Joint Mode Selection and Resource Allocation Using Evolutionary Algorithm for Device-to-Device Communication Underlaying Cellular Networks

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***Abstract*—**Device-to-Device (D2D) has been a potential technology to improve the sum-rate of cellular networks, especially in local communication. By reusing the resource of cellular user equipment (UE), D2D can enhance the spectrum efficiency, but at the cost of introducing extra co-channel interference. In this paper, we adopt a resource reusing mechanism in which multiple D2D pairs can share multiple resource block for the sake of higher sum-rate, and then propose a joint mode selection and resource allocation method based on evolutionary algorithm (EA-MSRA-MDMR) to reduce the extra interference. Simulations show that the proposed method can achieve a higher system sum rate and fairness.

***Index Terms*—**Device-to-Device communication, mode selection, resource allocation, evolutionary algorithm

I. INTRODUCTION

Device-to-device communication (D2D) is becoming a key technology to solve the bottleneck problem of sum rate in future wireless communication network, especially in local communication. D2D mode enables direct communication between devices nearby composing a pair with low power instead via the base station (BS), which reduces the overload of a BS and saves the energy of devices[1]. Unlike other short-range communication technologies such as blue-teeth and wifi, D2D utilizes the licensed frequency band, enabling the BS or the eNodeB to schedule wireless resource to guarantee the quality of communication.

Generally, in D2D underlaying network, there are three modes for D2D pairs to share the resource of cellular network. The first mode remains some dedicated frequency bands for D2D[2]. In the second mode[3], D2D share the uplink or downlink frequency bands with cellular UEs. And in the third mode, D2D regard the BS as a relay to implement communication. The first and the third modes are orthogonal sharing modes and cause no extra interference to the original cellular network, but D2D pairs occupy the resource of cellular UEs so it improves the spectrum efficiency limited.

In order to achieve multiuser gains and suppress extra interference, and enhance the system sum-rate finally, non-orthogonal sharing mode are discussed by a lot of literatures. Reference [4] presented a distance-based resource allocation scheme to mitigate cellular to D2D interference. A resource allocation scheme to optimize sum-throughput of D2D links with constraints of QoS of cellular users where each sub-carrier is allocated to one D2D user was discussed by reference [5], in which the nonconvex problem was solved by Lagrangian duality theory. Reference [6] utilized graph-coloring algorithms based on the collected information represented by the enriched node contention graph to provide an interference-free secondary allocation scheme.

But in some situation where the co-channel interference between D2D pairs and cellular UEs are serious in the whole available frequency band, non-orthogonal sharing mode is necessary. So, in order to achieve multiuser gains and suppress extra interference, and enhance the system sum-rate finally, mode selection and resource allocation of D2D are being researched and some solvable schemes have been proposed. Reference [7] presented the optimum resource allocation and power control between the cellular and D2D connections that share the same resources for different resource sharing modes, which is under minimum and maximum spectral efficiency restrictions and maximum transmit power or energy limitation. A joint resource allocation and resource reuse scheme is investigated in reference [8], in which resource allocation to cellular users is employed on proportional fair algorithm and resource reuse to D2D users is employed on a greedy heuristic algorithm. Deng *et al*[9]. proposed a joint scheme combining mode selection, subchannel allocation and power reallocation for D2D underlaying OFDMA networks, but it only discussed the orthogonal sharing modes. Su *et al*.[10] proposed another mode selection and resource allocation scheme (MSRA), in which D2D pair is allowed to reused resource blocks of different cellular UEs. It maximizes the system throughput under a minimum rate requirement

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guarantee for D2D communication underlaying cellular networks.

To the best of our knowledge, the prior studies restrict that one resource block is reused by not more than one D2D pair for avoiding co-channel interference among different D2D pairs. But if distance among different D2D pairs is large enough, it is feasible that D2D pairs share the same subchannels with weak co-channel interference. In order to further improve the sum-rate, in this paper we adopt a resource reusing mechanism allowing D2D pairs to share resource more flexibly, and proposed a joint mode selection and resource allocation method based on evolutionary algorithm (EA-MSRA-MDMR) to reduce the extra interference and achieve good system performance.

The rest of this article is organized as follows. In Section II, the system model of D2D underlaying OFDMA network and problem formulation will be described in detail. In section III, we propose a joint mode selection and resource allocation method based on evolutionary algorithm. Simulation results are shown in Section IV. The conclusion follows in section V.

In this paper, normal letter denotes scalar quantity; bold uppercase letter and bold lowercase letter signify aggregate and vector respectively; $|\cdot|$ indicates the number of element in the aggregate; $[\cdot]$ and $\lfloor\cdot\rfloor$ stand for rounding and rounding down separately.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. *System Model*

A D2D underlaying cellular network with OFDMA is considered in the following section. In the system, the BS configured with single antenna locates in the center of the cell, and cellular UEs and UEs of D2D pairs with single antenna distribute randomly in the cell coverage. $\boldsymbol{S}_c$ denotes the set of cellular UEs and $\boldsymbol{S}_d$ stands for the set of D2D pairs. So the set of active UEs in the network could be expressed as $\boldsymbol{S} = \boldsymbol{S}_c \cup \boldsymbol{S}_d$. Especially, we ultilize $\boldsymbol{S}_{bs} = \{0\}$ as the symbol of the BS, and treat it as a special UE in the following model.

Time-Division Duplexing (TDD) is adopted in the system, and without loss of generality, every frame is divided into two subframes as shown in Fig1, which illustrates that uplink transmission occupies the first subframe, while downlink transmission employs the last one. Here we set a parameter γ ranging from 0 to 1 to indicate the proportion of the uplink subframe in a frame, while $(1-\gamma)$ represents that of the downlink subframe. But D2D pairs don't exchange the roles of transmitting devices and receiving devices during one frame. Furthermore, each OFDMA frame consists of a set of subchannels denoted by $\boldsymbol{K}$ in the frequency domain, and every subchannel fades independently. The symbol B stands for the bandwidth of a subchannel. Resource block is the unity of resource allocation defined as one subchannel in frequency domain and duration of one frame in time domain. We assume that channel state keeps invariant during a frame time and the BS can obtain perfect channel state information to allocate resource blocks.

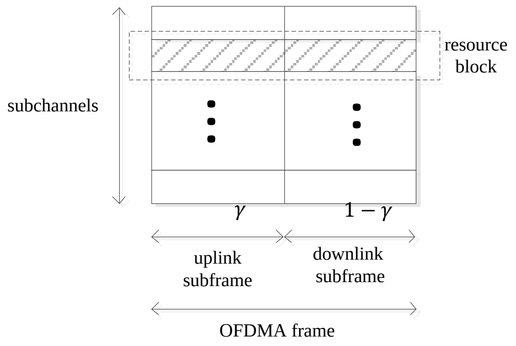
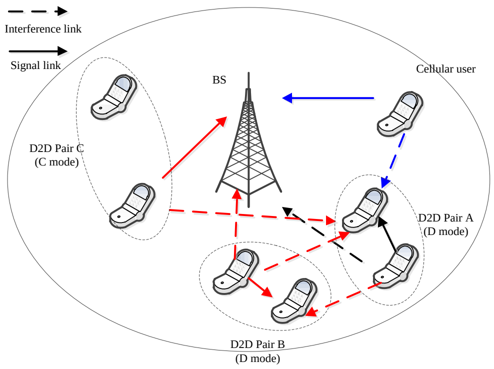
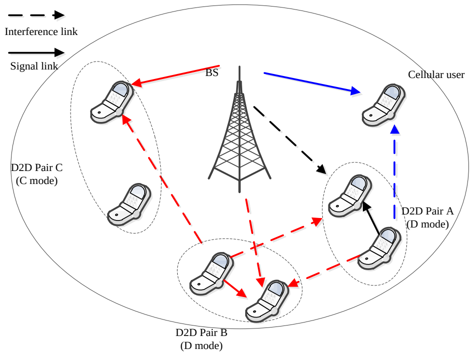


Figure 1. Frame structure



(a) Uplink model and interference



(b) Downlink model and interference

Figure 2. System model. The blue and red arrows indicate different subchannels, and black arrows represent the combination of these two groups of subchannels

D2D pairs in the network have an alternative between two types of mode: the cellular mode (C mode) as the third mode described in Section I, where devices communicate via the BS, and the direct communication mode (D mode) including the first two modes described in Section I. The communication mode of cellular UE is also defined as C mode. In order to avoid some interference, it is inadmissible to assign one resource block to more than one UE in C mode, and each D2D pair can not choose more than one mode in any subchannel. Furthermore, each resource block is allowed to be reused by multiple D2D pairs, and any D2D pair can reuse multiple resource blocks for the sake of higher sum-rate, which adds some extra interference. Fig 2. illustrates the system model and interference in both uplink and downlink.

We use a binary symbol $x_{i,k}^{q}$ to indicate whether UE i employs the subchannel k with mode q or not, where $q \in \{0,1\}$, and 0 represents D mode, while 1 represents BSC mode. We define $h_{ij,k}$ as the channel gain of subchannel k from cellular UE i or transmitting device of D2D pair i to cellular UE j or receiving device of D2D pair j, where $i \in \boldsymbol{S}, j \in \boldsymbol{S}, k \in \boldsymbol{K}$. Particularly, if $i = 0$ (or $j = 0$), it represents the BS, and $j = i$ is allowed only when $i \in \boldsymbol{S}_d$, and BS. $P_{i,k}$ denotes transmitting power of UE i or transmitting device of D2D pair in subchannel k, where $i \in \boldsymbol{S}$, $k \in \boldsymbol{K}$. Similarly, $P_{0,k}$ and $P_{n,k}$ indicates BS power and noise power in subchannel k respectively. Furthermore, we set the maximum transmitting power value of the BS, cellular UEs, and transmitting device of D2D pairs as P_{bs}, P_c and P_d, respectively.

B. Problem Formulation

Our target is to maximize the sum rate and guarantee the fairness of the system. The sum rate can be expressed as the sum of every UE's available rate. For the cellular UEs and D2D pairs in C mode, available rate of uplink subframe and downlink subframe in subchannel k can be calculated by Eq. (1) and Eq. (2) separately:

$$R_{i,k}^{UL(C)} = B\log\left(1 + \frac{P_{i,k}h_{i0,k}x_{i,k}^{1}}{P_{n,k}+\sum_{j\in S_d} P_{j,k}h_{j0,k}x_{j,k}^{0}}\right), \quad i \in \boldsymbol{S}, k \in \boldsymbol{K} \tag{1}$$

$$R_{i,k}^{DL(C)} = \mathrm{Blog}\left(1 + \frac{P_{0,k}h_{0i,k}x_{i,k}^{1}}{P_{n,k}+\sum_{j\in S_d} P_{j,k}h_{ji,k}x_{j,k}^{0}}\right), \quad i \in \boldsymbol{S}, k \in \boldsymbol{K} \tag{2}$$

As we adopt TDD transmission pattern in the system, the D2D pair with C mode communicates in half-duplex pattern, which means that the transmitter transmits signals during the uplink subframe and the receiver receives signals in downlink subframe via the BS. According to the max-flow min-cut theorem[11], the available rate of D2D pairs in C mode in subchannel k is based on the smaller value of uplink rate and downlink rate, which can be expressed by Eq. (3).

$$R_{i,k}^{(C)} = \min\left(\gamma R_{i,k}^{UL(C)}, (1-\gamma)R_{i,k}^{DL(C)}\right), \quad i \in \boldsymbol{S}_d, k \in \boldsymbol{K} \tag{3}$$

The available rate of D2D pairs with D mode in subchannel k during uplink half-frame and downlink half-frame can be calculated by Eq. (4) and (5) respectively:

$$R_{i,k}^{UL(D)} = B\log\left(1 + \frac{P_{i,k}h_{ii,k}x_{i,k}^{0}}{P_{n,k} + \sum_{q\in\{0,1\}}\sum_{j\in\boldsymbol{S}} P_{j,k}h_{ji,k}x_{j,k}^{q}}\right), \quad i \in \boldsymbol{S}_d, k \in \boldsymbol{K} \tag{4}$$

$$R_{i,k}^{DL(D)} = B\log\left(1 + \frac{P_{i,k}h_{ii,k}x_{i,k}^{0}}{P_{n,k} + \sum_{q\in\{0,1\}}\sum_{j\in\boldsymbol{S}_d\cup\boldsymbol{S}_{bs}} P_{j,k}h_{ji,k}x_{j,k}^{q}}\right), \quad i \in \boldsymbol{S}_d, k \in \boldsymbol{K} \tag{5}$$

So the available rate of UEs can be expressed as:

$$R_{i,k}^{UL} = \begin{cases} x_{i,k}^{1}R_{i,k}^{(C)} + x_{i,k}^{0}R_{i,k}^{UL(D)}, i \in \boldsymbol{S}_d, k \in \boldsymbol{K} \\ R_{i,k}^{UL(C)}, i \in \boldsymbol{S}_c, k \in \boldsymbol{K} \end{cases} \tag{6}$$

$$R_{i,k}^{DL} = \begin{cases} x_{i,k}^{1}R_{i,k}^{(C)} + x_{i,k}^{0}R_{i,k}^{UL(D)}, i \in \boldsymbol{S}_d, k \in \boldsymbol{K} \\ R_{i,k}^{DL(C)}, i \in \boldsymbol{S}_c, k \in \boldsymbol{K} \end{cases} \tag{7}$$

Therefore, the rate of UE in one frame can be expressed as the average of two half-frames.

$$R_{i,k} = \gamma R_{i,k}^{UL} + (1-\gamma)R_{i,k}^{DL} \tag{8}$$

Then we consider the fairness of the system, which can be measured by Eq. (9)

$$F_{fairness} = \frac{\sum_{i\in S}\left(\sum_{k\in K} R_{i,k} - \alpha_i \frac{\sum_{j\in S}\sum_{k\in K} R_{j,k}}{\sum_{j\in S}\alpha_j}\right)^2}{|\boldsymbol{S}|} \tag{9}$$

where serial $\{\alpha_1, \alpha_2, \ldots, \alpha_i, \ldots\}$ represents the proportion of the expected rate of all active UEs. Fairness signifies the deviation level between the available rate and the expected rate, so a smaller value of $\mathrm{F_{fairness}}$ indicates better fairness.

Based on the above analysis, our objective function and constraint can be expressed as Eq. (10) and (C1)~(C6)

$$\max\left(\sum_{i\in S}\sum_{k\in K} R_{i,k}, -F_{airness}\right) \tag{10}$$

$$\sum_{q\in\{0,1\}}\sum_{k\in\boldsymbol{K}} P_{i,k}x_{i,k}^{q} \le P_d, \forall\, i \in \boldsymbol{S}_d \tag{C1}$$

$$\sum_{k\in\boldsymbol{K}} P_{i,k}x_{i,k}^{1} \le P_c, \forall i \in \boldsymbol{S}_c \tag{C2}$$

$$\sum_{k\in\boldsymbol{K}} P_{0,k}\sum_{i\in\boldsymbol{S}} x_{i,k}^{1} \le P_{bs}, \forall\, i \in \boldsymbol{S}_c \tag{C3}$$

$$\sum_{i\in\boldsymbol{S}} x_{i,k}^{1} \le 1, \forall k \in \boldsymbol{K} \tag{C4}$$

$$\sum_{q\in\{0,1\}} x_{i,k}^{q} \le 1, \forall i \in \boldsymbol{S}, \forall k \in \boldsymbol{K} \tag{C5}$$

$$x_{i,k}^{q} = \{0,1\}, \forall q\ \in \{0,1\}, \forall i \in \boldsymbol{S}, \forall k \in \boldsymbol{K} \tag{C6}$$

(10) is the objective function to maximize the sum rate and meanwhile guarantee the fairness. Constraint (C1)~(C3) rules the power restraint. (C4) signifies that every resource block cannot be assigned to more than one UE with C mode. (C5) requires that in every resource block, any UE employs with at most one mode. In (C6) $x_{i,k}^{q} = 1$ indicates that UE i obtains the permission to employs the subchannel k with mode q, and vice versa.

Including subchannel assignment, mode selection, and power allocation, the joint optimization problem has a big challenge to allocate the limited resource for improving the sum rate and guaranteeing the fairness of the system. If processing power allocation after the other two procedures, the joint optimization problem can be regarded as a combinatorial optimization problem with $(|\boldsymbol{S}|+|\boldsymbol{S}_d|)\times|\boldsymbol{K}|$ binary variables $x_{i,k}^{q}$. In the next section we introduce an evolutionary algorithm to give a suboptimum solution to the problem.

III. JOINT OPTIMIZATION

Number footnotes separately in superscripts $^{1,\ 2,\ \ldots}$. Place the actual footnote at the bottom of the column in which it was cited, as in this column. See first page footnote for an example.

As a kind of artificial intelligence technique, evolutionary algorithm has good performance in terms of solving discrete optimization problem by simulating the process of biological evolution based on Darwin's theory of evolution. In this section, we present a fitness function for the optimization, and propose a coding scheme satisfying the constraints in section II.B applied to evolution algorithm below, and finally design a joint optimization method utilizing evolution algorithm based on the above fitness function and coding scheme. In the following, we set $\boldsymbol{S}_d=\{1,2,\ldots,|\boldsymbol{S}_d|\}$ and $\boldsymbol{S}_c=\{|\boldsymbol{S}_d|+1,|\boldsymbol{S}_d|+2,\ldots,|\boldsymbol{S}|\}$.

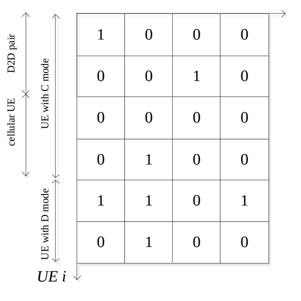
A. *Fitness Function*

In order to solve the multi-objective optimization problem described by Eq. (10), we design a fitness function for evolution algorithm as Eq. (11) to transform it to single-objective problem.

$$F=\sum_{i\in\boldsymbol{S}}\sum_{k\in\boldsymbol{K}}R_{i,k}-\beta F_{airness} \tag{11}$$

where β is the weight factor to adjust the weight of fairness and sum rate.

B. *Coding and Decoding Scheme*



1	0	0	0
0	0	1	0
0	0	0	0
0	1	0	0
1	1	0	1
0	1	0	0

Figure 3. An example of resource mapping table

According to section II, we have a resource allocation mapping table consisting of $x_{i,k}^{q}$ during a frame as shown in Fig 3. for one of the solutions to the joint mode selection and resource allocation problem . In order to satisfy the two constraints, a coding scheme is designed to express the individual in evolution algorithm instead of the resource table itself. Every individual is expressed by a $1\times 2|\boldsymbol{K}|$ vector $\boldsymbol{t}=\{t^1,t^2,\ldots,t^{2|\boldsymbol{K}|}\}$, signifying a solution of subchannel assignment and mode selection, of which the first $|\boldsymbol{K}|$ elements represent the resource allocation for the UEs with C mode, and the last $|\boldsymbol{K}|$ elements represent that with D mode. The Eq. (12) shows the mapping relationship between individual code and resource allocation table. Fig 4 gives the individual code mapping the instance in Fig 3.

$$t_k=\begin{cases}\{i\,|\,i\in\boldsymbol{S}, and\ x_{i,k}^{1}=1\}, k=1,2,\ldots,|\boldsymbol{K}|\\ \sum_{i\in S_d}x_{i,k}^{0}\times 2^{i-1}, k=|\boldsymbol{K}|+1,\ldots,2|\boldsymbol{K}|\\ 0, others\end{cases} \tag{12}$$

When $k=1,2,\ldots,|\boldsymbol{K}|$, the value of the kth element t_k is equal to the index of the UE employing the kth subchannel with C mode, so the range of value is integers in the interval $[0,|\boldsymbol{S}|]$, where 0 represents the kth subchannel allocated to no UE with C mode. When $k=|\boldsymbol{K}|+1,|\boldsymbol{K}|+2\ldots,2|\boldsymbol{K}|$, the kth element t_k consists of indexes of all D2D pairs assigned the $(k-|\boldsymbol{K}|)$th subchannel with D mode, the range of which is integers in the interval $[0,2^{|S_d|}]$, and $t_k=0$ indicates no UE employing the kth subchannel with D mode.

0	4	2	0	1	3	0	1

Figure 4. Coding result for the instance in Fig3

Therefore, we deduce the corresponding decoding scheme shown in Eq. (13) and Eq. (14), which will be utilized for calculating the fitness of every individual.

$$x_{i,k}^{0}=\begin{cases}1, if\ i=t_k, and\ k=1,2,\ldots,|\boldsymbol{K}|\\ 0, if\ i\neq t_k, and\ k=1,2,\ldots,|\boldsymbol{K}|\end{cases} \tag{13}$$

$$x_{i,k}^{1}=\begin{cases}1, if\ t_k\otimes 2^{i-1}\neq 0, and\ k=|\boldsymbol{K}|+1,\ldots,2|\boldsymbol{K}|\\ 0, if\ t_k\otimes 2^{i-1}=0, and\ k=|\boldsymbol{K}|+1,\ldots,2|\boldsymbol{K}|\end{cases} \tag{14}$$

where the operator $\otimes$ indicates bitwise-AND operation between its left and right operands.

The constraint (C4) is satisfied by the code scheme above naturally, but it requires modification for the code to meet the constraint (C5). So it is necessary to detect and modify the first $|\mathrm{S_d}|$ elements as follows:

If $t_{k+|\boldsymbol{K}|}\otimes 2^{t_k-1}\neq 0$ and $0<t_k\leq|\boldsymbol{S}_d|$, $k=1,2,\ldots,|\boldsymbol{K}|$

$$t_k=[|\boldsymbol{S}_c|\times rand]+|\boldsymbol{S}_d| \tag{15}$$

where $rand$ is a random number between the interval (0,1). If there is a D2D pair employing a subchannel with both modes, the modification forces the D2D pair to give up C mode and allocates the subchannel to a random cellular UE or gives up allocating the subchannel to any UE with C mode.

C. *Evaluation*

We take two indexes as the evaluation of the optimization algorithm: the sum rate of the system and the modified Jain's fairness index.

$$R_{sum} = \sum_{i\in \boldsymbol{S}} \sum_{k\in \boldsymbol{K}} R_{i,k} \qquad (16)$$

$$J_{modified} = \frac{\left(\sum_{i\in \boldsymbol{S}} \frac{\sum_{k\in \boldsymbol{K}} R_{i,k}}{\alpha_i}\right)^2}{|\boldsymbol{S}|\times\sum_{i\in \boldsymbol{S}}\left(\frac{\sum_{k\in \boldsymbol{K}} R_{i,k}}{\alpha_i}\right)^2} \qquad (17)$$

D. Evolutionary Algorithm

Step 1 Initialization. Set the parameters of evolution algorithm, including population scale M, crossover probability p_{c1}, p_{c2}, mutation probability p_m, maximum iteration times N_{max} and iteration-stopping criterion parameter N_{stop}. Initialize every individual by random generation and record the results as the personal best fitness for each individual. For the mth individual, generate an original vector $\boldsymbol{v}^{(m)}$ consisting of $2|\boldsymbol{K}|$ random decimal elements ranging from 0 to 1, and adjust the value by Eq. (18)

$$t_k^{(m)} = \begin{cases} \left\lceil v_k^{(m)} \times |\boldsymbol{S}| \right\rceil, k = 1,2,\dots,|\boldsymbol{K}| \\ \left\lfloor v_k^{(m)} \times 2^{|\boldsymbol{S}_d|} \right\rfloor, k = |\boldsymbol{K}|+1,\dots,2|\boldsymbol{K}| \end{cases} \qquad (18)$$

Then calculate the fitness for every individual according Eq. (11), and mark the individual with the maximum fitness as the global best individual.

Step 2 Crossover. Crossover is a random process to generate the filial generations. The operation is implemented on every individual by selecting $p_{c1} \times 2|\boldsymbol{K}|$ elements from the global best individual (GBI) and selecting $p_{c2} \times 2|\boldsymbol{K}|$ elements from the personal best individual (PBI) randomly to replace its elements in the corresponding positions. If replacements locate in the same position, the one from personal best individual will dominate. An example is shown as Fig. 5.

Step 3 Mutation. Evolution algorithm can avoid getting into the local optimum by mutation. Every individual, containing original ones and filial ones, chooses $p_m \times 2|\boldsymbol{K}|$ element positions randomly and replace with other elements in the corresponding range generated randomly, which is illustrated as Fig. 6.

Step 4 Modification. After crossover and mutation, there may be some individual unsatisfied constraint condition (C5). So it is necessary to detect and modify the individuals following the rules of Eq. (14). Fig. 7 shows a case of modification.

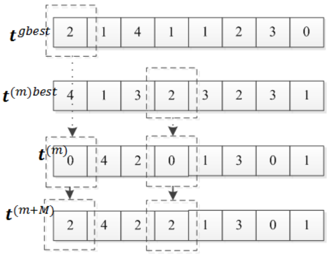


Figure 5. Crossover, $p_{c1} = 0.125, p_{c2} = 0.125$

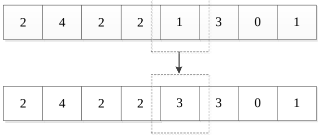


Figure 6. Mutation, with $p_m = 0.125$

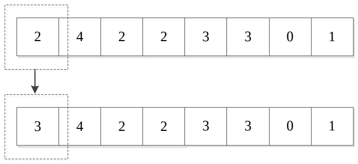


Figure 7. Modification

Step 5 Selection. Observing the mechanism for the survival of the fittest, selection evolves the population. The number of individuals expands to $2M$. Compute the fitness of all individuals by Eq. (10) after decoding every individual to $x_{i,k}^q$ table. If there is fitness larger than the global best fitness, update the global best fitness. Comparing the fitness of original and filial individuals, add the ones with better fitness into the original generation for the next iteration, and reject the other ones from the population. Finally compare the fitness with personal best fitness and update the personal best fitness for every individual.

Step 6 iteration-stop judgment. If the iterations equal to N_{max} or the GBI keeps invariable during N_{stop} iterations, stop the iteration and achieve the final solution as the GBI, otherwise go to step2 and start the next iteration.

E. Complexity Analysis

In every iteration, the computational complexity of each individual can be expressed as Table I.

TABLE I. COMPUTATIONAL COMPLEXITY OF EACH INDIVIDUAL

Decoding	$O\left(M\|\boldsymbol{K}\|(\|\boldsymbol{S}\|+\|\boldsymbol{S}_d\|)\right)$
EA	$O(M\times 2\|\boldsymbol{K}\|)$
Fitness calculation	$O\left(M\|\boldsymbol{K}\|(\|\boldsymbol{S}\|+\|\boldsymbol{S}_d\|)\right)$

If the iteration number is N, the computational complexity of EA-MSRA-MDMR is $O\left(NM|\boldsymbol{K}|(|\boldsymbol{S}|+|\boldsymbol{S}_d|)\right)$.

IV. SIMULATION

The simulation considers a scenario of a single cell with one BS located in the center and 4 active D2D pairs, 4 active cellular UEs distributed uniformly over the cell area. We set the proportions of expected rate of all active UEs as 4:4:4:4:1:1:1:1,indicating that the rate of D2D UE is expected as 4 times that of cellular UE. The max distance between the transmitting device and the receiving device of a D2D pair L ranges from 10m to 100m during the simulation. The other important parameters of the simulation are listed in Table II. The numerical results are averaged over 500 scenarios.

Through computer simulations, we evaluate the performance of the proposed joint mode selection and resource allocation method using evolution algorithm (EA-MSRA-MDMR) and compare it with the mode selection and resource allocation scheme based on particle swarm optimization (PSO-MSRA-SDMR) proposed by reference [10]. The parameters of PSO-MSRA are set the same as that in reference [10]. In order to compare the searching ability of EA and PSO in this joint optimization problem, a method adopting PSO in the system model of this paper is added to our simulations. The methods we discuss are listed in Table III.

TABLE II. SIMULATION PARAMETERS

System Parameter	Value
Channel model	Rayleigh
System bandwidth	3 MHz
Number of subchannels	15
Cell radius	500 m
Maximum transmission power of BS	36 dBm
Maximum transmission power of the device in a D2D pair	20 dBm
Maximum transmission power of UE	17 dBm
Noise density	−174 dBm/Hz
Path loss model	C mode: $L(d)=128.1+37.6\log_{10} d$, d in km
	D mode: $L(d)=148+40\log_{10} d$, d in km
β	1
γ	0.5
EA Prameter	Value
M	30
p_{c1}	0.2
p_{c2}	0.15
p_m	0.2
N_{max}	100
N_{stop}	50

TABLE III. METHODS IN SIMULATIONS

PSO-MSRA-SDMR	the mode selection and resource allocation scheme based on particle swarm optimization, in which a resource block is allowed to be reused by one single D2D pair, and a D2D pair can reuse multiple resource blocks
PSO-MSRA-MDMR	the mode selection and resource allocation scheme based on particle swarm optimization, in which a resource block is allowed to be reused by multiple D2D pairs, and a D2D pair can reuse multiple resource blocks
EA-MSRA-MDMR	the mode selection and resource allocation scheme based on evolutionary algorithm, in which a resource block is allowed to be reused by multiple D2D pairs, and a D2D pair can reuse multiple resource blocks

The average iterations to achieve their final solutions of the three methods in our simulations are 45, 60 and 60 respectively. The main reason causing this difference between PSO-MSRA-SDMR and the other two methods is the scale of the solution space. But with the little sacrifice of complexity, two methods of MSRA-MDMR achieve obvious enhancement in the system sum-rate and the fairness as shown in Fig. 8 and Fig. 9 separately. The fairness is evaluated by modified Jain's fairness as Eq. (17).

And Fig. 8 and Fig. 9 also show that with the approximate iterations, EA can achieve better performance than PSO in the MSRA-MDMR problem. Compared with PSO, which is generally applied to solve the continuous optimization and has weakness for presenting distance between individuals in discretely combinatorial space, EA is more suitable to global searching for the combinatorial optimization and has better performance in avoiding local optima. Therefore, EA-MSRA-MDMR outperforms the other two methods.

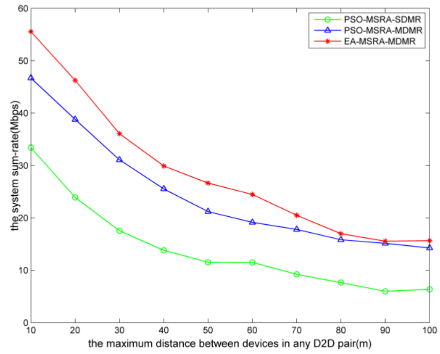


Figure 8. Sum-rate versus maximum distance between a D2D pair

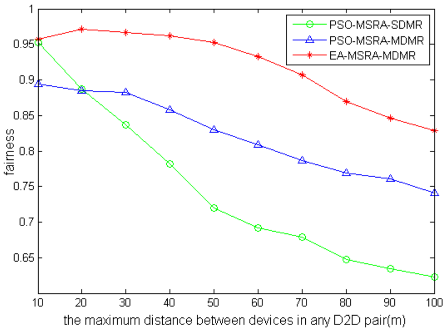


Figure 9. Fairness versus maximum distance between a D2D pair

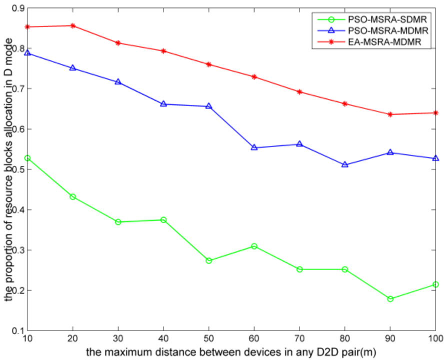


Figure 10. The proportion of resource block allocation in D mode versus maximum distance between a D2D pair

It is also observed that the sum-rate and the fairness of these three schemes decreases with increasing L. One obvious reason is that increasing distance between devices in a D2D pair causes channel gain falling. On the other hand, D2D pairs trend to choose C mode when the quantity of D2D channel is below a certain level. Fig 10 illustrates the proportion of resource blocks allocated in D mode of the three methods when increasing L, which also can explain the dominant performance of EA-MSRA-MDMR in some sense.

V. CONCLUSION

111In this paper, EA-MSRA-MDMR is proposed to maximize the system sum-rate and to guarantee the fairness for D2D communication underlaying cellular networks. The scheme establishes a flexible resource reusing mechanism, in which resource blocks are allowed to be reused by multiple D2D pairs, and takes joint mode selection and resource allocation optimization into consideration. Then we uses a proposed coding scheme to represent the solutions of the joint mode selection and resource allocation problem with satisfying all constraints, and finally solve the problem by evolutionary algorithm. Simulation results show that the proposed method has good performance. Future work will consider adaptive power allocation into the joint scheme to further enhance the performance.

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