{(t)}_{k,c,n}\right)^{1+\rho\beta-\beta} \Rightarrow \beta \leq \frac{1}{(1-\rho)}. \tag{16}$$

To ensure scalability, $aI(p_{k,c,n}^{(t)}) \geq I(ap_{k,c,n}^{(t)})$, for $a \geq 1$. This way

$$a^1 \geq a^{1+\rho\beta-\beta} \Rightarrow \rho \leq 1. \tag{17}$$

For power value in $p_{k,c,n}^{(t)} \leq P_{min}$,

$$I(p_{k,n}^{(t)}) = \left(p_{k,c,n}^{(t)}\right)^{1-\beta} \left(\frac{\Gamma_{max} \left(I_{\text{Cell}} + I_{\text{D2D}} + \eta^2\right)}{\left|h_{k,c,n}^{(t)}\right|^2 P_{min}^{\rho}} \right)^{\beta}, \tag{18}$$

and since all terms in Eq. 18 are positive, $I(p_{k,n}^{(t)})$ satisfies positivity. To verify monotonicity, it is necessary to ensure that $I(p_{k,c,n}^{(t)}) \geq I(p'^{(t)}_{k,c,n})$, or

$$\beta \leq 1. \tag{19}$$

To ensure scalability, $aI(p_{k,c,n}^{(t)}) \geq I(ap_{k,c,n}^{(t)})$, for $a \geq 1$,

$$\beta \geq 0. \tag{20}$$

Finally, the main relations may be summarized as defined below

$$-\infty \leq \rho \leq 0 \text{ and } 0 \leq \beta \leq \frac{1}{(1-\rho)} \tag{21}$$

ACKNOWLEDGMENT

This work was supported by the Innovation Center, Ericsson Telecomunicações S.A., Brazil, under EDB/UFC.33 Technical Cooperation Contract. Yuri Victor Lima de Melo is sponsored by CNPq, Carlos Silva and José Mairton da Silva Jr. would like to acknowledge CAPES for the financial support.

REFERENCES

[1] R. L. Batista, C. F. M. e Silva, J. M. B. da Silva Jr., T. F. Maciel, and F. R. P. Cavalcanti, "What happens with a proportional fair cellular scheduling when D2D communications underlay a cellular network?" in *IEEE WCNC 2014 - Workshop on Device-to-Device and Public Safety Communications (WCNC'14 - WDPC Workshop)*, Istambul, Turkey, Apr. 2014, pp. 260–265.

[2] C. Li, B. Li, B. Lan, Y. Zhang, and T. Wang, "Uplink power control for device to device communication underlaying cellular networks," in *Communications and Networking in China (CHINACOM), 2013 8th International ICST Conference on*, Aug 2013, pp. 256–259.

[3] G. Fodor, D. Della Penda, M. Belleschi, M. Johansson, and A. Abrardo, "A comparative study of power control approaches for device-to-device communications," in *Communications (ICC), 2013 IEEE International Conference on*, June 2013, pp. 6008–6013.

[4] S. Gupta, R. Yates, and C. Rose, "Soft Dropping Power Control - A Power Control Backoff Strategy," in *IEEE International Conference on Personal Wireless Communications, 1997*, Dec. 1997, pp. 210 –214.

[5] Y. V. L. Melo, R. L. Batista, T. F. Maciel, C. F. M. e Silva, J. M. B. da Silva Jr., and F. R. P. Cavalcanti, "Power control with variable target SINR for D2D communications underlying cellular networks," in *European Wireless 2014 (EW2014)*, Barcelona, Spain, May 2014.

[6] 3GPP, "Physical layer aspects for evolved universal terrestrial radio access (UTRA)," Third Generation Partnership Project, TR 25.814 V7.1.0, Sep. 2006.

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

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

[9] ——, "Spatial channel model for multiple input multiple output (MIMO) simulations," Third Generation Partnership Project, TR 25.996 V7.0.0, Jun. 2007.

[10] J. C. Ikuno, M. Wrulich, and M. Rupp, "System level simulation of LTE networks," in *Proceedings of the IEEE Vehicular Technology Conference (VTC)*, May 2010, pp. 1–5.

[11] T. Maciel and A. Klein, "On the performance of SDMA with soft dropping and SINR balancing power control in the downlink of multi-user MIMO systems," in *IEEE Workshop on Smart Antennas (WSA 2007)*, Vienna, Austria, Feb. 2007.