Throughput Maximization for Cellular Communication Underlay Device to Device Network

M. Abrar[1], R. Masroor[2]

[1,2]Electrical Engineering Department, Bahauddin Zakariya University, Multan-Pakistan
[1]mabrarbari@gmail.com

Abstract-This paper aims at designing a cellular system underlay device-to-device (D2D) system through Rate Proportional allocation (RPA) algorithm and Reuse allocation (RUA) algorithm. System throughput has been maintained between cellular users (CUEs) and D2D users (DUEs) through proposed schemes. Further, we analyzed our proposed schemes with Random Allocation (RA) algorithm. Simulation results have verified the increased gains in system throughput with proposed schemes.

Keywords-Cellular Networks, Resource Management, Resource Blocks, Wireless Networks, OFDM

I. INTRODUCTION

With the exponential growth in the number of users and their escalating demands, telecom operators are in no doubt battling for increasing their data demands with existing spectrum. Device-to-Device (D2D) communication is a propitious answer to the firing question of data demands. Third Generation Partnership Project (3GPP), and Long Term Evolution (LTE) are focusing on deployment of D2D [i]. Fifth Generation (5G) with deployment of D2D is no more far behind because large propagation loss with minimum multi-user interference is ideal for underlay which causes different types of interferences within and out of the network.5G is brainy network because it uses Millimeter Waves (mm Wave) which has highly directional antenna for small distances.D2D is a direct link, infrastructure less communication i.e. without or less involvement of the base station (BS). It is ideal for catastrophic conditions where requirement of a framework is really a big hurdle. For example, the tsunami and the earthquake occur in the last few years. On the basis of coverage of networks two classes are defined. Class A and Class B. Class A are for those networks which cover small distances. This class includes Bluetooth, ZigBee, Wi-Fi and many others like these. Some of them are unlicensed devices like Bluetooth which causes high interferences. Moreover, these devices are non-transparent to users. While Class B involves long distance covering networks like cellular networks and Worldwide Interoperability for Microwave Access .In [ii] it is described that a brainy algorithm is required for clever communication. So, different routing protocols have been defined. Moreover, the estimation in increment of number of user with time is given. Resource allocation and power control still remains a problem over many advantages of hop gain, proximity and spatial reuse. In [iii] every aspect of D2D has been discussed including in-band, out-band, overlay and underlay and controlled and autonomous approaches are reviewed. In [iv] resource allocation schemes are purposed to alleviate interferences. Moreover, the perspective of unlicensed band is discussed. Uplink resources can be reused efficiently while keeping cellular user in its high preference with maximum interference avoidance in D2D is discussed in [v]. In addition downlink user (DU) which is an exacerbate deals through interference alignment schemes for high throughput is focused in [vi]. Illustration of D2D is shown in Fig. 1.

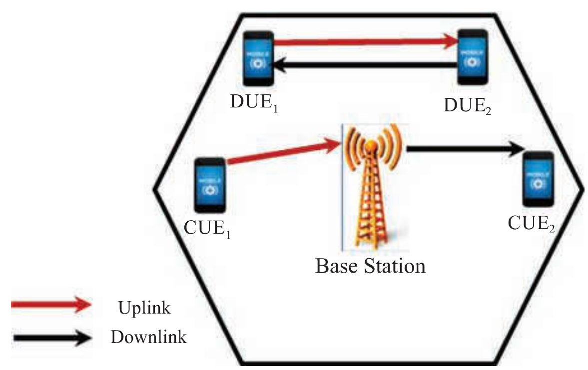

Fig. 1. Illustration of cellular system with D2D communication: Two types of users in the hexagonal cell: CUEs link through BS while DUEs links directly.

A. *Related work:*

Demands comes with generations. To cope with the increasing demands of data utilization, D2D is suggested as a promising solution. Interference management, resource allocation and power control are hurdles to be overcome and need more work to be done on them. The authors in [vii] have viewed underlay i.e.

both D2D and cellular user (CUE) use the same spectrum which in turn causes homogenous and heterogeneous interferences. Hence to alleviate this problem, it is critically analyzed in isolated and connected community network. While its solutions given through social aware resource allocation algorithm to give optimal allocation scheme.

In [viii] a cooperative multicast scheme is proposed instead of one stage multicast scheme. A near center protocol is suggested where successful users act as relays to resend data to the rest of unsuccessful users. While time allocation problem is solved by Sequential Quadratic Programming (SQP). A comparative study of single stage and dual stage multicast is done with briefing the pros and removing the obstacle through SQP in line allocation and data acknowledgment to the user. In addition [ix] has dealt with interference between two different broadcast groups of D2D. Inter broadcast group interference is depreciated with graph based algorithm.

To mitigate the effects of inter cell and intra cell interference when it is an underlay network, the authors in [x] purpose a solution through graph coloring based scheme. It took three steps to complete. First, a feedback strategy is introduced. Second, algorithm is specified. Third, resource allocation scheme is used on the basis of second step. Simulation is carried out to prove the excellence of proposed scheme. Fractal frequency reuse (FCR) based ICIC (Inter Cell Interference Coordination) is used in [xi] to relief heterogeneous inference and homogenous interference palliated by OFDMA-LTE system. FFR improves better performance with optimal spatial reuse. Major core of this paper is dedicated towards discussion at cell brink.

Sequential second price auction mechanism is used for the effective system sum rate over the sharing of spectrum of both D2D and CU. Spectrum is divided into expedient blocks and auctioned off the highest bid charges and cost the second highest bid. Process of auction continues until the last leave is reached. Number of D2D users and expedient blocks are not limited. Hence, spectrum utilization and efficiency are its resulting rewards and are discussed in [xii]. Issue of power control also has addressed through different and novel aspects in many research papers. In [xiii] two approaches i.e. Pricing Based Power Control and Two Layer Power Control Algorithm are used on uplink resource units to increase throughput and provide near to null interference. Moreover, these two mechanisms are critically analyzed and compared on performance basis. In [xiv], authors have gone through centralized and decentralized methods. Former is gifted with reliability and efficiency and lateral is defeated on reliability.

Weakening of signals at the edge of cells is mitigated in [xv] through introduction of mirror frequency concept. I/Q imbalance have studied in respect to near far effects and other impairments. In [xvi] and [xvii] iteration process is used but in different context. In former paper it is used as a bridge between scheduling problem and transmits power while in later power is controlled through setting it to zero or maximum value not in between it and consist of repetitive steps of power at start and modification of power level. In [xviii] a comparative study on iterative and binary power control scheme is done which is limited to small number of D2D and UE.

B. Motivations and Contribution

Theoretically, work has been done for single transmitter and single receiver system. While practically, multiple transmitters and antennas are deployed, this causes interferences. In order to mitigate the effect of interferences and cope with the problem of resource allocation different schemes are proposed which are Inband and Outband. We are focusing toward underlay (type of inband). Mostly overlay is purposed for interference mitigation but it is not spectrum efficient because underlay on the other hand uses same spectrum for both cellular user and D2D users. So, maximum throughput and sum-rate is gained by using underlay.

C. Organization

The remaining paper moves around following sections. Section II describes system model and mathematical description. In section III, problem formulation is provided to mitigate interference, while in section IV simulation parameters and simulation results are discussed. While Section V presents a conclusion.

II. System Design and Mathematical Description

A. System Design

In this paper, an Orthogonal Frequency Division Multiplexing (OFDM) cellular system is considered with BS at its core. In the given system model, *N* cellular users, known as CUEs and *M D2D* users, known as DUEs are considered. CUEs users communicate via BS while D2D users communicate via BS as well a scan communicate directly to each other but still these are considered under the control of BS when assuming them as underlay cellular system. All entities have single antenna systems.

A. Mathematical Description

For convenience, uplink transmission is only measured. Since Z_{bs} is the received signal via BS from n^{th} CUE in the uplink is given by

$$Z_{bs,m} = \sqrt{P_{cu,n}} H_{cu,n} D_{cu,n} + \sqrt{P_{dtx,m'}} H_{dtx,m} D_{dtx,m} + ¥_{bs} \quad (1)$$

where

$P_{cu,n}$: Power of n^{th} CUE to transmit in uplink

$H_{cu,n}$: n^{th} CUE and BS are separated by channel vector

$D_{cu,n}$: Symbolof n^{th} CUE data

$P_{dtx,m}$: m^{th} DUE_T power to transmit

$H_{dtx,m}$: m^{th} DUE_T and BS are separated by channel vector

$D_{dtx,m}$: Symbol of m^{th} $DUE_{T\ data}$

$¥_{bs}$: BS AWGN distortion

In the uplink, m^{th} DUE_T is the transmitting signal to m^{th} DUE_R is given as

$$Z_{drx,n} = \sqrt{P_{dtx,m}} L_{dtx,m} D_{dtx,m} + \sqrt{P_{cu,n}} L_{cu,m} D_{cu,n} + ¥_{drx} \tag{2}$$

where

$p_{dtx,m}$: Power of m^{th} DUE_T to transmit in uplink

$L_{dtx,m}$: m^{th} DUE pair separated by channel vector

$D_{dtx,m}$: m^{th} DUE_T Data symbol

$L_{cu,n}$: n^{th} CUE and m^{th} DUE_R separated by channel vector

D_{dtxm}: m^{th} DUE_T Data symbol

Interference signal, data signal and distortion has been represented in (1) and (2). $\psi_{cu,n}$ and $\psi_{dtx,m}$ are the received signal to Interference-noise ratio (SINR) at BS and at m^{th} DUE_R and can be expressed by

$$\Psi_{cu.n} = \frac{P_{cu,n}\left|H_{cu,n}\right|^2}{P_{dtx,m}|H_{dtxm}|^2 + n_0} \tag{3}$$

$$\Psi_{dtx,m} = \frac{P_{dtx,m}\left|L_{dtx,m}\right|^2}{P_{cu.n}|L_{cu}, n|^2 + n_0} \tag{4}$$

Uplink transmission throughput as a sum rate is given by

$$C_{n,m}^{rpa} = log_2(1 + \Psi_{cu.n}) + log_2(1 + \Psi_{dtx,m}) \tag{5}$$

III. Problem Formulation

A. Rate Proportional Allocation (RPA)

In order to maximize the sum-rate of system, both cellular and D2D users have supposed same goal rates. A number of RBs are considered with OFDM system and devised through Binary Linear Programming (BILP) method which is defined as

Maximize:

$$\sum_{n=1}^{N}\sum_{m=1}^{M} \delta_{n,m}^{x}\, C_{n,m}^{x} \tag{6}$$

Where X indicates the x^{th} term of RBs. RB allocation index is indicated by binary integer $\delta_{n,m}^{x}$

Subject to:

$$\sum_{n=1}^{N}\sum_{m=1}^{M} \delta_{n,m}^{x} \le 1, \forall x, \tag{6-a}$$

$$\delta_{n,m}^{x} \in \{0,1\}, \forall (n,m,x)$$

These limitations provide a result that there is only one CUE or DUE per RB. The homogenous interference is mitigated by this limitation

$$\sum_{x=1}^{X} log_2 \frac{P_{cu,n|H_{cu,n}|^2}}{P_{dtx,m|H_{dtxm}|^2+n_0}} \ge C_{cu} \tag{6-b}$$

$$\sum_{x=1}^{X} log_2 \frac{P_{dtx,m|L_{dtx,m}|^2}}{P_{cu.n|L_{cu}n|^2+n_0}} \ge C_{dxt} \tag{6-c}$$

Where C_{cu} and C_{dxt}: minimum rate requirements for CUE and DUE, respectively.

B. Reuse Mode Allocation (RUA)

For reuse mode selection it is assumed that there are no dedicated resources available for DUEs or CUEs. In Reuse mode interference between a DUE and CUE plays a vital role in the allocation of resources. DUEs are assumed to work in the same uplink band as CUEs and can reuse RBs of CUEs with least interference. With known channel conditions, BS can assign RBs to certain DUEs by keeping the interference level for CUEs to such extent that it is not harmful for CUEs links. The individual threshold SINRs are set for DUEs and CUEs to keep interference at control level.

Uplink transmission throughput as a sum rate in reuse mode can be given as:

$$C_{n,m}^{rua} = log_2\left(1 + \frac{P_{cu,n}\left|H_{cu,n}\right|^2}{I_{du,m}+n_0}\right) + log_2\left(1 + \frac{P_{dtx,m}\left|L_{dtx,m}\right|^2}{I_{cu,m}+n_0}\right) \tag{7}$$

where $I_{du,m}$ and $I_{cu,m}$ shows the maximum interference introduce by DUE to CUE and from CUE to DUE, respectively in reuse mode. To limit the level of the interference on CUE and DUE, the SINR at both selected DUE and CUE must be higher than some threshold value of SINR.

$$\frac{P_{cu,n}\left|H_{cu,n}\right|^2}{I_{du,m}+n_0} \ge SINR_{cu}^{th} \tag{8-a}$$

$$\frac{P_{dtx,m}\left|L_{dtx,m}\right|^2}{I_{cu,m}+n_0} \ge SINR_{du}^{th} \tag{8-b}$$

The problem formulation for reuse mode is same as earlier except the constraint in (6-a) is replaced with (8-a) and (8-b).

C. Proposed Scheme

The intended RB-allocation algorithm is primarily based on three rules, Precedence, Ampleness, and Maximization.

1. **Precedence**: In D2D underlay communication, cellular and D2D users share the same resources. While in this algorithm, resources are assigned by keeping commensurate precedence between CUEs and DUEs. Moreover, precedence is provided to CUEs and it is checked by analyzing the Signal to Noise Ratio (SNR) on all given RBs. It is advantageous to use this process because every single CUE achieves equivalent opportunity to utilize its channel excellence unless it reaches to require minimum rate (MR). When this process of MR completes for all CUEs then it happens again for DUEs.
2. **Ampleness:** It is the process of allocation of RBs or demand requirements i.e. MR of all CUEs and DUEs. This step took place for those CUEs and DUEs which don't have precedence until now. So, CUEs and DUEs which reach up to mark level of MR are impermanent removed from this process. Hence it gives opportunity to others to achieve its ampleness.
3. **Maximization:** For convenience, if some RBs are still not allocated then they follow the precedence rule and only allocated to CUEs. Actually it is the maximization of end throughput.

The proposed algorithm is shown in algorithm-1:

D. Power Allocation

In this paper we focus only on the allocation of subcarriers and it is assumed that power is fixed.

MATLAB optimization toolbox can also be used efficiently to optimize the power in such problems. An optimization tool "FMINCON" which is designed to find the minimum of a given constrained nonlinear multivariable function is applied.

Algorithm-1

1: Initialize all RBs, CUEs and DUEs

2: for rounds =1: X

3: $(n', x') = \arg\max(\Psi^{x}_{cu,n})\ \forall n, \forall x$

4: DO

$$\delta_n^x = 1, \{RBs\} = \{RBs\} - \{RB\ x'\}$$

5:if

For RPA:

$$\sum_{x=1}^{X} log_2\left(1 + \frac{P_{cu,n|H_{cu,n}|^2}}{P_{dtx,m|H_{dtxm}|^2+n_o}}\right) \geq C_{cu}$$

For RUA:

$$\frac{P_{cu,n}\left|H_{cu,n}\right|^2}{I_{du,m} + n_0} \geq SINR_{cu}^{th}$$

6: Do

$$\{CUEs\} = \{CUEs\} - \{CUE\ n'\}$$

7: end if

8: if $\{CUEs\} = \varnothing$,

9: go to 12

10: end if

11: end for

12:$(m', x') = \arg\max(\Psi^{x}_{dtx,m})\ \forall m, \forall x$

13: DO

$$\delta_m^x = 1, \{RBs\} = \{RBs\} - \{RB\ x'\}$$

14:if

For RPA:

$$\sum_{x=1}^{X} log_2 \frac{P_{dtx,m|L_{dtx,m}|^2}}{P_{cu,n|L_{cu,n}|^2+n_o}} \geq C_{dxt}$$

For RUA:

$$\frac{P_{dtx,m}\left|L_{dtx,m}\right|^2}{I_{cu,m} + n_0} \geq SINR_{du}^{th}$$

15: Do$\{DUEs\} = \{DUEs\} - \{DUE\ m'\}$

16: end if

17: if $\{DUEs\} = \varnothing$

18: go to 21

19: end if

20: end for

21: Do for all waiting RBs

22: for rounds= 1: waiting RBs length

23:

$(n'/m', x') = \arg\max\left(\Psi^{x}_{cu,n}/(\Psi^{x}_{dtx,m})\right)\ \forall n, \forall m, \forall x$

24: $\delta_{n/m}^x = 1, \{RBs\} = \{RBs\} - \{RB\ x'\}$

25: end for

26: exit

Maximization is achieved by multiplying the objective function with -1 before applying this optimization command. FMINCON is a gradient-based method that is designed to work on problems where the objective and constraint functions are both continuous and have continuous first derivatives. When the problem is infeasible, FMINCON attempts to minimize the maximum constraint value. This built-in function is flexible since it includes both equality and inequality constraints[xix].

IV. Numerical Results and Discussion

This section estimates the excellence of intended algorithms. The simulations are performed in MATLAB to prove the results. BS is considered as core in a single cell to serve CUEs and DUEs. All nodes are supposed to be familiar with Channel state estimation (CSI). Then, its estimation is done for individual and overall throughput of CUEs and DUEs. Other simulation variables are depicted in Table I.

TABLE I
SIMULATION VARIABLES

Variables	Values
Nominal SNR	20 dB
Available Channel Realization	1000
Channel Scheme	Rayleigh
Available CUEs	3
Available DUE Pairs	3

The results of the proposed rate proportional allocation (RPA) algorithm and Reuse allocation (RUA) algorithm are compared with the Random Allocation (RA) algorithm. Moreover the excellence of intended commensurate allocation algorithm is used in contrast with fixed RB allocation scheme. In random allocation RB scheme we divide fixed resources between DUEs and CUEs. In Random allocation, both CUEs and DUES have equal number of available resources and resources are allocated in Round Robin techniques. In all cases we fix the minimum rate requirement of 1 Mb/S for all CUEs and DUEs.

Fig. 2 is depicted between overall throughput and diverse number of given Rbs. Analysis has shown that proposed scheme RPA gives near optimal throughput. This is happening because CUEs and DUEs have assigned the excellent channel gains. A noticeable gain is achieved by applying RPA and RUA as compared to RA with increasing number of Rbs.

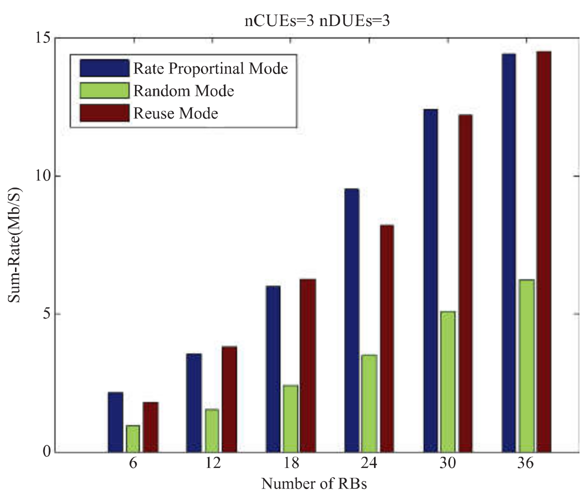

Fig. 2. Throughput of a system versus number of Rbs

Fig. 3 and Fig. 4 show the individual throughputs achieved by DUEs and CUEs, respectively in all scenarios. We can easily observe that when numbers of available resources are increased for DUEs, the CUEs are unable to meet minimum rate requirement as shown in Fig. 4. While in the proposed RPA algorithm and RUA, both CUEs and DUEs are able to meet this requirement in any scenario and the overall throughput is also enhanced as already shown in Fig. 2. The simulation results show nearly optimum throughput when intended commensurate allocation is made in whole scenarios i.e. in cellular network underlay D2D communication with fixed allocation.

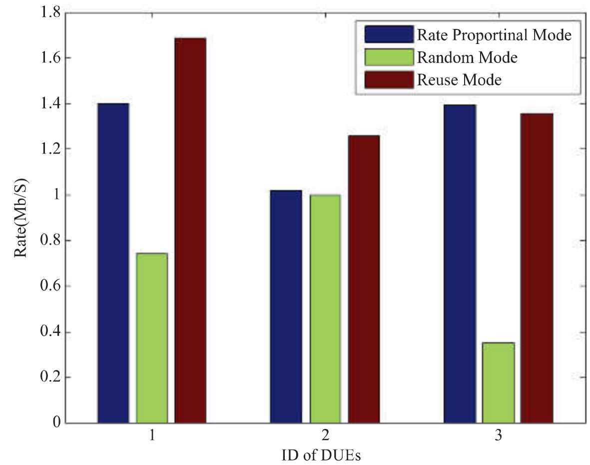

Fig. 3. Individual Throughput for Each DUE

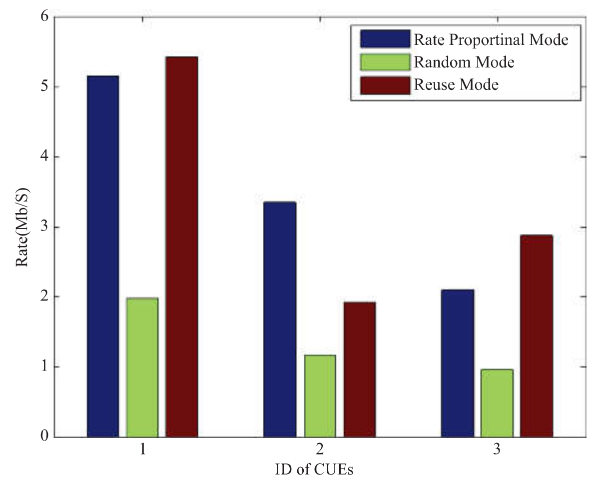

Fig. 4. Individual Throughput for Each CUE

V. CONCLUSION

D2D communication is a key feature of all future technologies. It provides high spatial efficiency and advantageous for catastrophe condition. This paper copes with problem of interference through maximum throughput algorithm in multi-user environment. RB utilization increases through this method. Moreover, the optimization problem for maximum throughput is explored for a Multi-user Cellular system underlay D2D system. A rate proportional resource allocation scheme is analyzed in correspondence with RUA and RA allocation. Simulation results verified the increased gain of the proposed algorithms in terms of proportional fairness between CUEs and DUEs. Simulation results have validated its effectiveness.

REFERENCES

[i] X. Shen, "Device-to-device communication in 5G cellular networks," *IEEE Netw.*, vol. 29, no. 2, pp. 2–3, 2015.

[ii] O. Bello and S. Zeadally, "Intelligent Device-to-Device Communication in the Internet of Things," *Ieeexplore.Ieee.Org,* pp. 1-11, 2015.

[iii] A. Asadi, Q. Wang, and V. Mancuso, "A survey on device-to-device communication in cellular networks," *IEEE Commun. Surv. Tutorials,* vol. 16, no. 4, pp. 1801-1819, 2014.

[iv] S. Mumtaz, K. M. S. Huq, A. Radwan, J. Rodriguez, and R. L. Aguiar, "Energy efficient interference-aware resource allocation in LTE-D2D communication," *2014 IEEE Int. Conf. Commun. ICC* 2014, pp. 282-287, 2014.

[v] W. Zhou, X. Sun, C. Ma, J. Yue, H. Yu, and H. Luo, "An interference coordination mechanism based on resource allocation for network controlled Device-to-Device communication," *2013 IEEE/CIC Int. Conf. Commun. China - Work. CIC/ICCC 2013,* no. Iot, pp. 109-114, 2013.

[vi] L. Yang and W. Zhang, "Interference alignment in device-to-device LAN underlaying cellular networks," *2014 IEEE Int. Conf. Commun. Syst. IEEE ICCS 2014,* pp. 21-25, 2014.

[vii] Y. Li, S. Su, S. Chen, and A. S. Overview, "Social-Aware Resource Allocation for Device-to-Device Communications Underlaying Cellular Networks," vol. 2337, no. c, pp. 1-4, 2015.

[viii] C. Yin, Y. Wang, W. Lin, and J. Xu, "Device-to-device assisted two-stage cooperative multicast with optimal resource utilization," *2014 IEEE Globecom Work. GC Wkshps 2014*, pp. 839-844, 2015.

[ix] C.-W. Yeh, G.-Y. Lin, M.-J. Shih, and H.-Y. Wei, "Centralized Interference-Aware Resource Allocation for Device-to-Device Broadcast Communications," *2014 IEEE Int. Conf. Internet Things(iThings), IEEE Green Comput. Commun. IEEE Cyber, Phys. Soc. Comput.,* pp. 304-307, 2014.

[x] C. Lee and A. Park, "Interference Avoidance Resource Allocation for D2D Communication Based on Graph-Coloring," pp. 895-896, 2014.

[xi] Hyung-sub Kim, Jee-hyeon Na, and Eunsun Cho, "Resource allocation policy to avoid interference between cellular and D2D Links/ and D2D links in mobile networks," *Int. Conf. Inf. Netw. 2014,* pp. 588-591, 2014.

[xii] C. Xu, L. Song, Z. Han, Q. Zhao, X. Wang, and B. Jiao, "Interference-aware resource allocation for device-to-device communications as an underlay using sequential second price auction," *IEEE Int. Conf. Commun.,* pp. 445-449, 2012.

[xiii] F. Teng, D. Guo, and M. L. Honig, "Power Control Based on Interference Pricing in Hybrid D2D and Cellular Networks," pp. 676-680, 2012.

[xiv] N. Lee, X. Lin, J. G. Andrews, and R. W. Heath, "Power control for D2D underlaid cellular networks: Modeling, algorithms, and analysis," *IEEE J. Sel. Areas Commun.,* vol. 33, no. 1, pp. 1-13, 2015.

[xv] U. Oruthota and O. Tirkkonen, "I/Q interference in device-to-device underlay communication with uplink power control," *IEEE Veh. Technol. Conf.,* vol. 2015, 2015.

[xvi] L. Zhou, K. Ruttik, and O. Tirkkonen, "Interference canceling power optimization for device to device communication," *IEEE Veh. Technol. Conf.,* vol. 2015, 2015.

[xvii] H. Kim, J. Na, and D. Kim, "Iterative Power Control to Mitigate the Interference between D2D and CDMA Uplink Services," pp. 254-258, 2015.

[xviii] J. Mairton, B. Silva, and G. Fodor, "A Binary Power Control Scheme for D2D Communications," vol. 2337, no. c, 2015.

[xix] (2016, 28-8-2016). Optimization Toolbox-MATLAB. Available: http://www.mathworks.com/products/optimization/