



A Resource Allocation Scheme Based on Predatory Search Algorithm for Ultra-dense D2D Communications

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Abstract. In this paper, resource allocation problem for ultra-dense D2D communications is studied. In ultra-dense scenarios, the number of D2D user equipments (DUEs) is far bigger than the number of cellular user equipments (CUEs). The dense user equipments (UEs) increase the complexity of resource allocation problem. Firstly, the system model of ultra-dense D2D communications is described. Then the resource allocation problem of ultra-dense D2D communications is formulated. Next a fast resource allocation algorithm based on predatory search algorithm is proposed and analyzed. Finally, the analysis and simulation results validate that the performance of proposed scheme is very efficient and has a low algorithmic complexity. This scheme can be applied into the ultra-dense D2D communication networks.

Keywords: Device to device · Resource allocation · Predatory search algorithm

1 Introduction

Now, satellite communications and terrestrial communications playing more and more significant role in the future information transmission [1–3]. To meet the demand of bandwidth efficiency improvement and more data services requirement, device-to-device (D2D) communication is presented. D2D communication system allows the terminals in proximity to directly communicate each other via the base station (BS). It will effectively improve spectrum efficiency and reduce terminal transmission power. It has become a key technique for 5G network and Internet of Things (IoT) [4–6]. Meanwhile, the concept of ultra-dense networks emerges to accommodate more user equipments (UEs).

In ultra-dense D2D communications, the resource allocation problem gets more challenging due to the randomness of the positions of the massive UEs. Meanwhile, the positions of the UEs will change frequently because of their movements. This makes the resource allocation problem more difficult to solve. In this case, it is very hard to obtain a better resource allocation scheme while guaranteeing the QoS of all UEs using

the traditional techniques. So we need to find a fast and efficient algorithm to solve the problem. Compared with other feasible algorithms, the predatory search algorithm has stronger global searching ability and faster convergence speed. Base on the idea of the predatory search algorithm, a resource allocation scheme based on predatory search algorithm for ultra-dense D2D communications is proposed in this paper.

It is generally known that resource allocation is an important problem in D2D communication. So there are many researchers who focus on this field according to the different application scenarios [6–12]. But in the work above, the conventional optimization methods are used to solve the resource allocation issues. Meanwhile, some researchers implement intelligent optimization methods to allocate the resource. To optimally get the number of frequency channels required in the system, Lee et al. proposed Genetic Algorithm (GA) with frequency hopping technique [13]. A GA scheme combining resource allocation and user matching algorithm is presented to minimize the intra-cell interference and maximize the throughput in this system [14].

In general speaking, the above algorithms are not suitable for the ultra-dense D2D communications where the number of DUE pairs is far bigger than that of CUE. In ultra-dense D2D communications, multiple DUE pairs share one sub-channel with one CUE. Due to the randomness of the positions of the massive UEs, it is very hard to obtain a fast and efficient resource allocation scheme while guaranteeing the QoS of all UEs. So we need to find an efficient algorithm to solve the problem. Compared with other intelligent algorithms, the predatory search algorithm has stronger global searching ability and faster convergence speed. The conventional predatory search algorithm was first presented by Linhares in 1998 [15]. This algorithm is a spatial search strategy simulating predation behavior of animals and it is used in solving combinatorial optimization problems. For the predators in the search process, the most well-known search strategy is as follows. When there is no prey and traces of prey, predators search for prey at a rapid speed in a certain direction in the whole predator space; once found prey or prey signs, they immediately change their movement, slow down, tour continually, search for a concentrated area in the vicinity of the discovery of prey or signs of prey, and keep on approaching the prey. After searching for a period of time without finding a prey, the predator will give up this concentrated area and continue to find the prey in the whole predator space. This is the famous Area-Restricted search strategy, and it is described in different species such as birds, lizards, many predators and other acts. This predation behavior appears to be adaptive and efficient for different environments and prey distribution. For example, if the search space is aggregated or randomly distributed, the Area-Restricted search can maximize the probability of successful search by performing a continuous search near the prey. As shown in Fig. 1, the search strategy for this predation of an animal can be summarized as the following two searches.

Search 1 (regular search): Conduct a full search throughout the search space until you find a prey or prey sign and go to search 2 for region search.

Search 2 (region search): We do concentrated search in the vicinity of the discovery of prey or signs of prey, and search for a lot of times and do not find prey, then give up local search, go to search 1 for regular search.

Inspired by this, the resource allocation scheme based on predatory search algorithm for ultra-dense D2D communications is proposed in this paper. The main contributions of our work are as follows:

1. We propose a fast and efficient resource allocation scheme based on predatory search algorithm for ultra-dense D2D communications.
2. We evaluate the system performance of ultra-dense D2D communications.

This paper is organized as follows. In Sect. 2, we establish and explain our system model in detail. In Sect. 3, problem formulation is presented. Then we propose a fast resource allocation scheme based on predatory search algorithm for ultra-dense D2D communications and evaluate the system performance of ultra-dense D2D communications in Sect. 4. Simulation results are presented in Sect. 5, and the conclusion is drawn out in Sect. 6.

2 System Model

In frequency division duplex cellular network, one sub-channel is only allocated to one CUE. We assume a single cellular network with K sub-channels, where N CUEs and M DUE pairs coexist, as shown in Fig. 1. We denote the transmitter and receiver of one DUE pair as DTUE and DRUE, respectively. In our cellular network, CUEs and DTUEs are evenly distributed in the cell with the radius of R . Meanwhile, DRUEs are evenly located in the circles with the radius of L , and the centers of the circle are the DTUEs. One sub-channel is only occupied by one CUE, but it can be shared by multiple DUE pairs. To make full use of the advantages of D2D technology, we solve the intricate resource allocation problem in the case that M is much larger than N . Meanwhile, uplink resources are easy to reuse for D2D communications compared with downlink resources. Therefore, we mainly consider the case of uplink resources sharing.

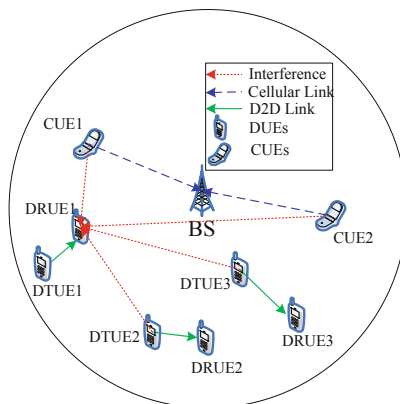


Fig. 1. System model of D2D communications.

3 Problem Formulation

As mentioned above, we assume that K sub-channels are provided by the communication network, where N CUEs and M DUE pairs coexist. Let $S = (K, N, M)$. The sets of CUEs and DUE pairs are denoted as $\mathbb{C} = (1, 2, \dots, N)$ and $\mathbb{D} = (1, 2, \dots, M)$. Meanwhile, one CUE only occupies one sub-channel, but multiple DUE pairs can share one sub-channel. Then we have $N \leq K$. Now, we can consider one sub-channel as one package. So there are K packages. What we need to do is to allocate all DUE pairs to K packages. The i th package is denoted as $\mathfrak{R}_i, i = (1, 2, \dots, K)$. The Fig. 2 shows an example of $S = (4, 3, 10)$. The goal that D2D technology is introduced into cellular networks is to improve bandwidth efficiency and network throughput. So throughput is selected as the optimizing criterion in this paper.

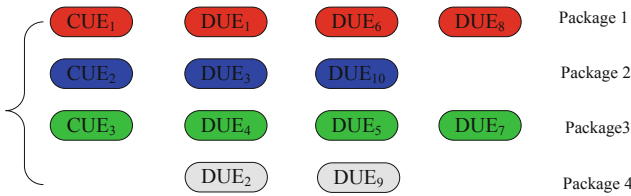


Fig. 2. An example of channel resource allocation.

The objective function is the performance indicator which needs to be optimized. In general, the network capacity is selected as the optimization objective. Obviously, the total capacity consists of two parts: CUEs and DUE pairs. For CUE i , the capacity is written as

$$C_c = B \log_2(1 + \gamma_i) = B \log_2 \left(1 + \frac{p_i z_i}{\sum_{\{D_j \in \mathfrak{R}_m | C_i \in \mathfrak{R}_m\}} p_T s_j^2 + N_0} \right) \tag{1}$$

Here, B is the bandwidth of one sub-channel. γ_i is the SINR value of CUE i , p_i is the transmitted power of CUE i , p_T is the transmitted power of the DTUE k , s_j is the channel gain between DTUE j and the BS, z_i is the channel gain between BS and CUE i , N_0 is noise power, α is path loss factor.

Similarly, for DUE pairs, we consider that DUE pairs j is belong to package m , i.e. $j \in \mathfrak{R}_m$. Then, we have

$$\begin{aligned}
 Cd_j &= B \log_2(1 + \beta_j) \\
 &= B \log_2 \left(1 + \frac{PTx_j}{\sum_{\{C_i \in \mathfrak{R}_m | D_j \in \mathfrak{R}_m\}} p_i h_{i,j} + \sum_{\substack{\{D_k \in \mathfrak{R}_m | D_j \in \mathfrak{R}_m\} \\ k \neq j}} PTg_{k,j} + N_0} \right) \quad (2)
 \end{aligned}$$

Here, β_j is the SINR value of DRUE j , x_j is the channel gain between DRUE j and DTUE j , $h_{i,j}$ is the channel gain between CUE m and DRUE j , $g_{k,j}$ represents the channel gain between DRUE j and DTUE k .

Therefore, the total capacity can be calculated as

$$C = \sum_{i=1}^N Cc_i + \sum_{j=1}^M Cd_j \quad (3)$$

Here, γ_i is maintained constant because power control scheme is applied into the CUEs. So the capacities of CUEs are considered as constant and denoted as C_c . Then the capacity is written as

$$C = \sum_{j=1}^N Cc_i + \sum_{j=1}^M Cd_j = N * C_c + B \sum_{j=1}^M \log_2(1 + \beta_j) \quad (4)$$

Next, we can get the optimization objective as:

$$\mathbb{Q}_1 : \max N * C_c + B \sum_{j=1}^M \log_2(1 + \beta_j) \quad (5a)$$

$$\text{subject to : } \gamma_i = \Gamma \quad \forall i \in (1 \cdots N) \quad (5b)$$

$$\beta_j \geq \Gamma \quad \forall j \in (1 \cdots M) \quad (5c)$$

$$0 < p_i \leq p_{\max} \quad \forall i \in (1 \cdots N) \quad (5d)$$

4 Resource Allocation Scheme Based on Predatory Search Algorithm

In this section, a fast resource allocation scheme based on predatory search algorithm for ultra-dense D2D communications is proposed. In D2D communications, CUEs have a higher priority over DUE pairs. So we must guarantee the QoS of CUEs firstly. Then DUE pairs will try best to access network with sharing resources whilst their QoSS

are guaranteed. For our scenario, some definitions and parameters are described as follows.

1. Coding

For CUEs, CUE i is allocated to i th sub-channel by default. We define an allocation scheme as $S = (s_1, \dots, s_i, \dots, s_M)$. The dimension of S corresponds to the number of DUE pairs, every bit represents one DUE pair. The value of s_i means that i th DUE pair use the index of package.

2. The selection of initial point

Generally speaking, we can select the initial point randomly.

3. Definition of neighbourhood

The neighbourhood is related to the scope of search and result precision. So it is crucial to the algorithm. In many research papers, the neighborhood node can be obtained by the reversion or bit mutation. However, the objective functions of neighborhood nodes fluctuate greatly. So it is not suitable to our scenario. As mentioned before, an allocation scheme corresponds to a code in base S . Let us take $S = (4, 3, 10)$ for example. We consider that a point A is $(1, 4, 3, 2, 3, 4, 2, 1, 3, 1)$, then the neighborhood of point A is defined as the set including the points which only have a different bit compared with point A and the value of the different bit is smaller or bigger than A by one. For example, the neighborhood of point A includes $(1, 4, 3, 2, 3, 4, 2, 1, 3, 2)$, $(1, 4, 3, 2, 3, 4, 2, 1, 3, 4)$, $(1, 4, 3, 2, 3, 4, 2, 1, 2, 1)$, $(1, 4, 3, 2, 3, 4, 2, 1, 4, 1)$, and so on.

4. Description of parameters

- (1) *NumLevel*: the maximum limit level is $NumLevel + 1$.
- (2) *Cthreshold*: the pointer threshold for increasing the limit level.
- (3) *Lthreshold*: When *Level* increases to *Lthreshold*, it indicates that the algorithm has performed multiple valid searches in the restricted area without finding an improved solution. Then the algorithm abandons the region-limited search mode.
- (4) *LhighThreshold*: It indicates a high fitness value for the search mode. It means that the algorithm will stop if the algorithm still does not find a new improved solution while completing the search of *Lthreshold* limit levels in the normal search mode.

Here the maximum limit level number $NumLevel + 1$ is equal to 6, the pointer threshold for increasing the limit level *Cthreshold* is equal to 1, the limit level of the area limit search mode *Lthreshold* is equal to 1, the high fitness value for the search mode *LhighThreshold* is equal to 4.

Based on the above basis, a predatory search algorithm is proposed as follows:

- (1) Initialize system parameters: the number of all sub-channels, SINR threshold, the transmitting power of the D2D, the numbers of CUE and DUE pairs, the positions of UEs, *NumLevel*, *Cthreshold*, *Lthreshold* and *LhighThreshold*.

- (2) The resource allocation scheme is encoded as $S = (s_1, \dots, s_i, \dots, s_M)$. s_i is the number of sub-channels which is allocated to DUE j , and its value ranges from 1 to N .
- (3) Randomly select an initial point $a, a \in \Omega$, where Ω is the set of all possible values. Let the optimal solution $b = a$, the counter $k = 0$, the limit level of search $l = 0$. Then initialize the limit set $res[NumLevel]$.
- (4) If $l < NumLevel$, we take 5% points of neighborhood of a to construct $N^l(s)$, and obtain the point $Mresult$ which is corresponded by its maximum function value (the function value in the algorithm is the channel capacity), then turn to step 5; Otherwise, the resources are allocated according to the scheme corresponding to the optimal solution b .
- (5) If the function value corresponding to $Mresult$ falls between $res[l]$ and the function values corresponding to b , that is, $Z(Mresult) \in (res[l], Z(b))$, let $a = Mresult$, then go to step 7; otherwise turn to step 6.
- (6) If $Z(a) > Z(b)$, let $b = a, m = 0, k = 0$, recalculate the limit set and turn to step 4; Otherwise, go to next step.
- (7) Let $k = k + 1$. If $k > Cthreshold$, let $l = l + 1$ and $k = 0$, then go to next step; Otherwise, turn to step 4.
- (8) If $l = Cthreshold$, let $l = LhighThreshold$, and go to step 4; Otherwise, go directly to step 4.

5 Simulation and Discussion

In our simulations, we assume that three CUEs and ten DTUEs are distributed in the cell. Simulation parameters are described in Table 1.

Table 1. Parameter settings in our simulation

Parameter	Value and unit	Parameter	Value and unit
Cell radius (R)	600 m	L	20 m
Path loss factor (α)	4	The number of DUE pairs (M)	10
The number of CUEs (N)	3	The maximum transmitted power of CUE	2 W
SINR threshold (β)	4.6 dB	The transmitted power of DTUE P_T	0.001 W
N_0	-105 dBm	$Cthreshold$	1
$NumLevel$	5	$LhighThreshold$	4
$Lthreshold$	1		

The channel capacity of the D2D communication using the predator search algorithm and other algorithms is compared in Fig. 3. It can be seen from the figure that although the method of resource allocation based on random algorithm is simple, the result is very poor. The exhaustive algorithm can find out the optimal resource

allocation method, but the exhaustive method is to traverse all feasible allocation schemes, so the computation is large and time consuming. And the predator-based search algorithm is computationally small and not time-consuming, and it can converge quickly to the optimal result of the exhaustive algorithm.

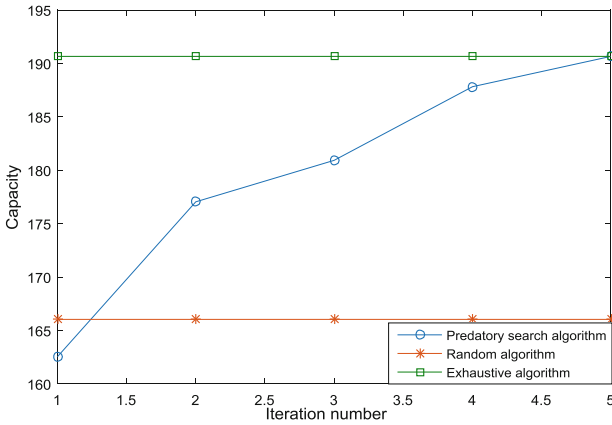


Fig. 3. The capacity of D2D communications.

At the same time, Fig. 4 demonstrates the average transmission power of CUEs based on these three algorithms. The exhaustive algorithm needs maximal transmission power compared with the proposed predatory search algorithm and random algorithm. The reason is that the exhaustive algorithm can get best resource allocation result which gets the maximum system capacity and lead to consume much energy.

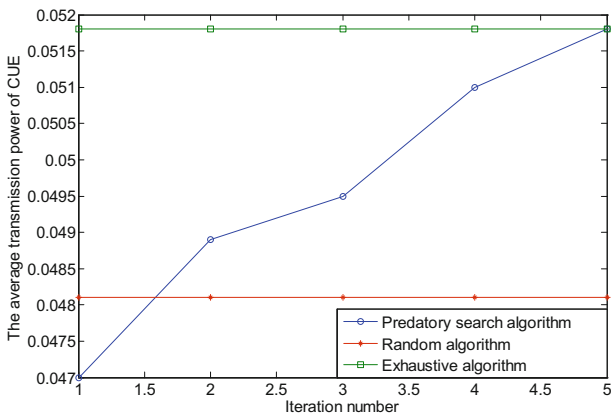


Fig. 4. The average transmission power of CUEs.

6 Conclusions

In this paper, the ultra-dense D2D communication system model where M DUE pairs and N CUEs coexist is described. Then resource allocation problem for ultra-dense D2D communications is formulated and analyzed. Next, a fast and efficient resource allocation scheme based on predatory search algorithm for ultra-dense D2D communications is presented. Finally, the analysis and simulation results validate that the performance of proposed scheme. This scheme can be applied into the ultra-dense D2D communication networks.

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