Interference Coordination for Multiple Resource Sharing in D2D Communication Underlaying LTE-A Network

Sharma, S.* and Singh, B.

Department of Electronics and Communication Engineering, National Institute of Technology, Kurukshetra-136119, India

ABSTRACT

Data traffic has been increasing at an exponential rate causing extremely heavy demand on cellular networks. Device-to-Device (D2D) communication is seen as a potential solution for data traffic offloading and enhanced performance of cellular networks. It improves the spectrum and energy efficiency of the network. But co-channel interference is the major concern while performing spectrum sharing in D2D communication. Most of the existing works have proposed power control schemes for non-overlapping spectrum allocation among D2D pairs. This paper focuses on reducing the co-channel interference by dynamic power control while allocating multiple resources to single D2D user. D2D system performance is formulated as an overlapping coalition game coupled with interference based transmit power distribution among the resource blocks assigned to a single user. Simulation results show that the proposed scheme outperforms the other existing techniques in terms of D2D throughput and total transmit power

Keywords: Device-to-Device communication, overlapping coalition game, power control, resource allocation

INTRODUCTION

The cellular data traffic has been increasing at an exponential rate as number of smart phone users are growing rapidly. The global mobile data traffic is expected to grow by more than200 times over the period from 2010 through 2020 and by nearly 20,000 times from 2010 to 2030. In order to accommodate the ever growing wireless users, provide better quality of service for applications like online gaming, social networking and video streaming. there is an imperative need to explore new radio spectrum enabling greater bandwidth and efficient radio access technologies. Basically there are two

approaches to increase the throughput and spectral efficiency of a cellular network, either to shift to a new broader spectrum or to efficiently utilize the available spectrum resources. To adopt the former approach researchers are exploring the millimeter wave (mmWave) band for next generation cellular communication. But at high operating frequencies omni-directional path loss is high as compared to conventional sub 3 GHz band hence making long distance communication difficult at millimeter frequencies. Also mmWave signals are very susceptible to shadowing, resulting in outages and reduced channel quality. Therefore to improve the utilization of available radio resources is an alternative approach to it which utilizes technologies like small cell deployment, heterogeneous network, redesigning backhaul links and spectrum sharing. To perform spectrum sharing, either transmission parameters can be adapted according to the characteristics of the environment in which it operates as done in cognitive radio or traffic may be offloaded to underutilized licensed and unlicensed spectrum as done in device-to-device (D2D) communication underlaying cellular networks. D2D communication is a potential solution to enhance the reuse of radio resources facilitating high throughput, improved spectrum and energy efficiency of mobile multimedia in 5G networks, and extended network coverage. But as implementing D2D communication requires introduction of new functionalities both at user device and base station, it significantly complicates the cellular network design. Hence D2D communication along with cellular networks has attracted significant attention and its feasibility in context of LTE-A is being investigated through academic and industrial research.

First implementation for D2D communication improving spectral efficiency as compared to the 802.11 architecture with RTS/CTS was proposed by Qualcomm (Wu et al., 2013). This concept was adopted for U-D2D communication to IMT-A and LTE-A cellular network, providing high speed, low cost and seamless connectivity for rich multimedia applications (Doppler et al., 2009; Feng et al., 2013; Janis et al., 2009). But various design issues like D2D mode selection, channel quality estimation with minimum signaling overhead, D2D bearer establishment, best selection of UL/DL resources for sharing, scheduling interaction time between network and D2D pair and optimal power control were encountered in realizing it (Fodor et al., 2012 ; Wang & Tang, 2016). To overcome these challenges various mode selection, resource allocation and interference management techniques have been proposed.

Resource sharing (uplink, downlink or both) with cellular users introduces problem of co-channel interference which limits overall performance of the cellular network and maximum number of D2D links that can be supported along with cellular links. Co-channel interference may be co-tier i.e. among the D2D pairs sharing same RBs and cross-tier which arises between cellular and D2D pair sharing same RB. In literature, several works have been proposed to alleviate this problem through optimal resource allocation, joint strategies either for mode selection and resource allocation or for resource and power

allocation (Sobhi-Givi, Khazali, Kalbkhani, Shayesteh, & Solouk, 2017). Location based mode selection and resource allocation were performed in Rodziewicz (2015). Advantage of such scheme is that it does not require any channel state information. Power control and resource allocation is optimized jointly for a predefined QoS, based on the type of application like video streaming, and file sharing in (Sun, Zhang, Liang, Zhang, & Chen, 2016). In Ma, Liu and Jiang, (2016) it was performed by calculating interference limited area (ILA) for each cellular user and D2D pair separately. Various game theoretic and matching techniques like Stackelberg game, reverse iterative combinatorial auction model, one-to-one matching, bipartite matching etc. have also been utilized to model and analyze the behavior of D2D users effectively (Li et.al., 2014; Song et al., 2014 ; Xu et.al., 2012; Xu et.al., 2014). Social context aware D2D architecture has been proposed by researchers (Ciou et al., Li et al., 2014; 2015; Semiari et al., 2015). Influence of social ties and energy consumption are current concerns arising in D2D networking scenario (Datsika, Antonopoulos, Zorba, & Erikoukis, 2016). D2D is also seen as a promising solution for Fog Radio Access Network (F-RAN). In F-RANs popular contents are stored in the mobile device and it is shared among other devices. Here social relationship strength maximizes the system utility and effectively alleviates the burden of front-haul (Zhang, Sun, Mo, Zhang, & Bu, 2016). To realize such group communication authors have suggested D2D communication in multi-cell architecture by using fractional frequency reuse (Jiang, Wang, Sun, Liu, & Wang, 2016).

Relaxing this constraint of allocating single RB to a D2D pair some work has focused on multiple resource sharing improving system sum rate up to 64% relative to one-to-one matching approaches adopted earlier. It also increases the number of successful D2D transmission by 60% (Zhao, Liu, Chai, Chen, & Elkashlan, 2017). Generally D2D User Equipment (DUE) transmit power used over all RBs allocated to a single D2D pair is obtained through uniform power distribution method i.e. maximum DUE transmit power is equally distributed among all the RBs allocated to it (Wang et al., 2011; Xiao et al., 2015; Xu et al., 2016; Xia et al., 2015).However, it is analyzed in literature that co-tier interference is a major reason to lower the potential gain of U-D2D. Therefore an attempt to reduce co-tier interference need to be made in multiple RB allocation mode through channel based power control. This method of power control has been used earlier to improve the performance of conventional OFDM systems (Cover & Thomas, 2012; Kim et al., 2005). They have shown significant enhancement in system capacity by utilizing iterative water-filling scheme for channel based power allocation

In this paper we investigate the problem of interference management in multiple RB allocation mode by proposing an overlapping coalition formation game framework coupled with dynamic control. Earlier works reported in literature in U-D2D as observed by us have not considered interference based power control scheme in multiple resource allocation

scenario. Our contributions are summarized as follows. Multiple resource allocation to a single D2D pair in U-D2D scenario is realized by formulating an overlapping coalition framework. D2D throughput is enhanced by optimizing the resource allocation and dynamically controlling the transmit power a D2D transmitter based on the interference experienced over each channel or RB allocated to it. The fractions of total transmit power (considered as resource residing with D2D pairs) contributed by a D2D pair to each coalition so formed is decided through modified Water-Filling approach. This results in higher system sum rate and D2D transmission ratio.

System Model

A single cell scenario is considered with BS situated at the centre, cellular users and direct D2D pairs distributed uniformly in the cell coverage area as shown in Fig.1. Each user device is equipped with a single antenna therefore a D2D pair can operate in half duplex mode only. It is assumed that at any instant, there are N cellular user equipments (CUEs) and K D2D pairs in the cell. Set of CUEs and D2D pairs can be represented as $C = \{C_1, C_2, ... C_N\}$ and $D = \{D_1, D_2, ... D_K\}$ respectively. Though whole uplink bandwidth is available for reuse, we assume that the available RBs are equal to those used by cellular users in the cell. We denote set of RBs as $B = \{B_1, B_2, ... B_K\}$. Each CUE from set C is assigned an RB from set B following similar indexing i.e. orthogonal resource allocation. As a CUE can share same RB with multiple D2D pairs, this causes interference at BS due to D2D transmission and at DUE receivers due to cellular uplink transmission. Element x_{C_i, D_i} is used to indicate sharing of B_i among cellular user and D2D pairs. If C_i shares a RB with D_j then $x_{C_i, D_i} = 1$. Element x_{D_i, D_j} is used to indicate mutual sharing of RBs among D2D pairs. If $x_{D_i, D_j} = 1$ then D_i is sharing same RB with D_j. Also one D2D pair may occupy multiple RBs such that SINR at all DUEs and CUEs sharing those RB is maintained above a threshold value.
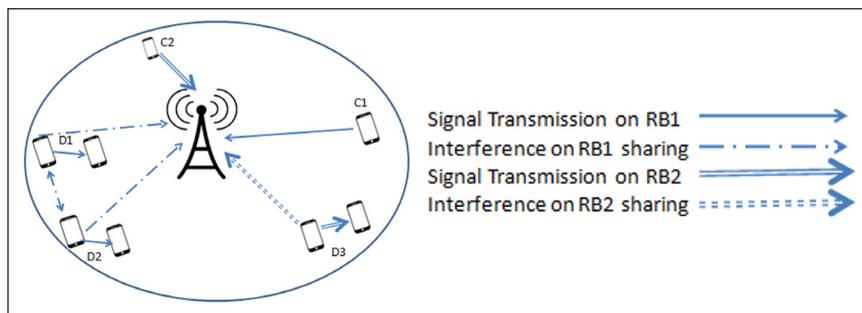
Figure 1. CUEs sharing RBs with D2D pairs causing uplink and mutual interference

Link quality is determined by computing SINR for cellular and D2D transmission links. It is considered as an important parameter for system performance evaluation. Effect of co-channel interference is also accounted for in SINR calculation by

$$SINR_{C_i} = \frac{P_{CUE}\, G_{C,BS}}{P_{noise} + \sum_{j=1}^{K} x_{C_i,D_j} P_{B_i,D_j} G_{C_i,D_j}} \tag{1}$$

$$SINR_{B_i,D_j} = \frac{P_{B_i,D_j}\, G_{D_j}}{P_{noise} + P_{CUE} G_{C_i,D_j} + \sum_{i=1}^{K} x_{D_i,D_j} P_{B_i,D_j} G_{D_i,D_j}} \tag{2}$$

Where, P_{CUE} denotes the transmit power of a CUE and P_{B_i,D_j} denotes DUE transmitter power of D_j while using B_i. P_{D_j} is the total transmit power at D_j. $G_{C,BS}$ is the channel gain between C_i and BS. G_{D_j} is the channel gain between DUEs forming D_j, G_{C_i,D_j} is the channel gain between CUE and D2D pair receiver sharing the same RB and G_{D_i,D_j} is the channel gain between transmitter DUE and receiver DUE of D2D pairs sharing the same RB. P_{noise} is noise power.

According to Shannon-Hartley theorem, data rates on j^{th} D2D pair using B_i can be calculated as follows

$$R_D^i = B \left(1 + log_2 SINR_{B_i,D_j}\right) \tag{3}$$

Where, B is sub channel bandwidth and R_D^i is the D2D data rate while using i^{th} resource block.

Considering all D2D and cellular users, the gain of system corresponds to a total D2D user throughput which can be computed as follows

$$U(R_D) = \sum_{i \in C} \sum_{j \in D} x_{C_i,D_j} R_D^i \tag{4}$$

The value of R_D depends on (i) sharing relation among different D2D pairs and between cellular user and D2D pairs (ii) co-channel interference. By devising optimal resource allocation and power control mechanism, system sum rate can be maximized. Sum rate maximization can be formulated as an optimization problem given below.

$$\max U(R_D),$$

$$\text{s.t.} \begin{cases} x_{C_i,D_j} \in \{0,1\} \; \forall i \in \{1,2,\ldots N\}, \forall j \in \{1,2,\ldots K\} \\ \sum_{i \in B} P_{B_i,D_j} \leq P_{D_j}, \forall j \in \{1,2,\ldots K\} \\ R_{C_i} \geq R_c^{th}, \forall i \in \{1,2,\ldots N\} \\ R_{D_j} \geq R_D^{th}, \forall j \in \{1,2,\ldots K\} \\ \sum_{i \in B} x_{C_i,D_j} \leq N, \forall j \in \{1,2,\ldots K\} \end{cases} \tag{5}$$

R_c^{th} and R_D^{th} are the threshold data rate values for C_i and D_j respectively which guarantees QoS requirements of the system . To limit the interference at each RB and reduce implementation complexity the maximal number of RBs that are allowed to be allocated to a single D2D pair can be restricted based on type of information that is to be shared among the D2D pairs. Here it is assumed to be equal to total number of RBs available. Further, overlapping coalition formation game theory is applied onto the scenario to maximize system sum rate under the given constraints.

Overlapping Coalition Formation for Multiple Resource Allocation

Overlapping coalition formation game theory is used to model practical scenarios in which players may belong to more than one coalition and contribute their resources among those coalitions to improve overall system performance (Wang, Song, Saad, & Han, 2016). The eNB forms cooperative groups termed as coalition based on the signal-to-noise ratio (SINR) feedback from DUEs so as to reduce the co-channel interference between D2D users and cellular users sharing the same RB. The maximum number of coalitions that can be formed is the total number of uplink channels (RBs) available for sharing. Hence K D2D pairs pairs in the given scenario which can form at most 'N' coalition when generally $N < K$. The aim is to derive a stable coalition structure which provides improved system utility value defined in terms of D2D user throughput as given in Eq.(5).

As it is assumed that a D2D pair can be allocated multiple RBs, therefore total DUE transmit power needs to be distributed among the number of RBs allocated to that pair. But as a user may experience different channel gain on different RBs therefore, uniform distributions of total DUE transmit power over each RB may not provide the desired performance. Hence, unlike earlier works which have assumed uniform distribution of DUE transmit power, the proposed approach distributes it in accordance with the interference experienced during that RB. Therefore, the term P_{B_i,D_j} is introduced to denote transmit power used by D_j while transmitting over B_i.

Definition 1. *(Overlapping Coalition Game for Resource Allocation):* The proposed overlapping coalition game $G = (D, R_D, F)$ with a transferable utility (TU), player set $D = \{D_1, D_2, ... D_K\}$ and coalition structure $F = \{F_1, F_2, ... F_N\}$, is given by a function given below

$$v = [0,1]^K \rightarrow R_{D+} \tag{6}$$

Such that $\begin{cases} v(0^K) = 0 \\ v(F_i) = \sum_{j \in D} R_D^i \end{cases}$

$v(F_i)$ is the value for every coalition F_i which is the subset of D and a transferable utility with the aim to maximize the system sum rate. This is distributed among the members of F_i depending upon the fraction of power contributed by individual member. Total payoff value of a D2D pair D_j, is the sum throughput achieved by it being the member of F_j^* where $F_j^* \subseteq F$ (F_j^* represents those coalitions which has D_j as its member).

In the proposed game D2D pairs are motivated to join a coalition to increase their own utility value given by $v\left(D_j^{F_j^*}\right)$ and coalition value $v(F_i)$ given in (6). Utility value of each D2D pair is expressed as

$$v\left(D_j^{F_j^*}\right) = \Sigma_{i \in F_j^*} R_D^i \tag{7}$$

Hence a preference order can be defined for each player and for each RB separately. That preference order can be used to perform split and join operation respectively, which leads to a stable coalition structure offering system sum-rate maximization.

Co-Channel Interfrence Based Power Control

As number of users sharing the same RB increases, co-tier interference experienced by D2D pairs over that RB also increases. Therefore separate power constraints are set for each RB allocated to a single D2D pair. Then P_{B_i,D_j} can be computed using modified water-filling approach as follows

$$P_{B_i,D_j} = \left[\Delta_{D_j} - \left(\alpha\left(\frac{1}{G_{B_i,D_j}}\right)\right)\right]^+ \tag{8}$$

$$\Delta_{D_j} = \frac{1}{g}\left(P_{D_j} + \Sigma_{G_{B_i,D_j} \in G_j}\, \alpha\left(\frac{1}{G_{B_i,D_j}}\right)\right) \tag{9}$$

$$G_{B_i,D_j} = \frac{\left|H_{B_i,D_j}\right|^2}{N_i} \tag{10}$$

Here 'α' is the regularization parameter which is used to scale the impact of interference for resource sharing relation among D2D pairs. G_j is the set of RBs allocated to j^{th} D2D pair and 'g' is the cardinality of G_j and $[b^+] = \max(b, 0)$. G_{B_i,D_j} is the SINR value at D_j while using B_i. H_{B_i,D_j} is channel impulse response and N_i is noise due to interference on B_i.

Proposed Algorithm (OCF-PC)

The proposed scheme is a two stage algorithm which comprises initialization and coalition structure update process as explained below

(a) Initialization: When D2D users request for channel assignment, eNodeB prepares a preference list of suitable RBs which can be reused for D2D communication based on the SINR achieved over each channel or RB as a feedback from D2D pairs. Such a preference list is prepared separately for each D2D pair and is valid for one session. In the initialization phase eNodeB allocates the best RB to each D2D pair. Number of coalition formed in this stage is equal to number of RBs available and users sharing a RB are the respective coalition members.

(b) Preference List Update Process: This process aims to update associated RB preference list for each D2D pair so as to maximize the overall utility value i.e. $U(R_D)$. Every coalition is updated through leave and join operations performed for each D2D pair. As overlapping coalition theory is used hence single D2D pair may join more than one coalition. The choice of joining a coalition is motivated by improvement in its own data rate and utility value of that coalition. D2D transmit power is adjusted over each RB after joining and leaving process.

The update process is repeated for each D2D pair until a stable coalition structure is attained.

Table1
Multiple resource allocation and power control (OCF-PC)

Input: 'N' cellular users and available RBs, 'K' D2D pairs, maximum D2D distance
Output: D2D user throughput
Begin

Begin
1. Initialization:
- D2D users request RBs from eNodeB.
- eNodeB prepares a preference list of RBs available for reuse based on the SINR feedback from each user. Each D2D pair is allocated the best RB.
- This provides an initial coalition structure.
2. Preference List Update:

For each D2D user D_j

  For each F_i if $F_j^* \cap F_i = \phi$

    If $v\left(D_j^{F_j^*}\right) > v\left(D_j^{F_j^* \cup F_i}\right)$

    and $v(F_i) > v(F_i \cup D_j)$

      Then join F_i

    Else

      Leave F_i

Table1 *(continue)*

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eNodeB resets P_{B_i,D_j} by using (8)

    End For

  End For

3. Compute $U(R_D)$

4. Repeat step 2 and 3 to achieve maximum $U(R_D)$ and a stable coalition structure

End

Properties of Proposed Algorithm.

(a) Stability. In the proposed overlapping coalition game $G = (D, R_D, F)$, if no player $j \in D$ can join or leave any coalition provided the sharing relations of other users, then G has attained a stable coalition structure referred here as Closure-stable (C-stable). In game G, total number of possible coalitions for a given set of D2D pairs and RBs is finite. Hence the sequence of CS-update process will terminate with probability 1 and algorithm converges to $F_{closure}$ (C-stable coalition structure). Suppose if $F_{closure}$ obtained from the given algorithm is not C-stable. Then there exist a D2D pair D_j for has higher preference for F_j^* than F_i. But in our algorithm, such a pair can join F_i with probability 1. This contradicts $F_{closure}$ being the final coalition structure.

(b) Convergence. Starting from an initial coalition structure the proposed algorithm converges to a C- stable coalition structure after limited number of iterations. If F_0 is an initial coalition structure, after an update process in which all users try to maximize their utility, the change in coalition structure can be expressed as $F_0 \rightarrow F_1 \rightarrow F_2 \cdots$.

After m^{th} iteration in an update process, F_{m-1} changes to F_m and for any user $j \in D$, F_j^* changes from $F_{m-1,j}^*$ to $F_{m,j}^*$ satisfying following equation

$$v\left(D_j^{F_{m,j}^*}\right) \geq D_j^{F_{m-1,j}^*}$$
(11)

If this change is a result of a D2D pair leaving a coalition then transmit power for every other user of that coalition increases as the co-channel interference reduces by a value G_{B_i,D_j} . Whereas if the change in coalition structure is a result of a D2D user joining a coalition then it can be shown that system utility increases.

(c) Complexity. The complexity of the proposed algorithm depends on the number of leave and join operations in one update process. The exhaustive optimal algorithm for the defined

game has the complexity of $O(N^K)$. Whereas the proposed algorithm has the worst case complexity of $O(KN)$ this is similar to the complexity of scheme utilizing overlapping coalition without power control. Hence it can be said that power distribution function does not add any complexity to the resource allocation algorithm.

Performance Analysis

To evaluate the performance of proposed algorithm, a single cell of radius 500 m is considered with eNB located at its centre. Cellular users and D2D pairs are distributed uniformly in the network area under consideration. Number of cellular users and thus the uplink resources are fixed a prior. Fixed number of available resources presents an upper limit on maximum number of D2D pairs which can share those. This is so because increase in 'K' implicitly increases co-channel interference as limited numbers of RBs are available for reuse among D2D pairs, during a given session. Therefore to maintain a minimum data rate over cellular and D2D links we have assumed 10 D2D pairs for given scenario. Different path loss models are considered for cellular and D2D users. Each RB is of 180 KHz. Maximum transmit power of a CUE and of DUE is taken as 26 dBm and 13 dBm respectively.

Figure 2 shows the comparative performance of proposed algorithm (OCF-PC) with existing techniques. Optimal Algorithm implies the exhaustive solution for the considered scenario. 'NOCF' refers to non-overlapping coalition formation approach. 'OCF-WPC' refers to overlapping coalition formation game without power control. It is observed that as the number of D2D pairs increases, OCF-PC offers significant improvement in system sum rate as compared to others. Figure.3 shows that as number of cellular user increases the D2D user throughput also increases. This is so because as N increases channels available
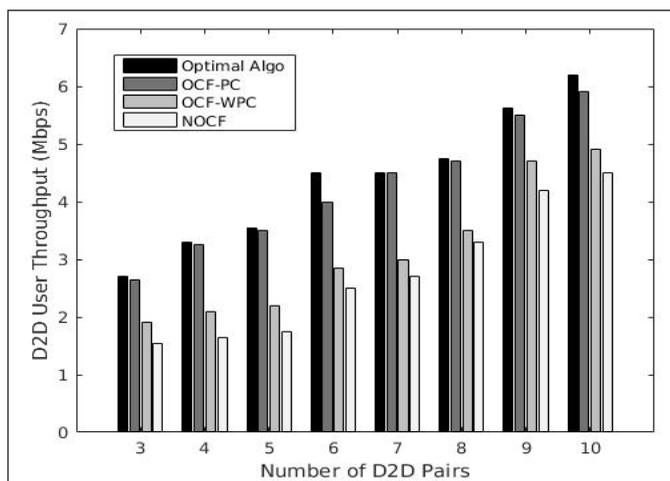
Figure 2. D2D user throughput vs Number of D2D pairs

for sharing also increases as assumed in the system model. This increase is greater in case of OCF-PC because of better interference management and power control as compared to OCF-WPC.
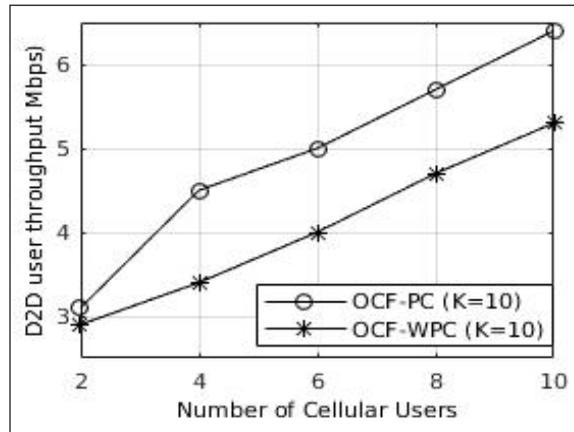
Figure 3. D2D system throughput vs number of cellular users
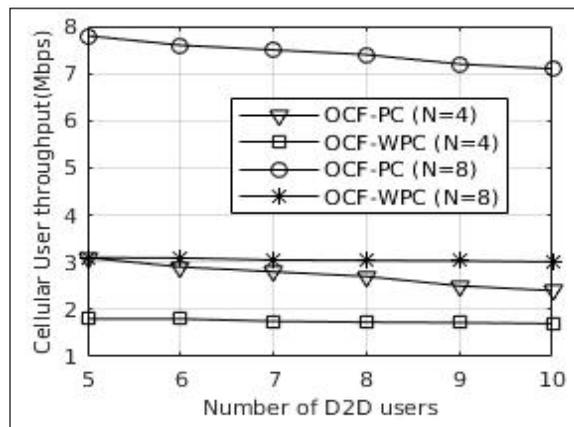
Figure 4. Cellular user throughput vs number of D2D pairs

But increase in number of D2D pairs affects the performance of cellular users because it increases the co-channel interference. The decrease in cellular user throughput can be observed in Figure.4 as 'K' increases. Higher cellular user throughput is achieved in case of OCF-PC for all values of 'N' because of less co-channel interference as compared to OCF-WPC.

Maximum achievable data rate decreases as the distance between source and destination increases. Therefore as the distance between D2D transmitter and receiver increases the D2D user throughput also decreases as shown in Figure.5. The throughput variation is shown for different values of 'N'.
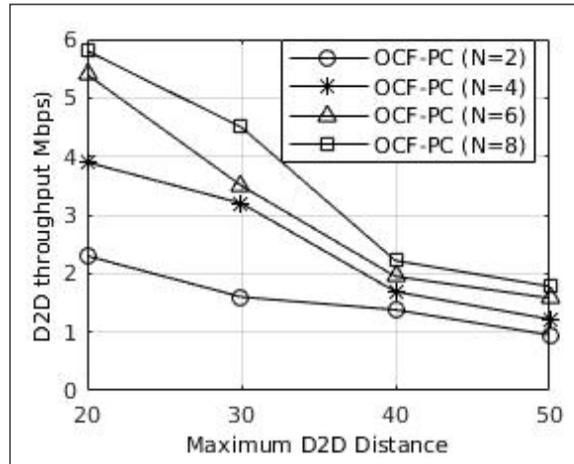
Figure.5. D2D user throughput vs maximum D2D pair distance (in meters)

CONCLUSION

In this work, we have addressed the problem of co-channel interference existing in D2D communication while allow multiple resource allocation for a single D2D pair. Multiple resource allocation and interference based power control scheme is implemented by applying overlapping coalition formation game model and water-filling approach for power distribution over multiple RBs. The proposed scheme provides increased transmission bandwidth and better interference management over each RB, which lowers the impact of co-channel interference. The effectiveness of this scheme is shown in terms of D2D user throughput. D2D user throughput is improved by 46.15% as compared to existing game and matching theoretic techniques. Our future work may consider the effect of co-channel interference in multiple cell scenario while considering the mobility of the D2D users.

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