An Interference Coordination Scheme for Device-to-Device Multicast in Cellular Networks

Dongyu Wang[1]*, Xiaoxiang Wang[1], Yuan Zhao[1]
[1]Key Laboratory of Universal Wireless Communications, Ministry of Education, Beijing University of Posts and Telecommunications, 100876, Beijing, P. R. China
Email: david.wangdongyu@gmail.com[1]*

***Abstract*—In this paper a multicast concept for Device-to-Device (D2D) communication underlaying a cellular infrastructure has been investigated. To improve system throughput and increase resource utilization, a novel interference coordination scheme is proposed. The proposed scheme includes two steps. First, in order to mitigate the interference from D2D transmission to cellular communication, we propose an efficient power control scheme to obtain an upper bound of D2D transmitter power. Next, based on the upper bound, two resource block (RB) allocation rules aiming to control the interference from cellular networks (CNs) to receivers in D2D multicast group are proposed. Simulation results show that by applying the proposed scheme, the performance of the hybrid system can be significantly improved compared to the conventional ways.**

***Keywords*—Device-to-Device Communication, Interference Coordination, Multicast Concept, Power Control**

I. INTRODUCTION

IN a time span of just few years the amount of multimedia and other data intensive traffic increases as the growth of the market for mobile device and its applications. WINNER+ project has considered D2D communication as one of the solutions to improve overall performance of cellular systems as well as unload traffic from the evolved NodeB (eNB) [1]. At the same time, next-generation wireless communication systems such as 3GPP Long Term Evolution (LTE) and WiMAX could allow D2D communication as an underlay to the cellular network to increase the spectral efficiency as proposed in [2].

In D2D communication, as for example in the Nokia Instant Community concept [3], devices transmit data directly to each other instead of conveying data via eNB in order to save transmission (Tx) power of both user equipments (UEs) and base station (BS). D2D communication only requires half of the radio resources compared to cellular communication mode thus offering double spectral efficiency per connection typically. Besides, D2D communication has potential to offer smaller delays, thus better user experience, than its cellular counterpart. However, one important problem can not be neglected: interference to and from in-band cellular mode UEs (CUEs). Since there are both cellular communication mode and D2D mode UEs (DUEs) accessing the same spectrum, the interference situations are different compared to a conventional cellular system.

While the advantages of multicast delivery over multiple unicast deliveries are undeniable, the application of the multicast communication in D2D mode can not be ignored. We consider a D2D multicast group in this paper. With modifications to the BS, multicast can also be used in D2D mode, providing service continuity to enhance the data sharing in the hybrid networks.

Recent studies of D2D communication have been more emphasized on interference coordination between CUEs and DUEs [4-10]. In [4], a δ_D-*interference* limited area (ILA) control scheme has been proposed in order to manage interference from cellular networks to D2D systems. In addition, interference tracing approach and tolerable interference broadcasting approach have been proposed to reduce the mutual interference between cellular and D2D sub-systems [5]. In [6], a fractional power control scheme has been proposed. This scheme categorized DUEs into several groups as path-loss values from eNB, and periodically updated Tx power values for groups. Furthermore, a mechanism in which the BS controlled the maximum transmission power of the D2D transmitter has been proposed in [7]. This method can efficiently manage the D2D interference to CNs and is also used in [8-10].

However, the aforementioned interference coordination schemes for the hybrid system did not take the D2D multicast scenarios into considerations. Therefore, DUEs may not capable to communicate with conventional schemes, especially in the case that multi-CUEs could generate sever interference to D2D multicast group. The power control in [6-10] can not improve the reliability of D2D multicast communication. Moreover, [4-5] had some difficult in managing RB allocation between multi-CUEs and D2D multicast group.

In this paper, in order to overcome these shortcomings, we integrate the multicast concept into D2D communication, at the same time multi-CUEs are also taken into account. First, to mitigate the interference from DUEs to CUEs, our work extends the power control to maximize throughput of overall systems in [8-10] by considering a minimum acceptable signal to interference plus noise ratio (SINR) of the BS as a threshold and the maximum power of the D2D transmitter together. Next, based on the obtained D2D transmitter power, we first propose an optimal RB allocation scheme that Full Set allocation (FSA) scheme to reduce the interference from multi-CUEs to D2D multicast group. The optimal scheme considers all possible RB allocation permutations and select the one that yields the best system performance depending on the channel instantaneous SINR between CUEs and DUEs in multicast group. After that, a suboptimal scheme is proposed to reduce computational complexity of the FSA scheme based on a subset of the permutations depending on the tolerable interference information.

We structure the paper as follows. The next section

978-1-4673-1881-5/12/$31.00 ©2012 IEEE

describes our system model. Next, Section III describes the proposed scheme for interference coordination. In Section IV, simulation settings, results and discussions are given. Finally, the conclusion is given in Section V.

II. SYSTEM MODEL

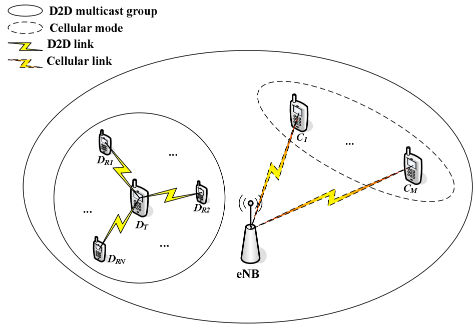
We study an isolated cell environment where M CUEs (i.e., C_1, C_2 ,…, C_M) and one D2D multicast group (i.e. one D2D transmitter, D_T, and N D2D receivers, D_{R1}, D_{R2},…, D_{RN}) share the available radio resources as illustrated in Fig. 1(a). In this paper, Orthogonal Frequency-Division Multiple Access (OFDMA) is assumed for all users in the hybrid system, which is in line with the current trend of wireless systems, e.g., 802.16-style networks and LTE-style systems. Besides, cellular up-link (UL) resource is reused by D2D transmission.

We assume the channel state information (CSI) of all the involved links is known at the eNB so that the eNB is capable of coordinating the frequency resources and Tx power. The eNB assigns either orthogonal or non-orthogonal frequency resources to the cellular or D2D multicast group. If DUEs occupy the resources which are orthogonal to those occupied by the CUE, they will cause no interference to each other and the analysis is simpler. On the other hand, the resource usage efficiency can be higher in non-orthogonal resource sharing, meanwhile, interference between CUEs and D2D multicast group will occur. Hence, we focus on non-orthogonal resource sharing and analyze the interference. To simplify the analysis all the D2D receivers within a group are combined to be one receiver to which the source device sends its data. Here, the UL interference scenario is described in Fig.1(b). After presented simplification we can consider that the source device in both cellular communication mode and D2D communication mode shares its data to only one destination. The received signal at the receivers in the D2D multicast group is

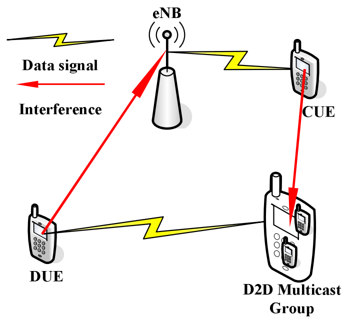
$$y_i = \sqrt{c(d_{D_T} d_{D_{Ri}})^{-\alpha} P_{D_T}} \cdot h_{D_T D_R} \cdot a_{D_T} + \sqrt{c(d_{C_i} d_{D_{Ri}})^{-\alpha} P_{C_i}} \cdot h_{C_i D_R} \cdot a_{C_i} + n_0 \qquad (1)$$

where a_{D_T} and a_{C_i} are the transmitted signal from D_T and that from the *i-th* CUE, C_i, respectively, and n_0 is the Additive White Gaussian Noise (AWGN) with one-side power spectral density (PSD), σ_n^2. In addition, h_{xy} is the channel coefficient between *x-y* link, and we assume that all channel coefficients follow an independent complex Gaussian distribution. Furthermore, d_{xy} is the distance between *x-y* link, and P_{D_T} and P_{C_i} are the Tx powers of D_T and C_i, respectively. In (1), a path-loss model defined as $P_\alpha = c \cdot (d_\alpha)^{-\alpha} \cdot P_0$ is used, where P_0 and P_α refer to an initial Tx power and a signal power measured at d_α away from the transmitter, respectively, where c and α are a path-loss constant and a path-loss exponent, respectively.

In this paper, in a system where there are both cellular communication mode and D2D multicast communication mode accessing the same spectrum, the interference situations are different compared to a conventional cellular system. Thus in the following two sections, the new schemes are proposed for interference coordination.



(a). Structure of the hybrid network, where C_1, C_2 ,…, C_M in cellular mode, and one D2D transmitter, D_T, and N D2D receivers, D_{R1}, D_{R2},…, D_{RN} are in a D2D multicast group.



(b). Interference between a CUE and a D2D multicast group.

Fig.1 Structure of the hybrid network and Interference between a CUE and a D2D multicast group.

III. STRATEGY FOR INTERFERENCE COORDINATION

In this section, we assign two steps for the interference coordination between CUEs and one D2D multicast group. The first step is to mitigate the interference from DUEs to CUEs by a proper power control scheme. Then we can obtain an upper bound of D2D transmitter power. In the second step, based on the obtained D2D transmitter power, we reduce the interference from DUEs to CUEs by an efficient RB allocation scheme. Details of two steps are in order.

A. Step 1: Interference from D2D to Cellular

The interference from DUEs to CNs UL is illustrated in the Fig.1(b). It shows when a D2D transmitter shares data with every receiver in D2D multicast group, the D2D transmitter will generate much more interference to the BS. The performance of cellular communication can be degreed. Especially compared to a conventional D2D system, which the initial powers of DUEs could be set usually much low Tx power. However, the D2D multicast system has rather different properties. In order to guarantee reliable communication of D2D multicast system, the transmitter needs more Tx power.

We assume that the average received powers at the BS from all CUEs are controlled to the same power level. For the sack of convenience in analysis and problem solving, we assume that the mean power of each channel for the C_i-BS link is 1, the SINR of BS for the $\mathrm{CUE_i}$ to BS link is expressed as

$$\gamma_{BS} = \frac{P_{C_iB}}{P_{D_TB} + N_0} = \frac{P_{CB}}{P_{D_TB} + N_0} \tag{2}$$

where P_{C_iB} means the signal power from C_i to BS, P_{D_TB} means the interference power from D2D transmitter to BS, N_0 means the power of AGWN.

Here a path-loss model defined as $P_\alpha = c \cdot (d_\alpha)^{-\alpha} \cdot P_0$ is used, the D2D Tx power P_{D_TB} can be rewritten as

$$P_{D_TB} = c(d_{D_TB})^{-\alpha} P_{D_T} \tag{3}$$

By substituting (3) into (2), (2) is represented as

$$\gamma_{BS} = \frac{P_{CB}}{P_{D_TB} + N_0} = \frac{P_{CB}}{c(d_{D_TB})^{-\alpha} P_{D_T} + N_0} \tag{4}$$

Let us denote the minimum acceptable SINR of the BS as $\gamma_{\min}$ i.e. thus the constraint is rewritten as

$$\gamma_{BS} = \frac{P_{CB}}{c(d_{D_TB})^{-\alpha} P_{D_T} + N_0} \geq \gamma_{\min} \tag{5}$$

The average signal power of D2D transmitter to the receivers can be limited to

$$\begin{aligned} P_{D_TD_R} &= c(d_{D_TD_R})^{-\alpha} P_{D_T} \\ &\leq \left(\frac{d_{D_TB}}{d_{D_TD_R}}\right)^{\alpha} \frac{P_{CB} - \gamma_{\min} \cdot N_0}{\gamma_{\min}} \end{aligned} \tag{6}$$

In addition, the maximum power of D2D transmitter is strictly limited so as not only to guarantee the DUEs in the multicast group receive normally, but also not to generate harmful interference to CNs. Thus the maximum power of the D2D transmitter is limited to $P_{\max}$. Then, the BS determines the power of the D2D transmitter as

$$P = \min\left\{P_{D_TD_R}, P_{\max}\right\} \tag{7}$$

B. Step 2: Interference from Cellular to D2D

On the contrary, as showed in Fig.1(b) , one of important issue in D2D multicast mode underlaying CNs is an efficient interference coordination to prevent generation of harmful interference from CUEs. Since receivers are allowed to operate in D2D multicast mode besides the traditional cellular mode and share resources between two modes. Therefore, how to select the appropriate RBs to avoid the severe interference is the problem addressed in this section. Based on the proposed power control scheme, we propose two RB allocation rules. Details of these schemes are addressed as follows.

1) Full Set (Optimal) Allocation

Based on the proposed power control scheme in step 1, the channel instantaneous SINR between the CUEs (interference sources) and the receivers in D2D multicast group, namely $\gamma_{C_iD_j}$ (for $i = 1, \cdots, M$, $j = 1, \cdots, N$) where similar to (2), $\gamma_{C_iD_j}$ can be calculated as

$$\gamma_{C_iD_j} = \frac{P_{D_TD_j}}{P_{C_iD_j} + N_0} \tag{8}$$

Similar to (3), the received signal at the *j-th* user and can be expressed as

$$P_{D_TD_j} = c(d_{D_TD_j})^{-\alpha} P_{D_T} \tag{9}$$

$$P_{C_iD_j} = c(d_{C_iD_j})^{-\alpha} P_{C_i} = \left(\frac{d_{C_iB}}{d_{C_iD_j}}\right)^{\alpha} P_{CB} \tag{10}$$

By substituting (7), (9) and (10) into (8), the SINR is expressed as

$$\gamma_{C_iD_j} = \frac{c(d_{D_TD_j})^{-\alpha} P}{\left(\frac{d_{C_iB}}{d_{C_iD_j}}\right)^{\alpha} P_{CB} + N_0} \tag{11}$$

The objective here is to optimize the end-to-end instantaneous SINRs. Since there are M receivers in D2D multicast group, the weaker link is the one that dominates the end-to-end instantaneous SINRs performance. Therefore, the optimal RB, allocation scheme is the one that results in the best channel among the weakest ones.

To elaborate, let Φ be the set containing all RB allocation permutations. We consider M CUEs in the cellular mode, thus the set Φ contains M elements. Each element of Φ consists of all end-to-end instantaneous SINRs, corresponding to one CUE. To simplify the presentation, let ϕ_k denote the *k-th* element of Φ for $k = 1, 2, \cdots M$, and ϕ_k =[$\gamma_{C_KD_i}$, for $i = 1, 2 \cdots N$], which is a set of the instantaneous SINRs between the *k-th* CUE and each receiver in D2D multicast group. Let $\gamma_{k,\min}$ denote the smallest element in ϕ_k , i.e., the weakest channel. Accordingly, the RB allocation, denote by ϕ_{k*}, has index k^*:

$$k^* = \arg\max_k \{\gamma_{k,\min}, k = 1, 2 \cdots M\} \tag{12}$$

While FSA scheme is optimal, it suffers from high complexity and brings BS more burdens. For example, where $M = N = 100$, there are $100 \times 100 = 10^4$ calculated amount to search over. Therefore, if not taking this problem into account, the FSA scheme will be not suitable for the real-time operation in practical systems. Thus, a suboptimal scheme with low complexity is proposed to solve the problem.

2) Subset (Suboptimal) Allocation

The objective here is to divide the set Φ into a new subset. We consider in LTE system each RB has a tolerable interference level (Interference-value). The tolerable interference information can be utilized by DUEs to choose the RBs. According to the pass-loss from D2D transmitter to BS and the D2D Tx power, we define a tolerable interference level threshold, $\lambda_{\inf}$. BS can calculate and update the tolerable interference level from the D2D transmission for each UL resource unit, and then make up an Interference-value list. BS will broadcast it to facilitate intelligent D2D radio resource management (RRM) of each DUE. With the notations above, we can write the steps as follows:

Step 1) BS calculates and updates the expected Interference-values for each RB, and generates an Interference-values set Γ. Corresponding with the set Φ, we define Γ = [$\lambda_1, \lambda_2 \cdots \lambda_M$] where λ_i is the Interference-values of the *i-th* RB.

Step 2) BS compares λ_i in set Γ with the tolerable interference level threshold, $\lambda_{\inf}$. Based on the compared results, we can get a new set $\Gamma' = [\lambda_1, \lambda_2 \cdots \lambda_K]$, where $\lambda_j \geq \lambda_{\inf}$, for $j = 1, 2 \cdots K, K \leq M$.

Step 3) Corresponding with the set Γ', we can get a new subset Φ'. Apparently, Φ' is one subset of Φ. Then we can apply FSA scheme to complete RB allocation.

Step 4) In a certain time period, the Interference-values can be updated based on need basis considering the dynamics of the cellular system.

IV. SIMULATION RESULTS

In this section, we introduce system simulation scenario and result in investigating the performance of hybrid system by applying the power control scheme and RB allocation schemes introduced in section III. Besides the general system description in section II, we present some details of system parameters in simulators. The main simulation parameters are presented in table I.

Based on the proposed power control scheme in step 1, we obtain an upper bound of D2D transmitter power. The cumulative relative frequencies for SINRs of cellular mode and D2D multicast mode UEs are illustrated in Figs. 3(a) and (b), respectively. In Fig. 3(a), SINRs of CUEs are distributed between -15.8*dB* and 26.6*dB*. Since modulation and coding schemes in LTE system does not support communication for SINR< -10*dB* [11], 17.3% of CUEs may not capable to communicate in random RB allocation scheme, which RB is randomly selected from the set Φ. On the other hand, in FSA scheme, because the lowest SINR among CUEs is -8.1*dB*, all CUEs can communicate with eNB. In addition, in FSA scheme, CUEs have on average 9.2*dB* higher SINR than those using the random allocation scheme. Since FSA scheme is an ergodic process, and then every CUE is less interfered from D2D transmitter by the helps of optimal allocation scheme. In addition, we also compare SSA scheme with the two schemes mentioned above. It shows the curve of SSA scheme distributed between -12.2*dB* and 25.8*dB*, and 6.5% of CUEs may not capable to communicate. Furthermore, in SSA scheme, CUEs have on average 6.2*dB* lower SINR than those using FSA scheme, which illustrates SSA scheme is suboptimal.

Fig. 3 (b) shows cumulative relative frequencies of receivers in D2D multicast group. In the figure, more than 7.68% of receivers in D2D multicast group using the random RB allocation scheme can be guaranteed SINR above 38*dB* than FSA scheme. However, because the maximum modulation and coding rate is 4.4 *bps/Hz* for 24*dB* SINR in LTE system [11], UEs having SINR above 24*dB* may experience same data rates. For SINR < 24*dB*, FSA scheme guarantees 5.21*dB* higher SINR of DUEs on average than the random RB allocation scheme. Thus, DUEs with FSA scheme are expected to have higher frequency efficiency and throughput on average than the conventional scheme. Besides, we also compare SSA scheme with the two schemes mentioned above. It shows the curve of SSA allocation scheme distributed between 5.9*dB* and 49.3 *dB*, and SSA scheme obtains 2.12*dB* lower SINR of DUEs on average than the FSA scheme.

TABLE I
SIMULATION PARAMETER

Parameter	Value
Stimulation drops	100
Drop duration	60*s*
Cellular layout	Isolated cell, 1-sector
Device per sector	One multicast group
Device distribution	Uniformly randomly distributed
Mobility	Static scenarios
Inter site distance	500*m*
Maximum D2D pair distance	25*m*
D2D multicast group radius	30*m*
CUEs per cell	*M*=100
D2D multicast group size	1 transmitter, N=50 D2D receivers
Path loss model for cellular link	128.1+36.7log10 (d[*km*]) [12]
Path loss model for D2D link	148+40log10 (d[*km*]) [12]
Shadow fading standard deviation	10*dB* for cellular mode links and 12*dB* for D2D mode links [12]
Noise spectral density	-174 *dBm/Hz*
Carrier frequency	1.9 *GHz*
Bandwidth	10 *MHz*
Resource allocation	Random, one RB per CUE
eNB Tx power	43 *dBm*
D2D maximum Tx power	15 *dBm*

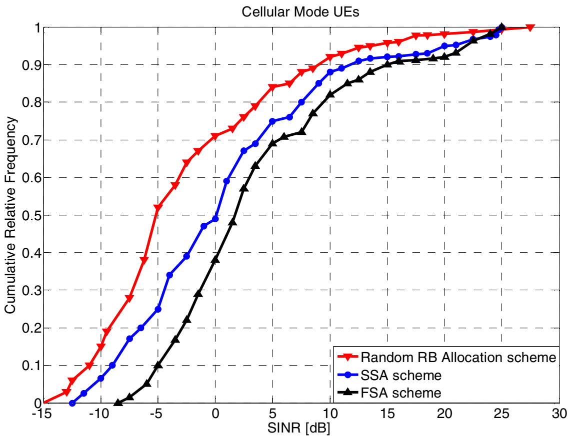
Fig. 4 shows total throughput of the sum of cellular mode and D2D multicast mode UEs in a cell as varying $P_{\max}$ for the proposed power control scheme and SSA scheme in section III, where D2D multicast mode transmitter uses maximum Tx power ($P_{\max}$) between -30*dBm* and +25*dBm*. We assume $\gamma_{\min}$ is a constant value. In Fig. 4, total throughputs with fractional power control scheme [6] increase as $P_{\max}$ increases. Nevertheless, total throughputs of the proposed power control scheme cannot increase constantly. On the other hand, the proposed mechanism always has higher total throughput than fractional power control scheme since it controls the Tx power of D2D multicast mode to certain level and minimizes interference to CUEs using same resources. Besides, we consider $\gamma_{\min} = 12dB, 24dB, 32dB$ respectively. Fig. 4 illustrates when $\gamma_{\min}$ increases, the throughput gets higher. The reason is the interference is limited from D2D transmitter to BS by the minimum acceptable SINR of the BS. When $\gamma_{\min}$ is at high value, however, the throughput gets lower with $P_{\max}$ increasing. The reason is when $\gamma_{\min}$ is at high value, CUEs could generate more interference to receivers in D2D multicast group.

V. CONCLUSION

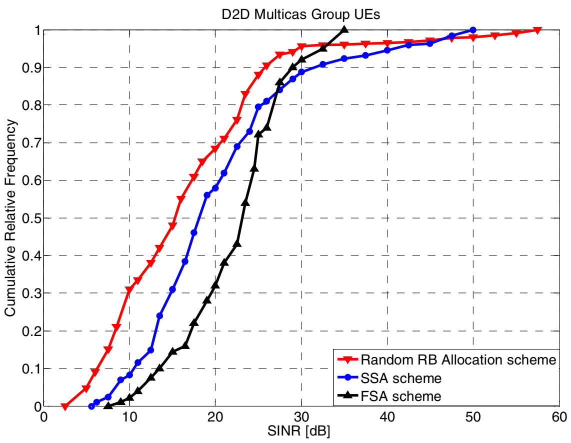
In this paper we gave the overviews of D2D multicast concept in a hybrid system. Notwithstanding the performance improvement achieved when integrating multicast concept into D2D communication, the problem of performance degradation due to severe interference has to be effective to avoid. In order to solve the problem, a power control scheme, which adjusts Tx powers of DUEs considering the minimum acceptable SINR of the BS and the maximum power of the D2D transmitter together, is proposed. Then we obtain an upper bound of D2D transmitter power. Based on the obtained D2D transmitter power, FSA and SSA schemes were proposed. FSA scheme considered all possible RB allocation permutations and selected the one that optimized the DUEs instantaneous SINRs. SSA scheme, which considered only a subset of these permutations and selected the best one to reduce the complexity of the system, was suboptimal. Simulation results illustrated the proposed power control scheme always had higher performance than fractional power control scheme. Moreover, CUEs and DUEs with the proposed schemes were expected to have higher frequency efficiency than the conventional scheme.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (60972076, 61072052) and important National Science and Technology Specific Projects (2012ZX03003011).



(a) Cellular mode UEs



(b) D2D multicast mode UEs

Fig.3. Cumulative relative frequency distribution of SINR

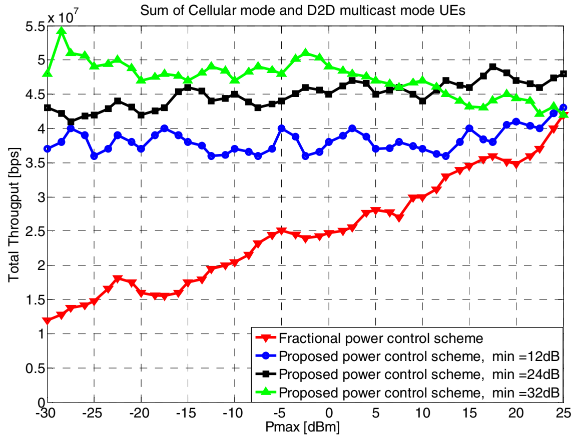


Fig.4. Total throughputs of cellular mode UEs and D2D multicast mode UEs in fractional power control scheme and proposed scheme

REFERENCES

[1] Wireless World Initiative New Radio-WINNER+ D2.1, "Preliminary WINNER+ System Concept," May 2009.

[2] Pekka Jänis, Chia-Hao Yu, Klaus Doppler, Cassio B. Ribeiro, Carl Witjing, Klaus Hugl, Olav Tirkkonen, and Visa Koivunen, "Device-to-Device Communication Underlaying Cellular Communications Systems," in *Proc. IEEE IJCNS*, vol. 2, no. 3, pp. 169-178, Jun. 2009.

[3] Nokia Instant Community gets you social. http://conversations.nokia.com/2010/05/25/nokia-instant-community-gets-you-social/.May.2010.

[4] Tao Peng, Qianxi Lu, Haiming Wang, Shaoyi Xu, Wenbo Wang, "Interference avoidance mechanisms in the hybrid cellular and device-to-device systems", in *Proc. IEEE PIMRC*, pp. 617-621, Sept. 2009.

[5] Hyunkee Min, Jemin Lee, Sungsoo Park, Daesik Hong, "Capacity Enhancement Using an Interference Limited Area for Device-to-Device Uplink Underlaying Cellular Networks", *IEEE Trans. Wireless Commun.*, Vol. 10, no.1, pp. 3995-4000, Dec. 2011

[6] Chia-Hao Yu, Olav Tirkkonen, Klaus Doppler, and Cassio B.Ribeiro, "Power Optimazation of Device-to-Device Communication Underlaying Cellular Communication," in *Proc. IEEE ICC*, pp.1-5, Apr 2009.

[7] H.-Y. Hsieh and R. Sivakumar, "On Using Peer-to-Peer Communication in Cellular Wireless Data Networks", *IEEE Trans*. Mobile Computing, vol. 3, no.1, pp. 57-71, Jan-Mar. 2004.

[8] S. McLaughlin and H. Haas, "Cellular communications system," International Patent WO 2005/060182, Dec. 2004.

[9] Y. Du, L. Sun and N. Ma, "Method and system for peer-to-peer communication management in wireless communication networks," U.S. Patent 7 308 266, Mar. 2004.

[10] K. Doppler, M. P. Rinne, C. Wijting, C. B. Ribeiro, and K. Hugl, "Device-to-device communication as an underlay to LTE-advanced networks," *IEEE Commun.* Mag., vol. 47, no. 12, pp. 42-29, Dec. 2009.

[11] "E-UTRA Radio Frequency System Scenarios." 3GPP TR 36.942 version 9.2.0,2011.

[12] "Selection procedures for the choice of radion transmission technologies of th UMTS," 3GPP TR 30.03U, version 3.2.0,1998.