Survey on Device-to-Device Communications: Challenges and Design Issues

Rawan Alkurd, Raed M. Shubair
Khalifa University, UAE
Rawan.Alkurd.A@ieee.org, rshubair@kustar.ac.ae

Ibrahim Abualhaol
Carleton University, Canada
ibrahimee@ieee.org

***Abstract*—Device-to-Device (D2D) communications has been proposed to cellular networks in order to optimize spectrum efficiency and resources utilization. In D2D-assisted networks, the traditional cellular communication techniques are not applicable but rather need to be redesigned to fulfill new requirements. Therefore, new communication techniques are proposed to take the advantages of the D2D connectivity in the network. In this paper, we describe the concept of D2D communications. Then, we review the main challenges and design issues of D2D-assisted networks. This survey focuses on cooperative communications in D2D-assisted networks and addresses challenges which limit the performance of the cooperative D2D-assisted networks such as relay selection, power consumption and multi-casting. Moreover, design issues and approaches to overcome these limitations are explained.**

I. Introduction

DEVICE-TO-DEVICE (D2D) communications were introduced many years ago in the context of wired communication networks. Recently, there are around five billion devices connected to the cellular network. This raised the need for high capacity and energy efficient mobile networks. Hence, D2D communications one of the proposed paradigms in the next generation cellular network. D2D communications is about enabling the direct flow of data between devices. In contrast to Human-to-Human (H2H) communications, D2D communications do not require human interaction. Instead, devices initiate the request for communication with near devices. The cellular network is optimized for traffic characteristics which are different from the characteristics of data traffic between devices. The length of the session, data rate, and communication patterns are the main differences between H2H and D2D communications. The transmission over D2D is a small burst transmission one-way data traffic.

In this survey, we first introduce the concept of D2D communications in section II. In section III, an overview the main challenges and research issues in D2D-assisted cellular networks is introduced. Section IV focuses on the employment of cooperative communications in D2D-assisted networks and summarizes the advantages of using cooperation in such networks. Finally, in section V, we address the main challenges in the design process of cooperative D2D-assisted networks and summarize the different approaches in literature to reduce the effects of these limitations on network performance.

II. D2D Communications

D2D communication networks can be classified into two main structures as shown in Fig.1. The first structure, illustrated in Fig.1.a, is called *Stand-Alone* D2D communications, whereas the second structure, illustrated in Fig.1.b, is called *Network-Assisted* D2D communications. The difference between the two structures is the existence of a helping infrastructure in (b) to organize the communications and resource utilization in the cell. On the other hand, in (a), the devices organize the communications themselves without the infrastructure help. Fig.2 delineate the fundamental network architecture of D2D communications, consisting of D2D area network, network management and D2D applications. The D2D area network consists of swarm of D2D devices communicating with each other directly using D2D links. D2D aggregators collect data from devices intending to connect to the core network and send them to gateways which connect to the access network. The access network can be wired or wireless network. The core network connects devices with service providers who manage the different D2D services. The

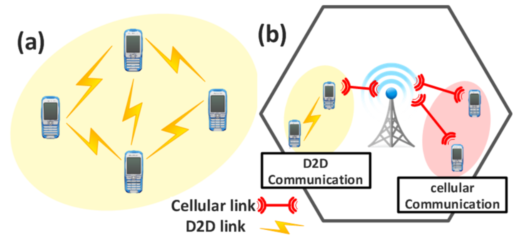

Fig. 1. D2D communications: (a) without infrastructure (Stand-Alone D2D) (b) with infrastructure (Network-Assisted D2D).

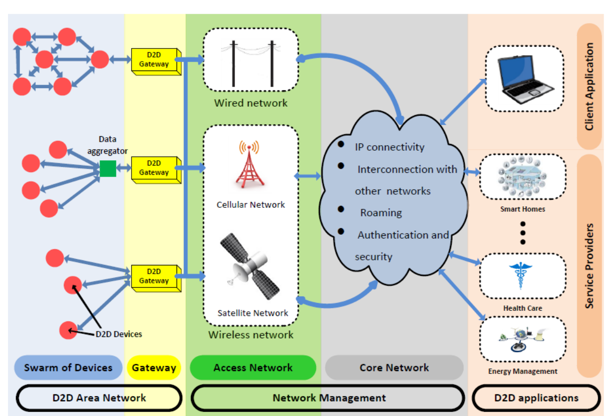

Fig. 2. D2D Network Architecture

978-1-4799-4885-7/14/$31.00 ©2014 IEEE

client application is connected with the core network to help end users to monitor and interact with devices in the network.

III. D2D Challenges and Design Issues

Enabling D2D communications on the cellular network will allow the network to benefit from the potential advantages of this technology. However, D2D communications will bring new challenges and design problems such as the optimization of power consumption and resource allocation. Another important challenge is the reuse of cellular frequencies which causes interference between the cellular users and D2D users as shown in Fig.3 for both (a) uplink and (b) downlink. Mainly, there are four different interference scenarios in D2D-assisted networks. When uplink frequencies are reused by D2D users in the cell, the base-station receiver will receive interference from the D2D user transmitter (DUT) (see ① in Fig.3.a). Similarly, the D2D user receiver (DUR) will receive interference signal from the cellular user transmitter (CUT) (see ② in Fig.3.a). On the other hand, when downlink frequencies are being reused by D2D users, CUR will receive interference from the DUT (see ③ in Fig.3.b) and DUR will receive interference from the base-station transmitter (see ④ in Fig.3.b). It is worth noting that downlink frequencies are more congested when compared to the uplink especially for applications that require high data rates. Hence D2D communication is mainly based on uplink frequencies and associated interference scenarios.

As mentioned earlier, mitigating the interference will maximize the system throughput for a certain maintained Qualify of Service (QoS). This can be achieved in a number of ways as follows:

A. *Mitigating Interference Using Mode Selection*

Mode selection is considered crucial to avoid the effect of interference. D2D users can communicate using the direct link in two modes which are overlay D2D and underlay D2D [1]. The work in [1], [2] on mode selection is directed at optimizing the selection between the two modes based on several parameters. Fig.4 illustrates two parameters of mode selection. The first parameter is the distance between D2D and cellular users. In Fig.4.*a*, both user1 and user2 are equally separated from the BS. However, user2 is closer to the D2D pair compared to user1. In this case, the mode selection algorithm will choose underlay mode for the D2D pair using f_1. The second parameter of mode selection is the distance between cellular users and the BS. In Fig.4.*b*, both users are equally separated from the D2D pair. However, the interference at the D2D pair is greater from user2 compared to user1 because the distance between user2 and the BS is greater. In this case, the mode selection algorithm will choose underlay mode for the D2D pair using f_1. In both cases (*a* and *b*), when frequency f_2 is available instead of f_1, the mode selection algorithm will choose the overlay D2D mode to avoid the potential interference.

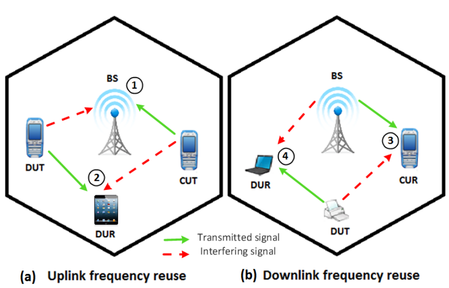

Fig. 3. Illustration of frequency reuse in D2D communications

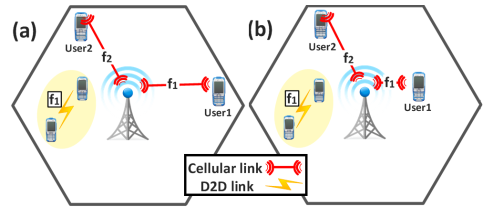

Fig. 4. Illustration of D2D mode selection parameters: (a) distance between D2D and cellular user , (b) distance between cellular user and BS.

B. *Mitigating Interference Using Resource Allocation*

Resource allocation is considered as one of the most important research areas in D2D due to its crucial impact on the system performance. The optimized allocation of resources such as power, frequency, and time can help in reducing the effect of interference. Novel optimized resource allocation techniques have been proposed in the literature based on a centralized approach [3]. However, using the centralized resource allocation protocols in D2D-assisted networks is very challenging due to the huge number of devices in the cell which will result in increased complexity of the protocol. On the other hand, distributed resource allocation proposed in [4] overcomes the complexity issue since devices are used to sense the network environment and utilize the available resources without causing interference to the cellular network devices.

C. *Mitigating Interference Using Power Control*

Power control is important for uplink due to co-channel interference and near-far effect. The most straightforward way to implement interference mitigation in D2D-assisted networks is to predefine a maximum power level to D2D users such that the QoS for cellular users is maintained [1]. Improved performance can be achieved using more sophisticated techniques for power control such as those introduced in [1], [5].

IV. Cooperative Communications for D2D-Assisted Networks

Cooperative Communications (CC) was proposed in literature as D2D communication paradigm to help in enhancing the network performance. Literature work discussing CC in D2D-assisted networks can be divided into two parts as follows:

A. *The Effect Of Cooperative Cellular Networks On D2D Communications*

It is well-known that CC in cellular networks improves the performance of cellular users. On the other hand, since

CC is one of the main technologies in the current cellular networks, it is important to take into account its impact on D2D users. Mode selection is one of the main challenges in D2D-assisted networks. The work in [6], investigated the effect of mode selection with and without cellular CC. The results show that the introduction of relay nodes in the cellular network will increase the chances of D2D users to share resources with cellular users because underlay D2D mode is chosen more often by the mode selection algorithm. This indicate that cellular CC increases spectrum efficiency of D2D-assisted networks. On the other hand, the work in [7] proposed mode selection algorithms in Heterogeneous D2D and IMT-Advanced Network. Beside mode selection, we discussed the issue of resource allocation and power control in D2D-assisted networks. Researchers proposed different techniques to optimize these issues in cooperative cellular networks [8].

B. *The Performance Of Cooperative D2D-Assisted Networks*

Cooperation among D2D users and between D2D and cellular users is widely studied topic in literature. In order to guarantee the improvements achieved by CC, the network should use cooperation when D2D-pairs are far away from each other and the direct communication link is not good enough to allow reliable transmission. Cooperation between users in D2D-assisted network will improve the spectral efficiency and QoS. In addition, CC in such networks can help in the extension of network coverage and reduction of interference. In [9], the authors proved via simulations that the throughput of cooperative D2D-assisted network outperforms the case without cooperation. As mentioned earlier, the user equipment in the cell or the D2D devices can act as relays to improve system performance. The work in [10] analyzed the performance of D2D-assisted network with D2D mobile relays. The results show that cell edge throughput improvements percentage as well as coverage improvements percentage can exceed 150% by utilizing idle users in the network as relays. In the literature, many researchers attempted to analyze the performance of different cooperative schemes in D2D-assisted networks in terms of capacity and QoS improvements. The work in [11] should that multi-hop relaying reduced the outage probability of the D2D links under certain power constrains. The capacity of D2D communication increased even under the influence of strong cellular signals.

V. Cooperative D2D communication Challenges and Design issues

In order to realize the potential gains of cooperative relaying in D2D-assisted networks, the main technical challenges need to be addressed and proposed solution approaches need to be discussed. These are presented as follows:

A. *Relay Selection*

Relay selection is a major issue in cooperative D2D networks, since the number of relays that can be utilized is huge. Generally, it is a design goal to make this selection process efficient and optimized. The role of the network in relay selection is an important design question. In the cellular underlay mode, the network can play an active role for relay selection. In the centralized method, the BS decides the relay selection for D2D transmission. The work in [12] proposes new relay selection methods for D2D-assisted networks where algorithms for relay selection are implemented in the BS. These algorithms enable the BS to choose the best relay for any user in the network. Most of the work on relay selection assumes passive role of the BS in the selection process due to the resulted increase of BS load in the *centralized method*. Passive network relay selection is achieved using two main methods. The first method is called *Random Relay Selection* where the user randomly selects one from all optional relays. The second method known as *Distributed Relay Selection* which was proposed in [13]. This methods eliminates improper relays and uses a distributed algorithm to choose the best relay. Numerical results show that the performance of the distributed method is closest to the *centralized* method whereas the *Random Relay Selection* method has the least performance.

B. *Multi-cast Services*

D2D communications is proposed to enhance the performance of cellular multi-cast services [14]–[16]. The major issue in cellular multi-cast transmissions is the different channel conditions for the multi-cast recipients. For this reason, the BS will find difficulty in choosing the transmission rate which suits all the recipients. In this situation, the BS chooses the transmission rate which suits the recipient with the worst channel conditions which will result in reducing the efficiency of multi-casting transmission. Alternatively in D2D-assisted networks, a number of D2D devices with good channel conditions are identified and used to communicate the multi-cast signal from the BS to nearby devices. Researchers approached this issue in many different ways. In [14] the authors assumed a *single* predefined multi-cast recipient called cluster head which is responsible for D2D retransmissions. On the other hand, the authors in [15] assumed *multiple* recipients of the multi-cast signal. Further improvement to the latter approach was proposed in [16] using a *dynamic multiple*, multi-casting technique which is based on the following:

- ❒ Selecting the optimum number of re-transmitters (or relays) since there is a trade-off between the multi-cast gain and multi-channel diversity.
- ❒ Optimize the retransmission scheme of the relays to enhance the throughput of multi-cast transmission.

C. *Optimum Power Consumption*

Optimum power consumption is one of the main requirements of D2D-assisted networks due to the limited energy available for the user devices in the network. Cooperative techniques can be used to extend the lifetime of D2D networks. Usually, power expenditure for cell-edge D2D devices is comparatively high due to the large distance between the transmitter and the receiver. However, D2D devices are characterized as low level power consumption devices. In [17] a cooperative scheme is proposed to lower power consumption of cell-edge users and improve power consumption of D2D-assisted networks. The authors in [18] discussed the necessity of cooperation in low power D2D networks. The work in [19] introduced a general framework to reduce power consumption by exploiting cooperative diversity. In literature, one of the main techniques proposed to improve power consumption of cooperative D2D-assisted networks is relay selection. The first technique is *Relay Selection* [20]. This technique involves Identifying the optimal relay node as the one that minimizes the total transmitted power. Another technique for optimum power consumption is *Resource Allocation.* The authors in [21] proposed a joint energy-saving resource allocation mechanism for cooperative D2D-assisted networks. Group-based D2D communication is one of the famous resource allocation techniques used to reduce power consumption in D2D-assisted networks. The main aim of grouping a number of devices is to reduce the number of communications between the cellular and D2D networks. Moreover, the D2D devices will communicate with the cellular network through group headers located near to the D2D devices in the network. This means that D2D devices need less power to communicate with the BS. The design of resource allocation using group communications involves deciding on

- ❒ The algorithm to perform devices selection and devices grouping and determine the number of groups.
- ❒ The power allocation scheme used with grouping to find the optimum transmission power for each device.

VI. Conclusion

In this paper, a survey on D2D communications is presented. The main concept and architecture of D2D communications are introduced. Then, the main challenges and design issues of D2D-assisted networks are explored. The remaining part of the survey focuses on the employment of cooperative communications in D2D-assisted networks and the associated challenges and design issues such as: relay selection, multicasting and power consumption.

References

[1] Si Wen, Xiaoyue Zhu, Zhesheng Lin, Xin Zhang, and Dacheng Yang, "Optimization of interference coordination schemes in device-to-device(d2d) communication," in *Communications and Networking in China (CHINACOM), 2012 7th International ICST Conference on*, 2012, pp. 542–547.

[2] K. Doppler, Chia-Hao Yu, C.B. Ribeiro, and P. Janis, "Mode selection for device-to-device communication underlaying an lte-advanced network," in *Wireless Communications and Networking Conference (WCNC), 2010 IEEE*, 2010, pp. 1–6.

[3] Chen Xu, Lingyang Song, Zhu Han, Qun Zhao, Xiaoli Wang, Xiang Cheng, and Bingli Jiao, "Efficiency resource allocation for device-to-device underlay communication systems: A reverse iterative combinatorial auction based approach," *Selected Areas in Communications, IEEE Journal on*, vol. 31, no. 9, pp. 348–358, 2013.

[4] Rui Yin, Guanding Yu, Caijun Zhong, and Zhaoyang Zhang, "Distributed resource allocation for d2d communication underlaying cellular networks," in *Communications Workshops (ICC), 2013 IEEE International Conference on*, 2013, pp. 138–143.

[5] Dongyu Wang and Xiaoxiang Wang, "An interference managment scheme for device-to-device multicast spectrum sharing hybrid network," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2013 IEEE 24rd International Symposium on*, 2013.

[6] Ziyang Liu, Tao Peng, Shangwen Xiang, and Wenbo Wang, "Mode selection for device-to-device (d2d) communication under lte-advanced networks," in *Communications (ICC), 2012 IEEE International Conference on*, 2012, pp. 5563–5567.

[7] Shangwen Xiang, Tao Peng, Ziyang Liu, and Wenbo Wang, "A distance-dependent mode selection algorithm in heterogeneous d2d and imt-advanced network," in *Globecom Workshops (GC Wkshps), 2012 IEEE*, 2012, pp. 416–420.

[8] Pei Liu, Chunjing Hu, Tao Peng, and Wenbo Wang, "Distributed cooperative admission and power control for device-to-device links with qos protection in cognitive heterogeneous network," in *Communications and Networking in China (CHINACOM), 2012 7th International ICST Conference on*, 2012, pp. 712–716.

[9] Ziyang Liu, Tao Peng, Bo Peng, and Wenbo Wang, "Sum-capacity of d2d and cellular hybrid networks over cooperation and non-cooperation," in *Communications and Networking in China (CHINACOM), 2012 7th International ICST Conference on*, 2012, pp. 707–711.

[10] K. Vanganuru, S. Ferrante, and G. Sternberg, "System capacity and coverage of a cellular network with d2d mobile relays," in *MILITARY COMMUNICATIONS CONFERENCE, 2012 - MILCOM 2012*, 2012, pp. 1–6.

[11] Donghoon Lee, Sung-Il Kim, Jaeyoung Lee, and Jun Heo, "Performance of multihop decode-and-forward relaying assisted device-to-device communication underlaying cellular networks," in *Information Theory and its Applications (ISITA), 2012 International Symposium on*, 2012, pp. 455–459.

[12] Lefei Wang, Tao Peng, Yufeng Yang, and Wenbo Wang, "Interference constrained relay selection of d2d communication for relay purpose underlaying cellular networks," in *Wireless Communications, Networking and Mobile Computing (WiCOM), 2012 8th International Conference on*, 2012, pp. 1–5.

[13] Xiran Ma, Rui Yin, Guanding Yu, and Zhaoyang Zhang, "A distributed relay selection method for relay assisted device-to-device communication system," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium on*, 2012, pp. 1020–1024.

[14] S.C. Spinella, G. Araniti, A. Iera, and A. Molinaro, "Integration of ad-hoc networks with infrastructured systems for multicast services provisioning," in *Ultra Modern Telecommunications Workshops, 2009. ICUMT '09. International Conference on*, 2009, pp. 1–6.

[15] Qi Zhang, F.H.P. Fitzek, and V.B. Iversen, "Design and performance evaluation of cooperative retransmission scheme for reliable multicast services in cellular controlled p2p networks," in *Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on*, 2007, pp. 1–5.

[16] Bin Zhou, Honglin Hu, Sheng-Qiang Huang, and Hsiao-Hwa Chen, "Intracluster device-to-device relay algorithm with optimal resource utilization," *Vehicular Technology, IEEE Transactions on*, vol. 62, no. 5, pp. 2315–2326, 2013.

[17] S. Andreev, O. Galinina, and Y. Koucheryavy, "Energy-efficient client relay scheme for machine-to-machine communication," in *Global Telecommunications Conference (GLOBECOM 2011), 2011 IEEE*, 2011, pp. 1–5.

[18] J Hern A Kountouris D Barthe A Bartoli, M Dohler, "Low-power low-rate goes long-range: The case for secure and cooperative machine-to-machine communications," *NETWORKING 2011 Workshops*, vol. 6827, pp. 219–230, Springer, 2011.

[19] T. Himsoon, W.P. Siriwongpairat, Zhu Han, and K.J.R. Liu, "Lifetime maximization via cooperative nodes and relay deployment in wireless networks," *Selected Areas in Communications, IEEE Journal on*, vol. 25, no. 2, pp. 306–317, 2007.

[20] Min Zhou, Qimei Cui, R. Jantti, and Xiaofeng Tao, "Energy-efficient relay selection and power allocation for two-way relay channel with analog network coding," *Communications Letters, IEEE*, vol. 16, no. 6, pp. 816–819, 2012.

[21] Linlin Sun, Hui Tian, and Lingling Xu, "A joint energy-saving mechanism for m2m communications in lte-based system," in *Wireless Communications and Networking Conference (WCNC), 2013 IEEE*, 2013, pp. 4706–4711.