Fast Spectrum Reuse and Power Control for Device-to-Device Communication

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***Abstract*—Future 5G mobile networks are expected to support high numbers of simultaneously connected devices and to achieve high system spectrum efficiency at low power consumption. To attain these goals, device-to-device (D2D) communication is a key component. We allow any cellular user equipment to share its radio resource with multiple D2D devices and then develop the MiSo algorithm, which considers spectrum reuse and power control jointly. Simulation results confirm that compared with several algorithms, MiSo achieves the highest system throughput and power efficiency with the shortest run time.**

***Index Terms*—D2D communication, mobile network, power control, resource allocation.**

I. Introduction

Fifth-generation (5G) mobile networks, compared to 4G mobile networks, are expected to support higher numbers of simultaneously connected devices and achieve higher system spectrum efficiency at lower power consumption. It is forcast in [1] that 5G mobile networks will have 10X connection density, 5X spectrum efficiency, and 100X energy efficiency.

Multi-sharing device-to-device (D2D) communication plays a key role to attain these goals [2]. Unlike the *single-sharing* counterpart in which each cellular user equipment (CUE) can share its resource blocks (RBs) with at most one D2D user equipment (DUE), multi-sharing D2D communication allows each CUE to share its RBs with multiple DUEs. This results in a frequency reuse factor of far greater than one.

Although D2D communication [3] can reuse either uplink or downlink RBs of CUEs, the research trend is more focused on uplink resource sharing. The main reason is underutilized uplink spectrum (due to asymmetric Internet traffic). In the single-sharing D2D communication scenario, Han et al. [4] in 2012 maximized the number of permitted DUE pairs, assuming that transmission power values at devices are given.

Feng et al. [5] also studied single-sharing D2D communication but maximized the system throughput instead. Feng et al. considered both RB reuse and power control and developed the Optimal Resource Allocation (ORA) algorithm. ORA consists of admission control, transmission power allocation, and DUEs-to-CUEs maximum weight matching. Wang et al. [6] also studied single-sharing D2D communication with joint consideration of RB reuse and power control. They developed a Stackelberg-game-based method in which CUEs and DUE pairs attempt to maximize their utility values.

For multi-sharing D2D communication, Sun et al. [7] developed the Greedy Resource Allocation (GRA) algorithm to increase the number of permitted DUE pairs, given transmission power values. The key idea is to form conflict graphs and to reuse RBs in the order of smallest degree first.

Given transmission power values on all DUE pairs, the multi-sharing resource allocation problem is proven NP-hard by Ciou et al. in [2]. They developed the GTM+ algorithm. GTM+ considers the minimum SINR requirements of CUEs and DUEs and exploits both conflict graph and maximal weight independent set to improve system throughput.

None of the above algorithms jointly deals with RB reuse and power control for multi-sharing D2D communication. ORA [5] is not designed for the multi-sharing scenario; GRA [7] and GTM+ [2] do not have power control capability. This motivates us to deal with RB reuse and power control jointly and to develop a new scheme that improves system throughput and power efficiency while being fast enough to support many DUEs in 5G mobile networks. This led us to develop the *M*aximum *i*ndependent set based and *S*tackelberg p*o*wer based (MiSo) algorithm.

Conceptually, the MiSo algorithm can be regarded as two parts—RB reuse and power control. The RB reuse part exploits maximum independent set and is accelerated by reducing the input size. The power control part is speeded up by using our derived Stackelberg power, which is of $\mathcal{O}(1)$ time complexity. With these deliberate designs, MiSo achieves great system throughput and power efficiency within a very short run time.

The remainder of this paper is organized as follows. Section II describes the system model. Section III presents our proposed MiSo algorithm. Section IV outlines the Stackelberg power we derive. Performance evaluation is shown in Section V. Concluding remarks are presented in Section VI.

II. System Model

This paper focuses on reuse of resource blocks (RBs) that are assigned to the uplink direction. Although our method can be applied (with slight modification) to the inter-cell scenario such as a cloud radio access network architecture where the same set of uplink resource blocks can be concurrently used in multiple cells, we explain our method by using the single-cell scenario for simplicity of exposition.

Same as [2], [8], a cell with M CUEs and N DUE pairs is considered, as shown in Fig. 1. Within the cell, RBs are pre-allocated disjointly/orthogonally among CUEs. These CUEs can share their pre-allocated *uplink* RBs with DUE pairs. The CUEs and DUEs are denoted by $C_1, C_2, \ldots, C_M$ and

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$D_1, D_2, \ldots, D_N$, respectively. For simplicity of exposition, when there is no ambiguity, c and d (or d') are also used to denote C_c and D_d (or $D_{d'}$), respectively.

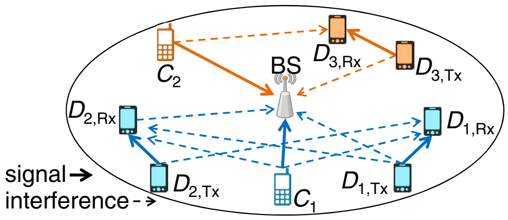

Fig. 1. CUEs share RBs with DUE pairs (C_1 shares with D_1 and D_2; C_2 shares with D_3 in this figure), causing mutual interference.

For any certain CUE, say c, we denote its allocated bandwidth by W_c, its (pre-determined) transmission power by P_c, and the encountered noise power by σ_c^2. To make the system model as general as possible for the need of future 5G mobile networks, different CUEs are allowed to have different bandwidth, transmission power, and/or noise power.

The serving base station (BS) is assumed to have the perfect channel state information of all communication channels. We use $G_{\text{Tx,Rx}}$ to denote the channel gain from the transmitter Tx to the receiver Rx. The transmitter Tx and receiver Rx can be a CUE c, a DUE pair d, and/or the serving base station B.

To specify CUE-DUE relationship, Δ_c is defined as the set of DUE pairs that reuse the RBs allocated to CUE c. For the DUE pair d, we denote the transmission power at the sender by P_d, and the noise power at the receiver by σ_d^2. P_d is often constrained within a range; that is, $P^{\min} \leq P_d \leq P^{\max}$. Since the sets $\{\Delta_c\}_{c=1}^{M}$ specify RB reuse and the numbers $\{P_d\}_{d=1}^{N}$ specify power control, they will be determined by the joint RB reuse and power control algorithm discussed in Section III.

All CUEs can have minimum SINR requirements. Each CUE, say c, can share its RBs with a set of DUEs if its SINR requirement is still satisfied. That is, the received SINR must be beyond the SINR threshold γ_c^t:

$$\frac{P_c G_{c,B}}{\sigma_c^2 + \sum_{d \in \Delta_c} P_d G_{d,B}} \geq \gamma_c^t \tag{1}$$

where B, c, and d denotes the serving base station, CUE c, and DUE pair d, respectively; $G_{\text{Tx,Rx}}$ is the channel gain from the transmitter Tx to the receiver Rx.

Similarly, each DUE pair, say d, also has its minimum SINR requirement. d can reuse c's RBs only if the received SINR can exceed the SINR threshold γ_d^t:

$$\frac{P_d G_{d,d}}{\sigma_d^2 + P_c G_{c,d} + \sum_{d' \in \Delta_c - \{d\}} P_{d'} G_{d',d}} \geq \gamma_d^t, \forall c\colon d \in \Delta_c \tag{2}$$

The main goal is to optimize both system throughput and power efficiency. System throughput is calculated by the sum of the Shannon capacity values of all CUEs and DUEs that satisfy their SINR requirements. It is assumed that the CUEs and DUEs that do not satisfy their SINR requirements are not granted to access any RBs. Power efficiency is defined as throughput divided by power consumption.

III. The MiSo Algorithm

The *M*aximum *i*ndependent set based and *S*tackelberg p*o*wer based (MiSo) algorithm is devised for joint RB reuse and power control of multi-sharing D2D communication. We elaborately design MiSo as a fast iterative algorithm consisting of one-time initialization and M iterations. DUE pairs are partitioned into groups and an iteration dealing with only one group consists of tier-1 allocation and tier-2 allocation. Tier-1 allocation exploits maximum independent set and is accelerated by reducing the input size. Tier-2 allocation is accelerated by our derived Stackelberg power of $\mathcal{O}(1)$ complexity.

Algorithm 1: MiSo

Algorithm *MiSo*
  Input: M CUEs and N DUE pairs.
  Output: RB reuse results $\{\Delta_1, \Delta_2, \ldots, \Delta_M\}$ and transmit power results $\{P_1, P_2, \ldots, P_N\}$.
  // Initialization.
  $U \leftarrow \{1, 2, \ldots, M\}$. // U is the set of unmarked groups/CUEs.
  Set $\Gamma_1, \Gamma_2, \ldots, \Gamma_M$ to be empty sets.
  Compute $P_1^{\text{init}}, P_2^{\text{init}}, \ldots, P_N^{\text{init}}$ by (4).
  Join($\{1, 2, \ldots, N\}$). // Each DUE pair joins a group that maximizes the sheer rate and becomes a candidate.
  while $U \neq \emptyset$ **do**
    Find the largest unmarked group c. // $c \leftarrow \arg\max_{c' \in U} |\Gamma_{c'}|$.
    $U \leftarrow U - \{c\}$. // Make group c marked.
    // Tier-1 allocation starts here.
    Form the modified conflict graph G_c for group c.
    $\Lambda_c \leftarrow$ the maximum independent set of G_c.
    $\Delta_c^1 \leftarrow \Lambda_c$. Then remove one DUE pair at a time from Δ_c^1, until each SINR requirement of $d \in \Delta_c^1$ is satisfied.
    $P_d \leftarrow P_d^{\text{init}}$, for each $d \in \Delta_c^1$.
    // Tier-2 allocation starts here.
    $\Lambda_c' \leftarrow \Lambda_c - \Delta_c^1$. $\Delta_c \leftarrow \Delta_c^1$.
    while $\Lambda_c' \neq \emptyset$ *and* $\lambda_{c,\Delta_c}(d^*) > 0$ **do**
      Compute M_c and M_d, $d \in \Delta_c$, by (5) and (6).
      foreach $d \in \Lambda_c'$ **do**
        Compute $P_d^{\min}$ by (8), $P_d^{\max}$ by (9), and the six possible values of (α_c^*, P_d^*) by (10) and (11). Among the six, the actual (α_c^*, P_d^*) is the one with largest $U_c(\alpha_c, P_d)$, which is defined in (12).
        Compute $\lambda_{c,\Delta_c}(d)$ by (7).
        $d^* \leftarrow \arg\max_{d \in \Lambda_c'} \lambda_{c,\Delta_c}(d)$. // Find the winner d^*.
      if $\lambda_{c,\Delta_c}(d^*) > 0$ **then**
        $P_{d^*} \leftarrow P_d^*$. // Transmission power of d^* is set to be P_d^*.
        Move d^* from Λ_c' to Δ_c.
    Join($\Gamma_c - \Delta_c$). // Candidates not getting elected join other groups.

Function *Join(D)*
  // Each DUE pair in the set D joins the unmarked group that maximizes the sheer rate.
  foreach $d \in D$ **do**
    $c^* \leftarrow \arg\max_{c \in U} r(c, d)$.
    $\Gamma_{c^*} \leftarrow \Gamma_{c^*} \cup \{d\}$.

A. Initialization

As shown in the pseudo code, all groups are unmarked at the beginning of MiSo. Every DUE pair joins the unmarked group that maximizes the *sheer rate* without causing the corresponding CUE's SINR below the required threshold. By DUE pair d joining group c, we mean that DUE pair d requests to reuse the RBs of CUE c and automatically becomes a *candidate*. The set of DUE pairs joining group c is named c's *candidate set* and is denoted by Γ_c. The sheer rate of group c and DUE pair d

$$r(c,d) = \log_2(1 + \tfrac{P_c G_{c,B}}{\sigma_c^2 + P_d^{\text{init}} G_{d,B}}) + \log_2(1 + \tfrac{P_d^{\text{init}} G_{d,d}}{\sigma_d^2 + P_c G_{c,d}}) \quad (3)$$

is defined as the sum of c's and d's throughputs, assuming that only d reuses c's RBs. P_d^{init}, the *initial transmission power* of DUE pair d, is defined as:

$$P_d^{\text{init}} = \min\left(P^{\max}, \min_{c\in\{1,2,\ldots,M\}} \frac{P_c G_{c,B}/\gamma_c^t - \sigma_c^2}{G_{d,B}}\right) \quad (4)$$

With such a value, DUE pair d can solely reuse any CUE's RBs without breaking any CUE's SINR requirement.

After initialization, each iteration in MiSo picks the largest one among unmarked groups, makes the picked group marked, and then proceeds tier-1 and tier-2 allocation for that group.

B. Tier-1 Allocation

Given the largest unmarked group c and the corresponding candidate set Γ_c, the main goal of tier-1 allocation is to select as many candidates as possible (from Γ_c) to reuse c's RBs, each at their respective initial transmission power. This is done by three steps—constructing a *modified conflict graph*, selecting *nominees*, and determining *tier-1 electees* from the nominees. All tier-1 electees are granted to reuse c's RBs at their (respective) initial transmission power.

Step 1: The modified conflict graph for group c, denoted by G_c, is constructed as follows. Each vertex in G_c corresponds to a DUE pair in Γ_c. For each pair of vertices, say vertices d and d', an edge connecting the vertex pair is added to G_c if the distance between d and d' is shorter than $R(d,d') + R(d',d)$. Adding edges in such a way aims to reserve an amount of interference margin so that additional DUE pairs can be allocated to reuse the same RBs later during the tier-2 allocation. $R(x,y)$ is the radius at which x's SINR requirement starts to be violated due to the interference from DUE pair y, if both x and y reuse c's RBs at their initial transmission power.

Step 2: Given the modified conflict graph G_c for group c, this step aims to find as many DUE pairs as possible to reuse c's RBs, each at their initial transmission power. Such DUE pairs are called *nominees* and the set of nominees for group c is denoted by Λ_c. Λ_c is found by taking the maximum independent set of the modified conflict graph G_c. Because the maximum independent set problem is NP-hard, we use the heuristic algorithm in [9] to obtain a maximal independent set instead. The heuristic algorithm is of time complexity $\mathcal{O}({n_c}^3)$, where n_c is the number of elements in Γ_c.

Step 3: Given the *nominee set* Λ_c, this step is to decide/elect *tier-1 electees*, which are defined as the nominees that can keep SINR requirements of c and themselves all satisfied if they reuse c's RBs at their own initial transmission power. The set of tier-1 electees is denoted by Δ_c^1. Δ_c^1 is initialized to be Λ_c; one element is removed from Δ_c^1 at a time, until all of the SINR requirements of all elements in $\Delta_c^1 \cup \{c\}$ are satisfied.

C. Tier-2 Allocation

The nominees not elected as tier-1 electees have a second chance to reuse c's RBs. Tier-2 allocation elects one *tier-2 electee* and decides its transmission power every round.

We define Δ_c^2 as the set of tier-2 electees that have already been elected and define $\Delta_c = \Delta_c^1 \cup \Delta_c^2$ as the set of tier-1 electees and tier-2 electees that have already been elected. In every round one new tier-2 electee is elected, so Δ_c^2 is updated every round. We also define $\Lambda_c' = \Lambda_c - \Delta_c$ as the the set of *undetermined nominees* for group c, which are the nominees that have not got elected (as either tier-1 or tier-2 electees) yet. Because there is no tier-2 electee at the beginning of tier-2 allocation, Δ_c and Λ_c' are initialized to be Δ_c^1 and $\Lambda_c - \Delta_c^1$, respectively.

Step 1: For group c, we compute/update the amount of interference margin of each electee $d \in \Delta_c$ and that of CUE c. By (1), c's interference margin can be expressed as

$$M_c = \frac{P_c G_{c,B}}{\gamma_c^t} - \Big(\sigma_c^2 + \sum_{d\in\Delta_c} P_d G_{d,B}\Big) \quad (5)$$

The interference margin of any electee d, $d \in \Delta_c$, can be expressed by using (2) as

$$M_d = \frac{P_d G_{d,d}}{\gamma_d^t} - \Big(\sigma_d^2 + P_c G_{c,d} + \sum_{d'\in\Delta_c - \{d\}} P_{d'} G_{d',d}\Big) \quad (6)$$

Step 2: In this step, all undetermined nominees compete for reusing c's RBs. The winner, denoted by d^*, is the one with the highest pairwise throughput [which is defined later in (7)]

$$d^* = \arg\max_{d\in\Lambda_c'} \lambda_{c,\Delta_c}(d)$$

under the power constraint

$$P_d^{\min} \le P_d \le P_d^{\max},\ \forall d \in \Lambda_c'$$

$P_d^{\min}$ ensures that d can meet its SINR requirement. $P_d^{\max}$ ensures that d will not break the SINR requirements of c and the electees in Δ_c after d is permitted to reuse c's RBs. $P_d^{\min}$ and $P_d^{\max}$ are expressed in (8) and (9), respectively.

The *pairwise throughput* of an undetermined nominee d, denoted by $\lambda_{c,\Delta_c}(d)$, is defined as the sum of c's throughput and d's throughput if c's and d's SINR requirements are both met; otherwise, the pairwise throughput is set to zero. That is,

$$\lambda_{c,\Delta_c}(d) = \begin{cases} \log_2(1 + \frac{P_c G_{c,B}}{P_d^* G_{d,B} + \Omega}) + \log_2(1 + \frac{P_d^* G_{d,d}}{P_c G_{c,d} + \Phi}), \\ \quad \text{if } \frac{P_c G_{c,B}}{P_d^* G_{d,B} + \Omega} \ge \gamma_c^t \text{ and } \frac{P_d^* G_{d,d}}{P_c G_{c,d} + \Phi} \ge \gamma_d^t \\ 0, \ \text{otherwise} \end{cases} \quad (7)$$

where P_d^* is the best Stackelberg power expressed in (11), $\Omega = \sigma_c^2 + \sum_{d'\in\Delta_c} P_{d'} G_{d',B}$, and $\Phi = \sigma_d^2 + \sum_{d'\in\Delta_c} P_{d'} G_{d',d}$.

As aforementioned, the transmission power of each undetermined nominee $d \in \Lambda_c'$ is bounded above and below. $P_d^{\min}$ is derived from d's SINR requirement (2) as:

$$P_d^{\min} = \frac{\gamma_d^t}{G_{d,d}} \Big(\sigma_d^2 + P_c G_{c,d} + \sum_{d'\in\Delta_c} P_{d'} G_{d',d}\Big) \quad (8)$$

$P_d^{\max}$ cannot incur interferences above interference margins. $P_d^{\max}$ cannot exceed $P^{\max}$, either. Using (5) and (6), we obtain $P_d^{\max}$ for each $d \in \Lambda_c'$ as:

$$P_d^{\max} = \min\left(\frac{M_c}{G_{d,B}},\ \min_{d' \in \Delta_c} \frac{M_{d'}}{G_{d,d'}},\ P^{\max}\right) \quad (9)$$

Step 3: After the winner d^* is determined, we check whether the winner has a nonzero pairwise throughput. If $\lambda_{c,\Delta_c}(d^*) > 0$, the winner d^* becomes a tier-2 electee. Tier-2 allocation repeats (by going to Step 1 again) until either the pairwise throughput of the winner is zero or there is no more undetermined nominee left.

After these steps, each tier-2 electee d, $d \in \Delta_c^2$, is granted to reuse c's RBs at transmission power of P_d^*.

Step 4: All the candidates not getting elected (i.e., the DUE pairs in Γ_c but not in Δ_c) leave the current groups and join other unremarked groups that maximize their sheer rates.

IV. Stackelberg-Game-Based Power Control

Due to the space problem, we put the analysis in [10] and only present the result here: The optimal price α_c^* (which is a variable used in our Stackelberg game) takes only on one of the six values $\{\alpha_{c,1}, \alpha_{c,2}, \alpha_{c,3}, \alpha_{c,4}, \alpha_{c,\min}, \alpha_{c,\max}\}$, where

$$\begin{aligned}
\alpha_{c,1} &= \frac{B}{\beta\Omega} - \frac{B}{A} \\
\alpha_{c,2} &= \frac{B}{A} - \frac{B}{(A+\Omega)\beta} \\
\alpha_{c,3} &= \frac{-B(A+2C) - \sqrt{D}}{2C(A+C)} \\
\alpha_{c,4} &= \frac{-B(A+2C) + \sqrt{D}}{2C(A+C)} \\
\alpha_{c,\min} &= \frac{B}{P_d^{\max} G_{d,B} + \Omega - C} \\
\alpha_{c,\max} &= \frac{B}{P_d^{\min} G_{d,B} + \Omega - C}
\end{aligned} \quad (10)$$

and

$$\begin{aligned}
A &= P_c G_{c,B} & C &= -\tfrac{G_{d,B}}{G_{d,d}}(P_c G_{c,d} + \Phi) + \Omega \\
B &= \tfrac{1}{\ln 2} & D &= AB^2(A + 4C(A+C)\tfrac{1}{(\Omega - C)\beta})
\end{aligned}$$

With these six possible values of α_c^* shown in (10), the corresponding *Stackelberg power* can be computed by:

$$P_d^* = \begin{cases} \hat{P}_d & \text{if } P_d^{\min} \le \hat{P}_d \le P_d^{\max} \\ P_d^{\min} & \text{if } \hat{P}_d < P_d^{\min} \\ P_d^{\max} & \text{if } \hat{P}_d > P_d^{\max} \end{cases} \quad (11)$$

where $P_d^{\min}$ and $P_d^{\max}$ are aforementioned in (8) and (9), and $\hat{P}_d = \frac{1}{\alpha_c^* G_{d,B} \ln 2} - \frac{P_c G_{c,d} + \Phi}{G_{d,d}}$.

What to do in our Stackelberg-game-based power control method is to find out, among the six (α_c, P_d) points, the one that makes c's utility largest, where c's utility is defined as:

$$U_c(\alpha_c, P_d) = \log_2\left(1 + \frac{P_c G_{c,B}}{P_d G_{d,B} + \Omega}\right) + \beta \alpha_c P_d G_{d,B} \quad (12)$$

This gives the best Stackelberg power value P_d^*. Since it takes six operations, the Stackelberg-game-based power control has a time complexity of $\mathcal{O}(1)$.

TABLE I
Simulation parameters.

Parameters	Values
Radius of BS coverage	500 m
Noise spectral density	-174 dBm/Hz
Path loss model for CUE and DUE	$128.1 + 37.6 \log_{10}(d \text{ [km]})$
Path loss model for DUE pairs	$148 + 40 \log_{10}(d \text{ [km]})$
CUE's SINR threshold	7 (or equivalently 8.45 dB)
DUE's SINR threshold	3 (or equivalently 4.77 dB)
TXer-RXer distance of a DUE pair	15 m
Bandwidth per RB	12 * 15 KHz = 180 KHz
Number of CUEs	10 (each CUE occupies one RB)

V. Performance Evaluation

We present simulation results of our proposed MiSo algorithm and compare its performance with three existing algorithms—GTM+, GRA, and ORA.

In our simulation, all CUEs are set to have the same SINR requirements and so are DUE pairs (although MiSo does not require this assumption). We also assume that each CUE is allocated exact one orthogonal RB. These settings are for fair comparison purpose; otherwise, some algorithms cannot be applied. Transmission power for the algorithms with power control capability can range from 0 Watt to 23 dBm. For the algorithms without power control, all CUEs transmit at 23 dBm and DUE pairs transmit at 10 dBm. All CUEs and DUEs are randomly distributed in a single cell with the serving BS at the center. Most parameters are set according to [7]; some of them are listed in Table I. All results are averaged over at least 100 instances to reflect average performance.

In terms of system throughput[1], MiSo performs best, GTM+ is the second place, and ORA performs worst, as seen in Fig. 2. The major reason of the outperformance is because only MiSo has both power control and multi-sharing capabilities. MiSo's power control capability can reduce interference imposed on CUEs and DUEs, which cannot be done by GTM+ and GRA. MiSo's multi-sharing capability allows multiple DUE pairs to reuse same RBs, which cannot be done by ORA.

In terms of DUEs' power efficiency, MiSo also outperforms the other three algorithms, as shown in Fig. 3. The reason behind is that MiSo attempts to both maximize throughput and minimize interference in our Stackelberg game analysis. On the other hand, ORA tends to increase CUEs' and DUEs' transmission power proportionally so as to increase SINR value and maximize throughput. GTM+ is more power efficient than GRA because GTM+ has higher system throughput. Note that MiSo performs drastically better than the other algorithms in terms of power efficiency because compared with other three algorithms, MiSo results in the highest throughput at the lowest transmission power.

[1] System throughput is the sum of the Shannon capacity values of all CUEs and DUEs that satisfy their SINR requirements.

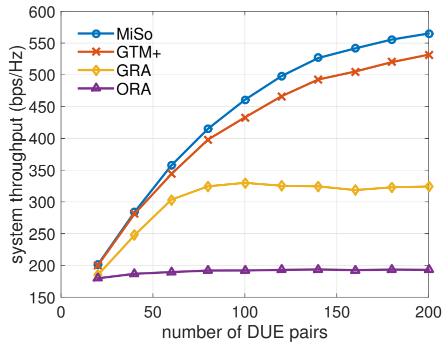

Fig. 2. System throughput.

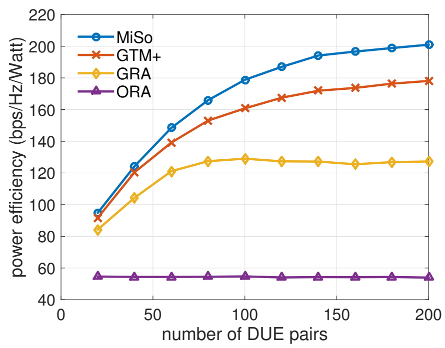

Fig. 3. DUEs' power efficiency.

Besides the performance indices aforementioned, we show the run time each algorithm takes in Fig. 4. As one can observe, MiSo is fastest among all the algorithms. Indeed, MiSo's speed advantage becomes even more significant when the number of CUEs increases, as shown in Fig. 5. MiSo can be faster than the other three algorithms by a factor of 10 times or even several orders of magnitude. The above measurement of run time is obtained from executing Matlab code.

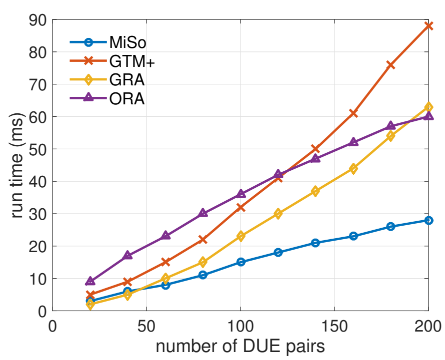

Fig. 4. The run time each algorithm takes in the case with 10 CUEs.

VI. Conclusion

5G mobile networks are expected to support high numbers of simultaneously connected devices and to achieve high system spectrum efficiency at low power. To achieve these

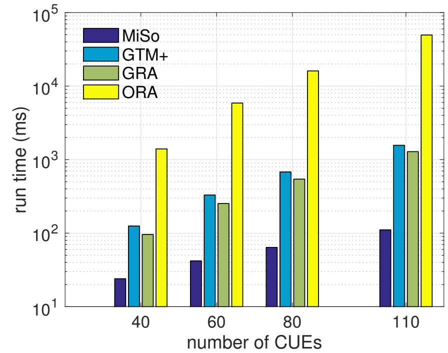

Fig. 5. The run time when the number of CUEs varies and $N = 4M$.

goals, we have studied the multi-sharing D2D communication with resource block reuse and power control jointly considered. Extensive simulation results show that compared to three existing algorithms, our proposed MiSo algorithm has outstanding performance in terms of power efficiency, system throughput, and run time.

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