3-D Matching-based Resource Allocation for D2D Communications in H-CRAN Network

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***Abstract*—To meet the immensely diverse service requirements, heterogeneous cloud radio access network (H-CRAN) architecture and D2D communication is embraced. Consequently, the resource allocation between D2D pairs and current users is a challenge. In this paper, a joint power control and sub-channel allocation scheme is proposed. The original mixed-integer nonlinear programming problem is decomposed into power and sub-channel allocation. Geometric Vertex Search approach and 3-dimensional (3-D) matching method are used to solve them. Finally, numerical results verify the proposed scheme has about 35% and 60% improvement in total throughput comparing with other approaches.**

***Keywords*—H-CRAN; D2D communication; Resources Allocation; 3-D Matching**

I. Introduction

To meet the ever-increasing needs for capacity and spectrum utilization, H-CRAN is presented, where remote radio heads (RRHs) and device-to-device (D2D) communications are recognized to realize the ambitious targets of 5G coverage, capacity, energy efficiency and user experience [1] [2] [3].

Although multi-tier H-CRAN with macro-cell/RRHs/D2D has many benefits, it also brings the some challenges. Correspondingly, [4]studied power allocation with Stackelberg game for D2D communication in Macro-Femto-D2D heterogeneous networks. [3] proposed a coalition formation game for D2D communication in Heterogeneous cellular networks (HCNs) with millimeter wave (mmWave) communications, where power allocation is not used. The author in [5] investigated a joint power and resource allocation strategy for D2D in a multi-femtocell system, who only focuses on maximizing the throughput of D2D link. A joint channel allocation, mode selection and power control scheme is proposed in [6] to improve the underlaying network capacity of D2D-enabled femtocells, where the performance of macrocell cellular system is neglected. Moreover, the work in [7] designed a matching game to assign the sub-channels with different bandwidths to multiple D2D pairs and the RRH users, which ignores power allocation. As we can see, the works mentioned above mainly consider optimizing underlying network (D2D or femtocell) performance. On the other hand, most of works focus on optimizing problem in D2D communications underlaying HetNets.

In this paper, we concentrate on optimizing the performance of overall H-CRAN with power allocation and resource allocation jointly considered. Firstly, we formulate the optimization problem into a non-convex mixed integer programming problem. Then, considering the complexity, we decompose the original problem into two sub-problems as the power allocation and channel allocation respectively. Finally, Geometric Vertex Search approach and three-dimensional hypergraph matching method are utilized to solve them.

The rest of the paper are organized as follows. Section II introduce the system model. In Section III, Geometric Vertex Search approach and 3-D Matching Game are showed. Section IV is numerical results. Finally, the conclusion is given in Section VI.

II. System Model

A. System Model

As shown in Fig. 1, we consider the uplink of H-CRAN with one eNB, some RRUs and some D2D pairs. Assume that the set of M-UEs is $\mathcal{M} = \{\mathcal{M}_m | m = 1, 2, \ldots, M\}$,the set of D2D pairs is $\mathcal{Q} = \{\mathcal{Q}_q | q = 1, 2, \ldots, Q\}$ and the set of R-UEs is $\mathcal{K} = \{\mathcal{K}_k | 1, 2, \ldots, K\}$. The total resource blocks (RBs) of the system in the uplink period is equally divided into F sub-channels, the set of sub-channels is denoted as $\mathcal{F} = \{\mathcal{F}_f | 1, 2, \ldots, F\}$. To avoid too many interference, the users of the same network layer communicate with orthogonal resources, users of different network layers resources.

The link gains among M-UEs, R-UEs and D2D pairs are given as following: h_m^M represents the link gain from the m-th M-UE to eNB. h_k^K represents the link gain from the k-th R-UE to RRU. h_q^Q represents the link gain of the q-th D2D pair. $g_{k,m}^K$ represents the link gain from the k-th R-UE to the m-th M-UE. $g_{k,q}^K$ represents the link gain from the k-th R-UE to the q-th D2D pair. $g_{m,k}^M$ represents the link gain from the m-th M-UE to the k-th R-UE. $g_{m,q}^M$ represents the link gain from the m-th M-UE to the q-th D2D pair. $g_{q,k}^Q$ represents the link gain from the q-th D2D pair to the k-th R-UE. $g_{q,m}^Q$ represents the link gain from the q-th D2D pair to the m-th M-UE. Owing to channel reciprocity, $g_{k,m}^K$ is equal to $g_{m,k}^M$, $g_{k,q}^K$ is equal to $g_{q,k}^Q$, $g_{m,q}^M$ is equal to $g_{q,m}^Q$.

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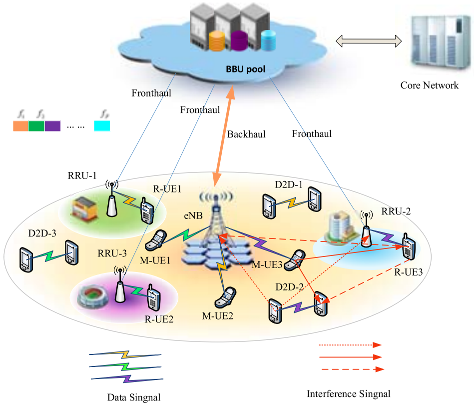

Fig. 1. System Model of Device to Device Communication in H-CRAN

B. Problem Formulation

Define a binary variable $x_{m,f}^{M}$ for allocation variables of M-UE on the channel f.When $x_{m,f}^{M}=1$, the channel f is allocated to M-UE m, other$x_{m,f}^{M}=0$. Correspondingly, the allocation variables of R-UE and D2D pair are denoted by $x_{k,f}^{K}$ and $x_{q,f}^{Q}$. We assume that the channel f can be shared by at most one M-UE, one R-UE and one D2D pair simultaneously, which can not be shared by two or more UEs in the same type. And each M-UE is assigned a channel.

$$\sum_{q=1}^{Q} x_{q,f}^{Q} \leq 1, \sum_{k=1}^{K} x_{k,f}^{K} \leq 1, \sum_{m=1}^{M} x_{m,f}^{M} \leq 1, \forall f \in \mathcal{F} \tag{1}$$

$$\sum_{f=1}^{F} x_{q,f}^{Q} \leq 1, \sum_{f=1}^{F} x_{k,f}^{K} \leq 1, \sum_{f=1}^{F} x_{m,f}^{M} = 1, \forall f \in \mathcal{F} \tag{2}$$

Let $p_{q,f}^{Q}$, $p_{k,f}^{K}$, $p_{m,f}^{M}$ represent the optimal transmission power variable of D2D pair q, R-UE k and M-UE m on the channel f, respectively. σ^2 represents Gaussian noise. Then, the signal to-interference-and-noise ratios (SINR) of D2D pair q, R-UE k and M-UE m on channel f are calculated.

$$\gamma_{q,f}^{Q} = \frac{p_{q,f}^{Q} h_{q}^{Q}}{\sigma^2 + p_{k,f}^{K} g_{k,q}^{K} + p_{m,f}^{M} g_{m,q}^{M}}, \forall f \in \mathcal{F}, q \in \mathcal{Q} \tag{3}$$

$$\gamma_{k,f}^{K} = \frac{p_{k,f}^{K} h_{k}^{K}}{\sigma^2 + p_{m,f}^{M} g_{m,k}^{M} + p_{q,f}^{Q} g_{q,k}^{Q}}, \forall f \in \mathcal{F}, k \in \mathcal{K} \tag{4}$$

$$\gamma_{m,f}^{M} = \frac{p_{m,f}^{M} h_{m}^{M}}{\sigma^2 + p_{k,f}^{K} g_{k,m}^{K} + p_{q,f}^{Q} g_{q,m}^{Q}}, \forall f \in \mathcal{F}, m \in \mathcal{M} \tag{5}$$

According to Shannon's theorem, the throughput of D2D pair q, R-UE k and M-UE m on channel f is obtained.

$$R_{q}^{Q} = \sum_{f=1}^{F} \log_2\left(1+\gamma_{q,f}^{Q}\right), R_{k}^{K} = \sum_{f=1}^{F} \log_2\left(1+\gamma_{k,f}^{K}\right), \\ R_{m}^{M} = \sum_{f=1}^{F} \log_2\left(1+\gamma_{m,f}^{M}\right) \tag{6}$$

Our aim to maximize the sum rate of system comprise of the D2D pairs, R-UEs and M-UEs.

$$\mathcal{P}1: \max_{P,X} \left(\sum_{q=1}^{Q} x_{q,f}^{Q} R_{q}^{Q} + \sum_{k=1}^{K} x_{k,f}^{K} R_{k}^{K} + \sum_{m=1}^{M} x_{m,f}^{M} R_{m}^{M} \right) \tag{7}$$

$$s.t. \sum_{q=1}^{Q} x_{q,f}^{Q} \leq 1, \sum_{k=1}^{K} x_{k,f}^{K} \leq 1, \sum_{m=1}^{M} x_{m,f}^{M} \leq 1, \forall f \in \mathcal{F} \tag{8}$$

$$\sum_{f=1}^{F} x_{q,f}^{Q} \leq 1, \sum_{f=1}^{F} x_{k,f}^{K} \leq 1, \sum_{f=1}^{F} x_{m,f}^{M} \leq 1, \forall f \in \mathcal{F} \tag{9}$$

$$0 \leq p_{q,f}^{Q} \leq x_{q,f}^{Q} P_{Q}^{\max}, 0 \leq p_{k,f}^{K} \leq x_{k,f}^{K} P_{K}^{\max}, 0 \leq p_{m,f}^{M} \leq x_{m,f}^{M} P_{M}^{\max} \tag{10}$$

$$\gamma_{q,f}^{Q} \geq \gamma_{\min}^{Q}, \gamma_{k,f}^{K} \geq \gamma_{\min}^{K}, \gamma_{m,f}^{M} \geq \gamma_{\min}^{M} \tag{11}$$

Where the $\gamma_{\min}^{Q}$, $\gamma_{\min}^{K}$ and $\gamma_{\min}^{M}$ are the SINR thresholds for D2D pairs, R-UEs and M-UEs. As constraint (11) show, each type of user on channel f should satisfy their QoS requirement. Constraint (10) forces the transmit power of D2D pair (R-UE, M-UE) on channel f to be 0 in case $x_{q,f}^{Q}=0$ ($x_{k,f}^{K}=0$, $x_{m,f}^{M}$=0) and their power must not exceed the maximum power. Constraint (8-9) ensure that each M-UE is assigned with one sub-channel and each R-UE is assigned with at most one sub-channel as well as each D2D pair. $P_{Q}^{\max}$, $P_{K}^{\max}$ and $P_{M}^{\max}$ are the maximum transmit power on each channel for D2D pair, R-UE and M-UE.

III. Problem Decomposition

A. Power allocation based on Geometric Vertex Search

The optimization problem $\mathcal{P}1$ is a non-convex NP-hard, we decomposed it into power and sub-channel allocation. In this section, we solve the problem of power allocation.$\mathcal{P}2$ is a simplified version of $\mathcal{P}1$ by considering only one D2D pair, one R-UE and one M-UE in one channel.

$$\mathcal{P}2: \max_{p_{q,f}^{Q}, p_{k,f}^{K}, p_{m,f}^{M}} \left(R_{q,f}^{Q} + R_{k,f}^{K} + R_{m,f}^{M} \right) \tag{12}$$

$$0 \leq p_{q,f}^{Q} \leq P_{Q}^{\max}, 0 \leq p_{k,f}^{K} \leq P_{K}^{\max}, 0 \leq p_{m,f}^{M} \leq P_{M}^{\max} \tag{13}$$

$$\gamma_{q,f}^{Q} \geq \gamma_{\min}^{Q}, \gamma_{k,f}^{K} \geq \gamma_{\min}^{K}, \gamma_{m,f}^{M} \geq \gamma_{\min}^{M} \tag{14}$$

We adopt solid geometric approach to find the maximum power. Setting the constraint condition (14) into an equation, then we get the following formula:

$$f_Q \triangleq p_{q,f}^{Q} h_{q}^{Q} - \gamma_{\min}^{Q} \left(\sigma^2 + p_{k,f}^{K} g_{k,q}^{K} + p_{m,f}^{M} g_{m,q}^{M}\right) = 0 \tag{15}$$

$$f_K \triangleq p_{k,f}^{K} h_{k}^{K} - \gamma_{\min}^{K} \left(\sigma^2 + p_{m,f}^{M} g_{m,k}^{M} + p_{q,f}^{Q} g_{q,k}^{Q}\right) = 0 \tag{16}$$

$$f_M \triangleq p_{m,f}^{M} h_{m}^{M} - \gamma_{\min}^{M} \left(\sigma^2 + p_{k,f}^{K} g_{k,m}^{K} + p_{q,f}^{Q} g_{q,m}^{Q}\right) = 0 \tag{17}$$

The above three equations represent three planes in 3-dimensional space while the size and slope of the plane are related to the constraint of power and SINR. For convenience, we set orthogonal axes to be the powers. As shown in Fig.2 the transparent cube with the edge of black solid line represent the maximum individual power constraints. The yellow, blue, gray plane represent the SINR constraint conditions of D2D

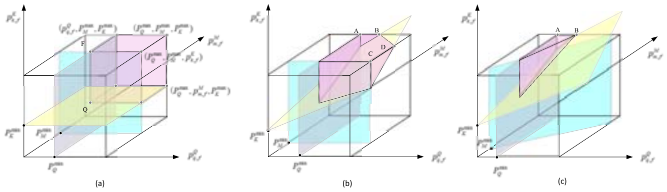

Fig. 2. Illustration of different types of power regions

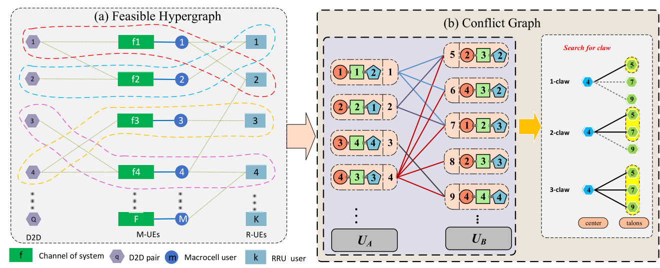

Fig. 3. Illustration of 3D Matching Channel Allocation

pairs M-UEs and R-UEs,respectively. The admissible power region is formed by the intersection of the three planes in 3-dimensional space as show as red multilateral, and is bounded by these yellow, blue, gray three planes and the three faces of the transparent cube. The optimal powers lie within this power region. In order to avoid an computationally expensive exhaustive search, a near optimal solution is proposed to reduce the process of testing and selecting the optimal powers from a finite set.

It is known that at least one of the powers is at its maximum when maximizing sum rate. However, the sum rate expression in (12) is non-convex with respect to arbitrary combinations of varying powers. Consequently, for arbitrary number of transmitters, the optimal powers may not necessarily lie on the vertices of the power region, leading to a possibly infinite set of points to test. Since the objective function on the boundary and SINR constraint is a quasi convex function, their optimal solution has the same power. Then, the optimal power of throughput can be obtained by finding the optimal solutions of SINR, which lies on the corners or vertices of the power region.

B. Channel Allocation based on 3D Matching Problem

Based on the above results of power allocation, the the sum throughput $R_{m,k,q}^{f}$ of M-UE m, R-UE k, D2D q on channel f is obtained. And a three-dimensional throughput matrix $R_{M\times K\times Q}$ is obtained by all possible combinations of D2D pairs, M-UEs and R-UEs. Our goal is to find a subset $T_{M\times K\times Q}\in R_{M\times K\times Q}$ that maximizes throughput. To make it concise, we define binary variable $\xi_{m,k,q}^{f}$ to indicate whether the channel f is reused by M-UE m, R-UE k, D2D q, simultaneously.

$$\xi_{m,k,q}^{f}=\begin{cases}1, x_{q,f}^{Q}=x_{k,f}^{K}=x_{m,f}^{M}=1\\ 0 \qquad\qquad\qquad \text{otherwise}\end{cases} \tag{18}$$

The original problem $\mathcal{P}1$ transformed into a problem $\mathcal{P}3$. It can modeled as a three-dimensional maximum weighted matching problem based on the hypergraph theory.

$$\mathcal{P}3:\max_{\xi_{m,k,q}^{f}}\sum_{\mathrm{m}=1}^{M}\sum_{k=1}^{K}\sum_{q=1}^{Q}\xi_{m,k,q}^{f}\times R_{m,k,q}^{f} \tag{19}$$

$$\begin{aligned}&s.t.\ \sum_{q=1}^{Q}\xi_{m,k,q}^{f}\le 1\ \sum_{k=1}^{K}\xi_{m,k,q}^{f}\le 1\\ &\sum_{m}^{M}\xi_{m,k,q}^{f}\le 1\ \sum_{f=1}^{F}\xi_{m,k,q}^{f}\ge 1,\forall f\in\mathcal{F}\end{aligned} \tag{20}$$

A hypergraph can be expressed as $\mathcal{HG}\left(\mathcal{V},E,\omega\right)$ where $\mathcal{V}$ is the set of vertices and E is the set of hyperedges. A hyperedge $e\in E$ is a nonempty subset of the vertices. A hypergraph $\mathcal{HG}\left(\mathcal{V},E,\omega\right)$is called a κ-partite hypergraph if $\mathcal{V}$ can be partitioned into κ subsets $\mathcal{V}_1,\mathcal{V}_2,\ldots,\mathcal{V}_\kappa$ such that every hyperedge contains exactly one vertex from every vertex subset. The hypergraph matching problem on a κ-partite graph is also called the κ-dimensional matching problem. As shown in the Fig.3(a), our extended graph containing the sets of M-UEs, R-UEs and D2D pairs is a three-partite hypergraph, and the hyperedge $e_{m,k,q}$ represents the combination of the m-th M-UE, k-th R-UE and q-th D2D, which has a weight $\omega\left(e_{m,k,q}\right)=R_{m,k,q}^{f}$. if two hyperedges contain at least one common vertex, they are adjacent (neighbors). The neighbours of $e_{1,2,2}$, denoted as $N\left(e_{1,2,2}\right)=\left\{(2,3,2),(4,3,2),(1,2,3)\right\}$. The hypergraph matching aims at finding a independent subset $A\subseteq E$ whose hyperedges are mutually disjoint (i.e.different hyperedges in A have no common vertices) with the largest sum weights of hyperedges in E.

The conflict graph $G\left(\mathcal{V}',E',\omega\right)$ of hypergraph $\mathcal{HG}\left(\mathcal{V},E,\omega\right)$ is the graph where every hyperedge e' is denoted by a vertex and the weight of each vertex corresponds to the weight of the related hyperedge. As shown in the Fig.3(b), $\mathcal{V}_1{}'$ is used to denote the hyperedge $e_{1,2,2}$. If the hyperedges in hypergraph is adjacent, then the corresponding vertexs who denoted them are adjacent. After connecting all the adjacent vertices, we can obtain the conflict graph of the original hypergraph. For convenience, we divide all the vertices $\mathcal{V}'$ into two parts, $\mathcal{A}$ and $\mathcal{B}$. It assumes that the set $\mathcal{A}$ is the initial independent set, and the set $\mathcal{B}$ contains all the adjacent vertices of $\mathcal{A}$.

A τ-claw C_τ is defined as a subgraph of $G\left(\mathcal{V}',E',\omega\right)$. C_τ consists of a set T_{C_τ} including τ independent nodes, called talons, and one center node that is connected to all the talons. For a given center node e, a τ-claw can be accomplished by finding τ mutually independent neighbors of e. So for a κ-partite hypergraph, it is impossible to find $\kappa+1$ mutually no-adjacent neighbors for a hyperedge. In other words, any vertex in the conflict graph $G\left(\mathcal{V}',E',\omega\right)$ cannot find a $\kappa+1$-claw and $G\left(\mathcal{V}',E',\omega\right)$ is $\kappa+1$-claw free. For example, κ=3, u_4 can find 5 adjacent vertices u_5,u_6,u_7,u_8,u_9 in Fig. 3(b), but u_5 and u_6 occupy the same elements and u_7 and u_8 occupy the same elements, u_4 can find the 3-claw further.

With the above knowledge, we first use greedy algorithm to find independent hyperedge set $\mathcal{A}$ with the maximum weight, then for a given center vertex e_n find τ-claw $e_1,e_2,...e_l$ in set

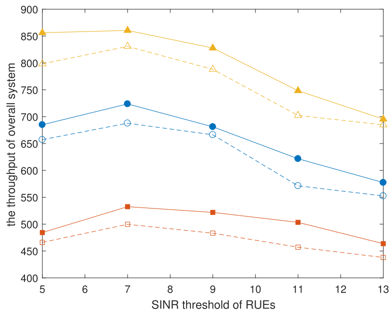

Fig. 4. Total throught versus RUEs SINR

$\mathcal{B}$ (contains all the adjacent vertices of $\mathcal{A}$). If adding τ-claw in set $\mathcal{A}$ can improve the overall performance, we add them to get a new matching result $\mathcal{A}_{new}$ and remove all the hyperedges intersecting with them in $\mathcal{A}$.

IV. Numerical Results

In this section, we present the simulation results and their corresponding analysis. Specific simulation parameters and values are listed in TABLE I. On one hand, we insight into the throughput behavior of the proposed algorithm with different parameter settings. On the other band, we compared the performance of our proposed algorithm with the iterative Hungarian matching (IHM) algorithm in [8] and MAP algorithm in [9] who transform the three-dimensional matching problem into the two-dimensional matching problem. In the following simulation results, GHM is used to represent our proposed algorithm.

TABLE I
PARAMETERS OF SYSTEM

Parameter	Value
Macro-cell radius	1km
RRU radius	100m,200m
D2D distance,r	25m
Number of D2D pairs, Q	10,12,$\cdots$,18
Number of of R-UEs, K	18
Number of M-UEs, M	20
$P_Q^{\max}$, $P_K^{\max}$, $P_M^{\max}$	23dBm,20dBm,23dBm
Noise spectral density	-117 dBm
Path loss model for M-UE links	127+30log(d[km])
Path loss model for R-UE links	128.1+37.6log(d[km])
Path loss model for D2D links	148+40log(d[km])
$\gamma_{\min}^{Q}$, $\gamma_{\min}^{M}$,$\gamma_{\min}^{K}$,	3dB,7dB; 3dB;5...13dB

Fig.5 illustrate effects of different algorithms under different QoS requirements of D2D pairs and R-UEs. It is shown that increasing the SINR threshold constraint leads to decreasing of total throughput. To meet increase of SINR requirement, all types of users need to increase the transmission power, which cause the access probability of under-laying users reduce due to the limitation of maximum power. Moreover, the performance of our proposed algorithms is better than the IHM and MAP algorithm about 35% and 60%. The reason is that the proposed GHM have more opportunities for D2D and R-UEs to access the network than IHM and MAP.

V. Conclusion

This paper investigated the joint power control and channel allocation problem for D2D and RRUs uplink communications under-laying H-CRAN. Since the original problem is NP hard, then the original problem decomposed into two subproblems (e.g. power allocation and channel allocation) for solution. Firstly, we proposed Three-dimensional geometric programming expressions of the optimal power under given sub-channel allocation profile and the solution obtained by the Geometric Vertex Search approach. Then, we proposed a three-dimensional bipartite graph to formulate this optimization problem with the optimal power profile. The optimization objective obtained through an 3-D Hypergraph matching algorithm. Finally, both the theoretical analysis and numerical results demonstrated the efficiency of the proposed scheme.

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