Joint Power and Channel Allocation for Relay-Assisted D2D Communications

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***Abstract*—Relay-assisted D2D (Device-to-Device) communication was proposed as a supplement to direct D2D communications for enhancing traffic offloading capacity in Long Term EvolutionAdvanced (LTE-A) systems. In this paper, we formulate the joint power and channel allocation problem for relay-based D2D communications aims at maximizing the system sum rate of all cellular and D2D links while guaranteeing the minimum required SINR (Signal to Interference and Noise Ratio) of both links. As it is a MINLP (Mixed Integer Non-linear Programming), which can not be solved in polynomial time, we propose two heuristic algorithm (named Proposed HA1 and Proposed HA2) with different complexity levels to solve our design problems. Monte-Carlo simulation results show that the performances of our proposed algorithms with acceptable complexity have a good performance compare to the optimal performance. The trade-off between complexity and performances is illustrated.**

Keywords- Device-to-Device (D2D) communications; Relay-assisted D2D communication; Power Allocation; Channel Allocation.

I. Introduction

The fast development of wireless applications lead to the explosion of multi-media services, which consumes a large amount of resources in the present network and continues keeping vigorous demand. Many new technologies such as relay, CoMP and so on have been introduced to the cellular network under the scope of IMT-Advanced. While the traditional spectrum utilization method is hard to solve the above problems effectively and thus the local peer-to-peer technologies enabling high data rate local service such as device-to-device (D2D) communication draws much attentions and investigations. The D2D communication can operate in two basic modes: underlay and overlay, which means the D2D user shares the spectrum with the cellular user in orthogonal or non-orthogonal way[1]. The most important aspect of D2D communication is that it can improve the network capacity greatly by spectrum reusing between D2D and cellular user[2][3]. The resource reusing is based on the criteria that it would not bring harmful interference to the cellular user. Many researchers already work on resource allocation for D2D communications underlay cellular system[4]-[13].

However, only using direct D2D mode may limit the benefits bring in by D2D communications to long-term evolution-advanced (LTE-A) systems, because D2D transmitter and receiver may not be able to perform direct D2D communications due to long separation distance and poor channel condition between them[14]. In such cases, network-assisted transmission through relays could enhance the performance of D2D communication, which is called as relay-assisted D2D communications.

Authors in [15] propose distributed solution for resource allocation on relay-assisted D2D communication system under channel uncertainties. Genetic Algorithm (GA) is applied to solve resource allocation problem for relay-assisted D2D communications[18]. Also, authors in [16] proposed a distributed solution to solve the relay selection under relay-assisted D2D communications. Authors in [17] propose a cross-layer relay selection scheme that consider several criteria jointly, including end-to-end data rate, relay nodes remaining battery time and end-to-end transmission delay on relay-assisted D2D path. Joint relay selection and resource allocation problem is proposed in [19][20]. In [20], the joint relay selction and channel allocation become a 3-Dimensional assignment problem, which need higher computational complexity.

However, the primary challenge we face here is how to devise an algorithm that solve our design problem within an acceptable computational complexity while guaranteeing the system performance. In this paper, we focus on power and channel allocation for relay-assisted D2D communications to maximize system sum rate under lower computational complexity while guaranteeing the QoS of all links. In Proposed HA1, we first allocate the optimal power resource for each links under given channel assignment, then followed by our proposed channel allocation algorithm. In contract, we first figure out the best reuse pair between cellular and D2D links, then distribute power resource for reusing links in Proposed HA2. Moreover, the complexity of Proposed HA2 is lower than Proposed HA1. Simulation results show that Proposed HA1 achieves the trade-off between computational complexity and performance.

The remainder is organized as follows. Section II introduce the system model for relay-assisted D2D communications and the problem formulation. Section III illustrate our proposed solutions. Simulation results and analysis are shown in section IV. Section V concludes this paper.

II. System Model and Problem Formulation

A. System Model

We consider a single cell system with a BS in the central, where M cellular users in the set $\mathcal{M} = \{1, ...m, ...M\}$, N

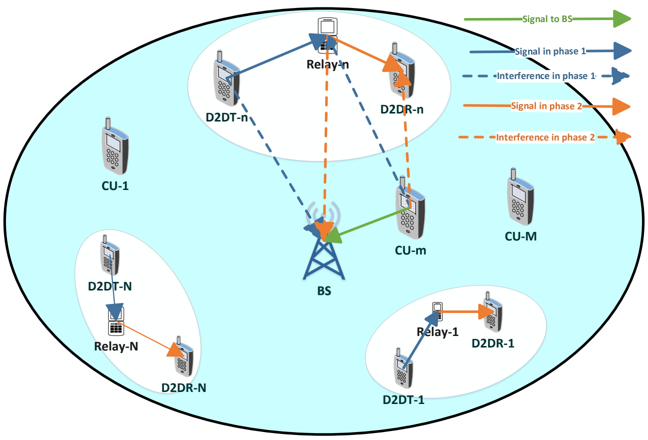

Fig. 1. A Single Cell System with M cellular links, N D2D links and R relay nodes

D2D links in the set $\mathcal{N} = \{1, ...n, ...N\}$ and R relay nodes in the set $\mathcal{R} = \{r_1, ...r_n, ..., r_N\}$ as shown in Fig.1. We assume that all cellular links have been pre-allocated the corresponding resource blocks, and we are interested in allocating channels to D2D links efficiently. Without loss of generality, we do not mention any resource block index in this paper, we use symbols (m, n, r_n) to denote cellular users, D2D links and relay nodes. We also assume that each D2D link can only reuse one resource of cellular link, and each resource of cellular link is assigned to at most one D2D link. D2D link n is supported by relay r_n in the set R.

We denote X as a binary channel allocation decision matrix, where binary variable

$$\chi_{mn} = \begin{cases} 1 & \text{D2D link } n \text{ resue resource of cellular user } m, \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

We denote h_{ab} as the channel gain from transmitter of link or relay node a to receiver of link or relay b. We assume that the Decode and Forward (DF) relaying strategy is employed where each communication period is divided into two equal intervals corresponding to the D2D transmitter to relay node communication phase (phase 1) and relay node to D2D receiver communication phase (phase 2). Also, we assume that communications in phase 1 and phase 2 use the same cellular channel resource. In phase 1, D2D link n reuse the resource of cellular link m,, the SINR of cellular link m and D2D link n are

$$\gamma_{mn}^{c1} = \frac{p_m^c h_{mm}}{\sigma^2 + p_n^d h_{nm}}, \tag{2}$$

$$\gamma_{mn}^{d1} = \frac{p_n^d h_{nr_n}}{\sigma^2 + p_m^c h_{mr_n}}, \tag{3}$$

respectively, in where p_m^c and p_n^d are the transmitter power of cellular link m and D2D link n. σ^2 denotes the noise power. In phase 2, the SINR of cellular link m and D2D link n are

$$\gamma_{mn}^{c2} = \frac{p_m^c h_{mm}}{\sigma^2 + p_{r_n} h_{r_n m}}, \tag{4}$$

$$\gamma_{mn}^{d2} = \frac{p_{r_n} h_{r_n n}}{\sigma^2 + p_m^c h_{mn}}, \tag{5}$$

respectively. The data rate in bits per second per hertz (i.e. normalized by the channel bandwidth) of cellular link m and D2D link n can be expressed as

$$R_{mn}^c = 0.5log_2(1 + \gamma_{mn}^{c1}) + 0.5log_2(1 + \gamma_{mn}^{c2}), \tag{6}$$

$$R_{mn}^d = 0.5log_2(1 + min\{\gamma_{mn}^{d1}, \gamma_{mn}^{d2}\}). \tag{7}$$

When cellular links without any co-channel interference from D2D links, the maximum throughput could be achieved while cellular links transmit with their maximum power (i.e. P_{max}^c). Thus, the data rate of cellular link m without reused can be expressed as

$$R_m^0 = log_2(1 + \frac{P_{max}^c h_{mm}}{\sigma^2}). \tag{8}$$

B. Problem Formulation

In this section, we formulate the joint power and channel allocation problem, which aims to maximize the sum rate of all communication links while guaranteeing the required minimum rates of cellular and D2D links. The problem can be expressed as

$$\max_{P,X} \sum_{m=1}^{M} (1 - \sum_{n=1}^{N} \chi_{mn}) R_0 + \sum_{m=1}^{M} \sum_{n=1}^{N} \chi_{mn} R_{mn}^c + \sum_{n=1}^{N} \sum_{m=1}^{M} \chi_{mn} R_{mn}^d, \tag{9}$$

s.t.

$$\gamma_{mn}^{c1} \geq \gamma_{min}^c, \gamma_{mn}^{c2} \geq \gamma_{min}^c, \forall n \in \mathcal{N}, \tag{10}$$

$$\gamma_{mn}^{d1} \geq \gamma_{min}^d, \gamma_{mn}^{d2} \geq \gamma_{min}^d, \forall m \in \mathcal{M}, \tag{11}$$

$$0 \leq p_m^c \leq P_{max}^c, \forall m \in \mathcal{M}, \tag{12}$$

$$0 \leq p_n^d \leq P_{max}^d, \forall n \in \mathcal{N}, \tag{13}$$

$$0 \leq p_{r_n} \leq P_{max}^{r_n}, \forall r_n \in \mathcal{R}, \tag{14}$$

$$\sum_{n=1}^{N} \chi_{mn} \leq 1, \forall m \in \mathcal{M}, \tag{15}$$

$$\sum_{m=1}^{M} \chi_{mn} = 1, \forall n \in \mathcal{N}, \tag{16}$$

$$\chi_{mn} \in \{0, 1\}, \forall m \in \mathcal{M}, \forall n \in \mathcal{N}, \tag{17}$$

in where γ_{min}^c and γ_{min}^d are the minimum SINR requirement of cellular and D2D links, respectively. $P_{max}^c, P_{max}^d, P_{max}^{r_n}$ are the maximum transmission power of cellular, D2D and relay node transmitters. Constraints (10) and (11) show the minimum SINR requirement of each link in all transmission intervals is guaranteed. Constraints (12) and (13) express the limited transmission power of each cellular and D2D link, respectively. Constraint (15) shows each cellular link can only be shared by no more one D2D link, and constraint (16) shows each D2D link can reuse only one cellular link's resource. The final constraint (17) means the value of resource allocation indicator should be binary.

TABLE I
PROPOSED HA1

Channel Allocation in Proposed HA1
Input
The set of cellular link M
The set of D2D link N
The optimal sum rate matrix Π_{mn}
Output
The set of channel resource of cellular links shared by D2D links: Ω
1.Initialization $\Omega = \phi, \Omega_{avail} = M$
2. for $n \in N, m \in \Omega_{avail}$
3. $m^* = arg \max_{n \in N, m \in \Omega_{avail}} \Pi_{mn}$
4. $\Omega_n = \Omega_n \cup \{m^* \| m^* \in \Omega_{avail}\}$
5. $\Omega = \{\Omega_n \| n \in N\}$
6. $\Omega_{avail} = \Omega_{avail} - m^*$
7. end for

III. PROPOSED SOLUTION APPROACH

Our design problem (9) with constraints (10)-(17) is a mixed-integer programming which is an NP-hard problem. It implies that there is no known polynomial-time algorithm for finding all the feasible power and channel allocation. In this section, we proposed two heuristic algorithm (named Proposed HA1 and Proposed HA2) with lower complexity. Our main ideas is to divide our original design problem into two subproblems: and then solve them individually. In Proposed HA1, we first allocate the optimal power for each communication link when the resource of cellular link m reused by D2D link n. Then we assign the resource for each D2D links. However, in Proposed HA2 we first allocate the resource for each D2D links, then allocate the power for each sharing link, which reduce the complexity further.

A. Proposed HA1

We denote the power allocation vector is $P_{m,n} = [p_m^c \quad p_n^d \quad p_{r_n}]$,when D2D link n reuse the resource of cellular link m. Then we have the following power allocation problem, which can be solved by using the algorithm in [21] and can be expressed as

$$\max_{P_{m,n}} \quad \Pi_{mn} = (R_{mn}^c + R_{mn}^d - R_m^0), \tag{18}$$

s.t. constraints(10)-(14).

After getting the data rate increase matrix Π_{mn} due to D2D communications reuse, our design problem can be transmitted into the following job assignment problem, which can be expressed as

$$\max_{X} \quad \sum_{m=1}^{M} \sum_{n=1}^{N} \Pi_{mn} \chi_{mn}, \tag{19}$$

s.t. constraints(15)-(17).

We then sequentially select the resource for each D2D link from the available channel pool Ω_{avail}. D2D link n be allocated the resource of cellular link m^*, which can bring the maximum sum rate value. After individually allocate for D2D links, we can get the set of channel resource of cellular links Ω, which shared by D2D links. More details of our proposed channel allocation algorithm is given in TABLE I.

B. Proposed HA2

In this algorithm, we first allocate the resource to D2D link without considering power control. In order to maximize the sum rate of cellular and D2D links, we switch the optimization problem into minimize the interference caused by frequency reuse. Then the problem is converted into finding the best resource pairing relationship between cellular links and D2D links that can minimize the reuse interference. We define the interference when cellular link m reused by D2D link n is $i_{mn} = P_{max}^d (h_{nm} + h_{r_n m}), \forall m \in M, \forall n \in N$. Then build the interference matrix I_{mn}. Again our design problem become the following job assignment problem, which can be expressed as

$$\max_{X} \quad \sum_{m=1}^{M} \sum_{n=1}^{N} I_{mn} \chi_{mn}, \tag{20}$$

s.t. constraints(15)-(17).

We use the our proposed channel allocation algorithm in last subsection to solve above problem. Once we get the resource pairing relationship between cellular and D2D links, our problem become the power allocation problem can be expressed as

$$\max_{P_{m,n}} \sum_{m=1}^{N} \sum_{n=1}^{N} (R_{mn}^c + R_{mn}^d), \tag{21}$$

s.t.

$$\gamma_{mn}^{c1} \geq \gamma_{min}^c, \gamma_{mn}^{c2} \geq \gamma_{min}^c, \forall n \in \mathcal{N}, \tag{22}$$
$$\gamma_{mn}^{d1} \geq \gamma_{min}^d, \gamma_{mn}^{d2} \geq \gamma_{min}^d, \forall m \in \Omega, \tag{23}$$
$$0 \leq p_m^c \leq P_{max}^c, \forall m \in \Omega, \tag{24}$$
$$0 \leq p_n^d \leq P_{max}^d, \forall n \in \mathcal{N}, \tag{25}$$
$$0 \leq p_{r_n} \leq P_{max}^d, \forall n \in \mathcal{N}. \tag{26}$$

And it can be solved by algorithm in [21]. Noted that, after the channel allocation, the number of candidate cellular links set is reduced, which actually equal to the number of D2D links N.

The complexity of our proposed algorithm is analysed by studying power and channel allocation. In Proposed HA1, we first solved MN power allocation problem with complexity of O(1), which mean the power allocation complexity is $O(MN)$. Then the complexity of proposed channel allocation is $O(MN - N(N-1)/2 - 1)$. Therefore, the total complexity of Proposed HA1 is $O(MN + (MN - N(N-1)/2 - 1))$. However, in Proposed HA2, after channel allocation we only solved N power allocation problems with $O(N)$ complexity. Thus, the total complexity of Proposed HA2 is $O(N + (MN - N(N-1)/2 - 1))$, which is less than $O(MN + (MN - N(N-1)/2 - 1))$.

IV. SIMULATION RESULTS AND ANALYSIS

In this section, we use Monte Carlo simulation to evaluate the performance of our proposed algorithm. We consider a single cellular network with a radius R. The BS is located in the centre of the cell, cellular user and relay nodes are distributed uniformly in the cell. Each D2D transmitter and

TABLE II
SIMULATION PARAMETERS

Cell Radius R (m)	500
Maximum distance between D2D pairs d_{max} (m)	(20,...,200)
Number of cellular links M	10
Number of D2D links N ($N \leq M$)	(1,..,9)
Maximum cellular transmission power P^c_{max}(dBm)	24
Maximum D2D transmission power P^d_{max} (dBm)	24
QoS requirements γ^c_{min} (dB)	5
QoS requirements γ^D_{min} (dB)	15
Noise power σ^2 (dB)	-110
Pathloss exponent for D2DT-Relay-D2DR links $\alpha 1$	3
Pathloss exponent for other communications $\alpha 2$	4

receiver are located randomly whose distance to its relay node varies within d_{max}. The channel gain in our proposed model is modelled as $h_{a,b} = d_{a,b}^{-\alpha}\chi$ for all communication links, where $d_{a,b}$ is the distance between node a and b, α is the pathloss exponent[1]; χ represents the Rayleigh fading, which follows exponential distribution with mean value of 1. Our simulation parameters are summarized in TABLE II.

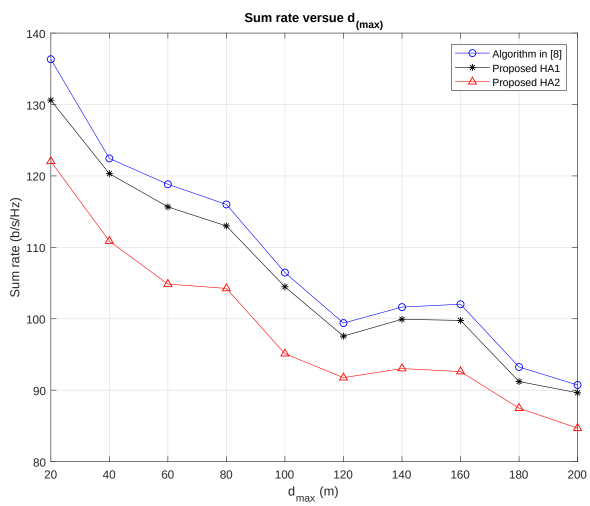

Fig. 2. System sum rate varying d_{max} under different algorithms ($M = 5, N = 3$).

Fig. 2 shows system sum rate with algorithm in [21], our Proposed HA1 and our Proposed HA2 under varying maximum distance between D2D transmitter and receiver d_{max}. In [21], authors get the optimal performance by finding all the feasible power combinations in the search space and applying the well-known Hungarian algorithm to get optimal channel allocation. Its complexity is $O(ML + M^3)$, which grows exponentially with the number of cellular link increasing, larger than complexity of our Proposed HA2 ($O(ML + M^3) >> O(MN+(MN-N(N-1)/2-1))$). From this figure, we can see that our Proposed HA1 has close performance of algorithm in [21]. As d_{max} increases, the system sum rate decreases dramatically. That is because as the d_{max} becomes larger, the data rate that D2D links contribute to become small. Also, it is because that the radius increment requires increasing the D2D transmission power, which will bring larger interference to cellular.

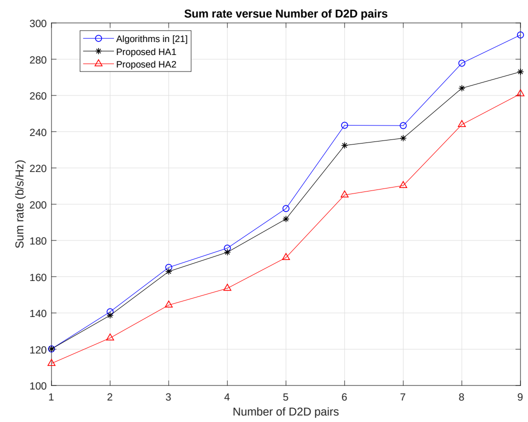

Fig. 3. System sum rate varying different number of D2D links under different algorithms ($M = 10, d_{max} = 100m$).

From Fig. 3 we can see that as the number of D2D links increase, the system sum rates increase dramatically. That is because the more D2D links involve, the higher data rate it will bring. We can also see that the performance of our Proposed HA1 is close to optimal performance when number of D2D is small. Even the performance gap between Proposed HA1 and optimal algorithm in [21] become larger as the involved number of D2D links increasing, Proposed HA1 can bring the closed perfoemcen with acceptable computational complexity. From above Fig. 2 and Fig. 3, although Proposed HA2 has lowest computational complexity, its performance is lower than Proposed HA1. Considering the trade-off between performance and computational complexity, our Proposed HA1 is the best way to choose.

V. CONCLUSION

In this paper, we have developed the efficient power and channel allocation algorithm for relay-assisted D2D communications underlay cellular systems. We proposed two algorithms (Proposed HA1 and Proposed HA2) with different computational complexity level. Simulation results show that under acceptable complexity, our Proposed HA1 can bring better performance than Proposed HA2. Efficient algorithms on joint mode and relay selection, power and channel allocation will be consider in our future work.

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