Decentralized Resource Allocation for Multicast D2D Communications Using Stochastic Geometry

Devarani Devi Ningombam[1], Suk-seung Hwang[2], and Seokjoo Shin[1*]
[1, 1*]Department of Computer Engineering
[2]Department of Electronic Engineering
Chosun University
Gwangju, Rep. of Korea
devaraninin@gmail.com, {hwangss, sjshin}@chosun.ac.kr

Abstract— In this paper, we discuss on the device-to-device (D2D) communication to fulfill the exponentially growing demands of the high data rate services. Multicast D2D communication is envisioned as a promising solution due to its advantages of high data rates and high spectrum efficiency. However, integrating D2D communication severely degrades the quality of service (QoS) of the network. To improve the QoS, we formulate a self-organizing resource allocation scheme using a stochastic algorithm for multicast D2D communication. Using the proposed algorithm, each uplink cellular resource can be simultaneously reused by the active D2D users in a network. Theoretical analysis and simulation results validate the proposed scheme.

Keywords—device-to-device communication; multicasting; decentralized; stochastic geometry; probability of successful transmission.

I. Introduction

The massive increasing demands for high data rate services in cellular networks have inspired researcher to focus on expanding capacity of the network. In this context, device-to-device (D2D) communication has been considered as a promising solution. Multicast D2D communication can provide higher network capacity and spectral efficiency by reusing the cellular frequency resources. However, the performance of the overall system can deteriorate after integration of D2D communications, if there is absence of proper resource management techniques. Resource management framework is of two types [1]. First is the centralized algorithm in which resource management is performed based on the global channel state information while achieving the individual target signal-to-interference-plus-noise ratio (SINR) constraints for D2D users. Second is the decentralized resource management algorithm, which requires channel state information of the direct link between a transmitter and its corresponding receiver.

In this paper, we propose an uplink self-organizing resource allocation for multicast D2D communications in which multiple receivers in a group can simultaneously communicate at same rate (single-rate) or at different rates (multi-rate). In the decentralized scheme, there is no coordination between transmitters and the signaling overheads for sharing channel state information. Thus, it can mitigate interference between conventional cellular users and D2D users effectively. Moreover, we employ stochastic geometry to analyze the performance of the system, which accounts for real-time applications. In the stochastic geometry, the devices in a cell are distributed using a Poisson random distribution model. The performance of the proposed scheme is analyzed in terms of the cumulative distribution function (CDF) of signal-to-interference-plus-noise ratio (SINR) and probability of successful transmission with varying user density.

The rest of this paper is organized as follows. Section II presents related literature works on resource allocation schemes. In Section III, we propose decentralized resources allocation scheme and stochastic algorithm for multicast D2D communications. Section IV presents the performance analysis and discussion. A brief conclusion is presented in Section V.

II. Related Works

Recent advances in D2D communications based on stochastic geometry constitute a wide outlook of practical applications. A number of surveys related to D2D communication have been done in literature. In [2], the authors proposed a decentralized spectrum allocation for underlay D2D users and formulate an optimization problem using matching theory. A flexible D2D communications has been discussed in [3] and compared multi-cell centralized and decentralized techniques. The results showed that their proposed scheme improves system level gain above 30% by enabling resource reuse method. In [4], the authors proposed a three-stage energy efficient resource allocation algorithm. In their proposed scheme, the centralized and decentralized algorithms are compared using Lagrange dual decomposition and nonlinear fractional programming methods.

The authors in [5] proposed a novel centralized device discovery scheme for underlay D2D communications system. In their network, stochastic geometry is considered to analyze system performance based on success probability. In [6], the authors discussed a disaster relief solution, when network infrastructure is failure or a natural disaster is occurred on D2D communications system. In their network, a stochastic geometry is assumed to analyze an analytical methodology. The authors in [7] proposed a stochastic geometry model for a cellular network with multicell cooperation, which considers irregular terrains of evolved node B (eNB). Also, the proposed scheme considers cluster formation to mitigate mutual interference between users and calculates the outage probability. In [8], the authors analyzed a D2D communication operating over generalized fading conditions. Also, the Laplace transform of the interference over different fading channels are derived and evaluate the spectral efficiency and outage probability of the network.

III. Proposed Scheme

A. System Model

In this paper, we focus on the uplink transmission in which D2D users share the same resource with cellular users. As shown in Fig.1, the considered network contains random distribution of users in a cell and eNB is placed at cell center. In this system model, CU stands for the user who communicate through the eNB and D2D pair stands for the pair of user which communicate with each other directly without passing data traffic through the eNB. We supposed that there are totally I_C CUs comprising a set I, I={1,2,…, I_C}, and totally K_D D2D users comprising a set K, K={1,2,…, K_D}. In the proposed scheme, the CUs and multicast D2D groups use the same set of resources in an orthogonal mode to mitigate the uplink interference. Furthermore, we assume that there is one D2D transmitter D_T and there are totally J_R D2D receivers comprising a set J={1,2,…, J_R}.

We define a set of binary variables $X_{I,J}$ in which $X_{I,J} = 1$ when the multicast D2D groups reuses cellular resources and $X_{I,J} = 0$ otherwise. To analyze the resource allocation scheme, we assume one multicast D2D group reuses at most one cellular resource at a time, and each resource can be reused by at most one multicast group. That is,

$$\left.\begin{array}{l} \sum_{I=1}^{I_C} X_{I,J} \le 1, \forall\, J \in J_R \\ \sum_{J=1}^{J_R} X_{I,J} \le 1, \forall\, I \in I_C \end{array}\right\}. \tag{1}$$

Moreover, some of the D2D users form multicast groups to employ multicast communications as shwon in Fig 1. For analysis, we consider multicast group *a*, in which three D2D receivers are connected to single D2D transmitter. It is worth to mentioning that D2D transmitter in a multicast group has same data for all corresponding receivers.

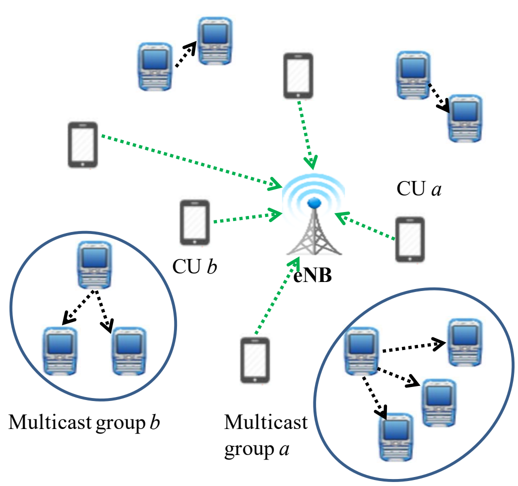

Fig. 1. System model of the multicast D2D communication.

B. Channel Model

The path loss is modeled according to urban micro models in the International Telecommunication Union Radio-communication Sector (ITU-R) reports. In this paper, we consider the Winner II B5f path loss model as follows [9]:

$$PL = 57.5 + 23.5log_{10}(d) + 23log_{10}\left(\frac{f_c}{5}\right), \tag{2}$$

where d denotes the distance between the transmitter and receiver in meters (30 m< l <1.5 km) and f_c is the carrier frequency in GHz (2 GHz < f < 6 GHz).

C. Problem Formulation

In this section, to analyze the channel state information (CSI) for a realistic network model, we consider the Poisson point process (PPP). We assume ρ as the PPP with density of λ, which decides the locations of the users within the network area. We neglect the co-channel interference and consider that uplink cellular resources are reused by the multicast D2D users. In order to achieve a higher system performance, the SINR level should be above a predefined threshold level. Therefore, the probability of successful multicast transmission should satisfy the following relation as

$$P_M = P[\gamma \ge \gamma_{Th}], \tag{3}$$

where γ is the SINR of the system and γ_{Th} is the threshold SINR. Moreover, we defined the interference tolerance levels (-60 to -120) dBm to find the resource reuse partner. The interference tolerance levels are assigned to available resources while finding matching users to overcome the severe interference. The search for resource reuse partner will terminate when all the available users satisfy the threshold criteria.

To characterize the randomly distributed D2D receivers in a multicast group, we assume the path loss and log-normal shadowing propagation scenarios [10]. Then, the probability that available receivers detect the signal transmitted by the D2D transmitter at a distance l is expressed as

$$P_D = P\left\{\frac{T\prod_n \beta_n}{l^{2\alpha}} \ge P_{Th}\right\}, \tag{4}$$

where T is the transmit power, β_n is the independent random variable, α is the path loss exponent and P_{Th} is the threshold probability level. Using Gaussian Q-function, (4) can be rewritten as

$$P_R = Q\left(\frac{1}{\varphi} ln\left(\frac{P_{Th}.l^{2\alpha}}{P_R}\right)\right), \tag{5}$$

where φ is the shadowing coefficient and P_R is receiver power.

Therefore, the desired SINR can be formulated as

$$P[\gamma \ge \gamma_{Th}] = \mathbb{E}\left\{Q\left(\frac{1}{\varphi} ln\left[\frac{l^{2\alpha}.P_{Th}(n+N)}{P_S}\right]\right)\right\}, \tag{6}$$

where P_S is power of the interference signal. Correspondingly, the data rate of user is given by

$$R = B.log_2(1+\gamma) \tag{7}$$

where B is the uplink channel bandwidth. We have the optimization formulation problem of resource allocation as below

$$\max \sum_{I_C \epsilon I} \sum_{K_D \epsilon K} R \tag{8}$$

$$\text{s.t.} \quad X_{I,J} \epsilon \{0,1\} \tag{9}$$

$$\gamma \geq \gamma_{Th} \tag{10}$$

$$\sum_{I=1}^{I_C} X_{I,J} \leq 1, \forall J \epsilon J_R \tag{11}$$

$$\sum_{J=1}^{J_R} X_{I,J} \leq 1, \forall I \epsilon I_C \tag{12}$$

IV. Performance Analysis

In this paper, we assume a multicell network where cellular users and D2D users are randomly distributed in each cell. Moreover, multicast D2D communications range is randomly selected to be within the distance (10-70) m. In order to analyze the performance of the proposed scheme, we introduced interference tolerance threshold and SINR threshold levels. The proposed scheme has been implemented in Matlab. The main simulation parameters and values are summarized in Table 1.

TABLE I. Simulation Parameters and Values

Parameter	**Value**
Cell radius (*R*)	500 m
Multicast D2D transmission distance	70 m
Maximum transmission power	20 dBm
Noise power	-174 dBm
Number of cellular users	20
Channel Bandwidth	10MHz
Number of D2D users	30
Path loss exponent	4
Number of realization	10,000

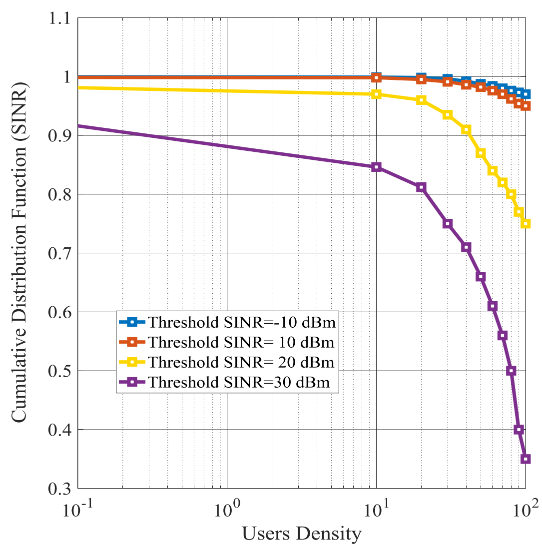

Fig. 2. CDF of SINR with varying users density.

Fig. 2 shows the CDF of SINR with varying user's density for different values of threshold SINR. It can be seen that with the increase of threshold SINR value, the SINR of the system reduces. This is because higher threshold SINR value generates more interference paths. But, for lower threshold SINR the SINR curve is not severely disturbed. Moreover, a low-density scenario achieved higher SINR as compared with high-density scenario.

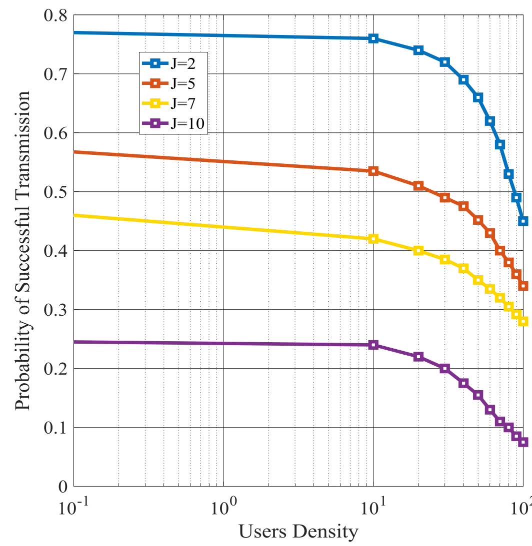

Fig. 3. Probability of successful transmission with varying users density for different number of D2D receivers in a multicast group.

Fig. 3 shows the probability of successful transmission with varying user's density for different values of D2D receiver in a multicast group. It can be seen that probability of successful transmission is smaller for denser density. This is because the interference is larger when the network supports more receivers in a multicast group. Therefore, in order to guarantee a higher system performance, the density of the users in each cell should maintain a specific level.

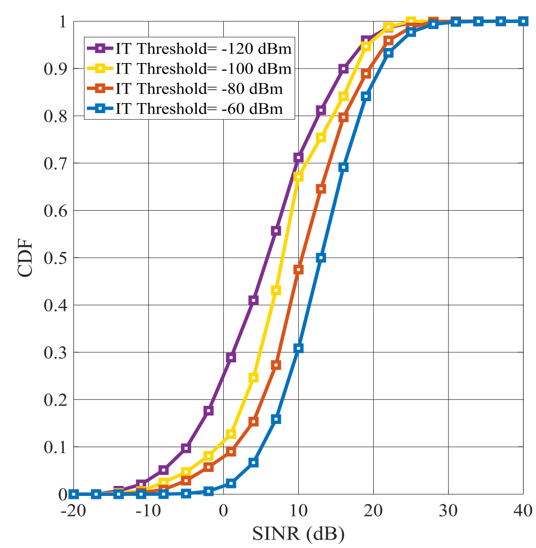

Fig. 4. CDF with varying SINR under various interference tolerance threshold levels.

Fig. 4 shows the CDF with varying SINR for different values of interference tolerence threshold. It can be seen that the SINR becomes larger when the interference threshold value is lower and the SINR is significantly lower under high interference tolerence threshold value. This is because of the fact that some multicast D2D transmissions are limited to overcome the interference to conventional cellular users.

V. Conclusion

In this paper, we propose a resource allocation scheme for decentralized multicast D2D communications by employing stochastic geometry. Our proposed scheme can reuse same cellular resource by a multicast D2D group. Simulation results show that with the proposed algorithm, the system can achieve better performance.

ACKNOWLEDGMENT

This research is under the project titled 'Development of Automatic Identification Monitoring System for Fishing Gears', funded by the Ministry of Oceans and Fisheries, Korea with Grant No. 20170388.

REFERENCES

[1] N. Lee, X. Lin, J. G. Andrews, and W. W. Heath, "Power control for D2D underlaid cellular networks:modelling, algorithms, and analysis," IEEE Journal of Selected Areas in Communications, vol. 33, no. 1, pp. 1-13, 2015.

[2] S. M. A. Kazmi, N. H. Tran, T. M. Ho, D. K. Lee, and C. S. Hong, "Decentralized spectrum allocation in D2D underlaying cellular networks," In Proc. of the 18th Asia-Pacific Network Operations and Management Symposium (APNOMS), pp. 1-6, 2016.

[3] V. Venkatasubramanian, F. S. Moya, and K. Pawlak, "Centralized and decentralized multi-cell D2D resource allocation using flexible UL/DL TDD," In Proc. of the IEEE Wireless Communications and Networking Conference (WCNC), pp. 305- 310, 2015.

[4] Z. Zhou, M. Dong, Z. Chang, and B. Gu, "Combined centralized and distributed resource allocation for green D2D communications," IEEE/CIC International Conference on Communications in China (ICCC), pp. 1-6, 2015.

[5] M. Naslcheraghi, L. Marandi, and S. A. Ghorashi, "A novel device-to-device discovery scheme for underlay cellular networks," In Proc. of the Iranian Conference on Electrical Engineering, pp. 2106-2110, 2017.

[6] A. Al-Hourani, S. Kandeepan, and A. Jamalipour, "Stochastic geometry study on device-to-device communication as a disaster relief solution," IEEE Transactions on Vehicular Technology, vol. 65, no. 5, pp. 3005-3017, 2016.

[7] K. Huang, and J. G. Andrews, "A stochastic-geometry approach to coverage in cellular networks with multi-cell cooperation," In Proc. of the IEEE Globecom, pp. 1-5, 2011.

[8] Y. J. Chun, S. L. Cotton, H. S. Dhillon, A. Ghrayab, and M. O. Hasna, "A stochastic geometric analysis of device-to-device communications operating over generalized fading channels," IEEE Transactions on Wireless Communications, vol. 16, no. 7, pp. 4151-4166, 2017.

[9] M. Hamid, and I. Kostanic, 'Path Loss Models for LTE and LTE-A relay stations," Univ. J. Commun. Netw., vol. 1,pp. 119–126, 2013.

[10] M. Win, P. Pinto, and L. Shepp, "A mathematical theory of network interference and its applications," In Proc. of IEEE, vol. 97, no. 2, pp. 205–230, 2009.