Wireless Network Virtualization with Long-Term Device-to-Device Communication

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Abstract. To reduce the transmission energy and latency when servicing the users who are interested in a common popular content, the base station (BS) chooses to deliver the content to the users nearby with less power. After these users receive and cache the required content, they can act as relay users (RUEs) to serve those who are far away from the BS by means of Device-to-Device (D2D) and thus are called D2D users (DUEs). In such a scenario, how to classify the users into RUEs and DUEs and associate the DUEs to the RUEs is an important but not trivial problem. In this paper, we formulate the joint RUEs selection and DUEs association problem from a long-term perspective. To find a low complexity computational solution to the problem, we first propose an algorithm to select the RUEs based on the set criteria, and then a coalition formation game based algorithm is proposed for the DUEs association. We further prove that the proposed algorithm is convergent. Numerical results demonstrate that the algorithms we proposed yield notable gains compare with short-term optimal scheme and non-cooperative scheme.

Keywords: Device-to-Device communication · Long-term users association · Coalition formation game

1 Introduction

Industry foresee a gigabit experience with zero latency for the next generation mobile communication systems beyond 2020. The fifth generation wireless system brings together novel advanced services to offer a solid user experience, such as tactile internet, high resolution (4K) video streaming, advanced sensing and monitoring, autonomous driving. Besides throughput enhancements and reduction of cost and power requirements of devices, latency and reliability requirements are among the key performance indicators to meet the targeted in the 5G.

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In order to meet the low-latency communication requirement in the 5G, many approaches have been proposed. In [1], the authors investigate the latency performance of content delivery networks with the aid of edge-caching, in which a data center is serving the users via a shared wireless medium. The latency-minimization resource allocation for a multi-user mobile edge computation offloading system is studied in [2]. The authors in [3] study a minimum delay routing problem in the context of distributed networks and propose novel predetermined path routing algorithms. In [4], the authors investigate the latency-minimization problem in a multi-user time-division multiple access mobile-edge computation offloading system. In [5], the authors study delivering delay-sensitive data to a group of receivers with minimum latency which consists of the time that the data spends in overlay links as well as the delay incurred at each overlay node.

In the 5G network, all users are cognitive which can perceive the changing network conditions and optimize end-to-end performance. Device-to-Device (D2D) communication as an underlay to heterogeneous cellular network can facilitates the direct communication between the cellular users [6]. Since users within communication range can directly communicate with each other without relying on the base station, D2D communication can provide several benefits for the heterogeneous networks in reusing spectrum resources and achieving high bit rate. A number of works studied content distribution problems in mobile wireless networks with D2D communication [7–9]. In particularly, the typical resource allocation problem has been addressed under versatile content distribution scenarios including relay networks [7], social networks [8], as well as mmWave cellular networks [9]. Many comprehensive studies on the co-existence of large-scale deployed cellular and D2D networks are pursued in [10,11]. In [10], underlay and overlay D2D communications are considered along with users access selections. The transmission capacity region in D2D integrated cellular networks when two prevalent interference management techniques, power control and Successive Interference Cancellation are utilized is studied in [11].

However, aforementioned works focus only on the strategies that are suitable for short-term period, e.g., one time slot. When the network condition changes in the next time slot, the optimal strategy has to be changed, which may lead to instability problem. What's more, users' association schemes change between time slots will cause switching cost. In such a case, the existing studies cannot make full use of existing resources. In this paper, to minimize the average downloading duration from a long-term perspective, we use the existing resources more efficiently by integrating long-term D2D communication into cognitive wireless virtual network (WVN) where users from different operators can perform D2D communication and be served by a same base station (BS). It must be mentioned that in the long-term communication scenario we studied, the users can only associate one access node until a complete content is received. The considered scenario is shown in Fig. 1 where users from different operators require a popular content simultaneously. To reduce the average transmission latency of the network, the BS first chooses to deliver the content to the users nearby.

After these users receive the content, they can act as relay users (RUEs) to serve those who are far away from the BS by means of D2D and thus are called D2D users (DUEs). Different from other scenarios, the users will change their locations between time slots but remain stationary in one time slot. If the problem is solved by traversal algorithm, the optimal solution can be obtained but the complexity of the algorithm will increase exponentially as the number of users increases. To find a low complexity computational solution to the problem, we propose an algorithm to select the RUEs and a coalition formation game based algorithm for the DUEs association. We further prove that the coalition formation game based algorithm is convergent. Finally, our proposed scheme and algorithms are proved to achieve a great performance by simulation when compared to the short-term optimal scheme and non-cooperative scheme.

The remainder of this paper is organized as follows. Section 2 introduces the system model of the long-term D2D communication in cognitive WVN and the selection criteria for all users. The RUEs selection algorithm and the coalition formation game based algorithm that is used to determine the DUEs served by each RUE are described in Sect. 3. Experiment setup and numerical results are presented in Sect. 4. Finally, we conclude this study with future work in Sect. 5.

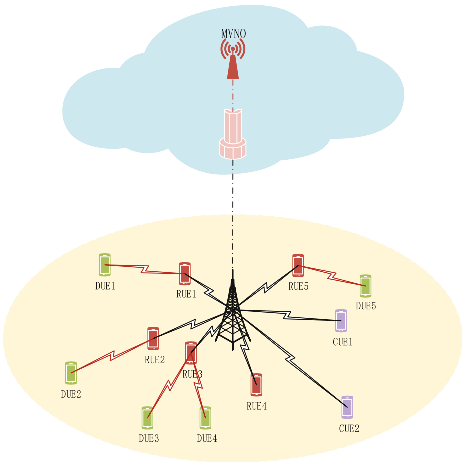

Fig. 1. A downlink cognitive wireless virtual network.

2 System Model

As shown in Fig. 1, we present a downlink 5G system with a single BS managed by a single mobile virtual network operator (MVNO), where users requiring the same popular content with size L, form the set $\mathcal{U}$ with size $|\mathcal{U}|$. To characterize the users' quality of experience (QoE), we assume each user has a same latency threshold, i.e., the maximum number of time slots it can tolerate according to its QoE constrain $t_{\max}$. How $t_{\max}$ is obtained will be introduced in Sect. 2.2.

To reduce the transmission energy and service latency, the BS chooses to deliver the content to the users nearby with less power. After these users receive and cache the required content, they can act as RUEs to serve the users far away from the BS by means of D2D that are called DUEs. The other users that served by the BS but are not suitable to serve the DUEs are called cellular users (CUEs).

2.1 Achievable Rates

Before we introduce the algorithms for selecting RUEs and associating them with the DUEs, the achievable rate (AR) and the latency of each type of user is defined first.

Suppose K resource blocks (RBs) are set aside in the BS, each of which is assigned to one RUE and then reused by DUEs that the RUE served in the D2D communication stage. In such a case, $M(M \leq K)$ users will be selected from $\mathcal{U}$ as RUEs and form a set $\mathcal{U}^{\mathcal{R}}$.

Let $h_m^t = d\left(w_0 - w_{\mathrm{m}}^t\right)^{-\alpha}$ be the path loss of wireless channel between the BS and RUE$_m$ at time slot t. Here, w_0 and w_m^{t} are the locations of the BS and RUE$_m$ at time slot t, respectively, and $d\left(w_0 - w_m^t\right)$ is the distance between them. Then the SNR and AR of RUE$_m$ can be calculated as

$$\gamma_m^t = \frac{P_0 h_m^t}{N_0}, \tag{1}$$

and

$$r_m^t = B \log_2\left(1 + \gamma_m^t\right), \tag{2}$$

where B is the bandwidth of one RB, P_0 is the transmission power the BS uses when it serves RUEs, α is the path loss exponent, and N_0 is the power of the additive white Gaussian noise.

As a result, the latency, i.e., the number of time slots used by RUE$_m$ to get the content, is

$$t_m = \sum_{t=0}^{t_{\max}} O\left(L - r_m^t * \tau\right), \tag{3}$$

where τ is the duration of a time slot, and $O(x)$ is an indicative function whose value equals to 1 when x is greater than 0, and 0 otherwise.

For those users in $\mathcal{U} \setminus \mathcal{U}^{\mathcal{R}}$, if a user can get the content from one RUE with the latency not exceeding t_{max}, then it can be one DUE. Otherwise, it has to appeal to the BS and becomes one CUE. Let $\mathcal{U}^{\mathcal{D}}$ and $\mathcal{U}^{\mathcal{C}}$ be the set of DUEs and CUEs, respectively. Suppose the number of DUEs is $N(N \leq |\mathcal{U}| - M)$, then the number of CUEs will be $|\mathcal{U}| - M - N$. Obviously, $\mathcal{U}^{\mathcal{R}} \cup \mathcal{U}^{\mathcal{D}} \cup \mathcal{U}^{\mathcal{C}} = \mathcal{U}$.

We assume that one DUE can only connect with one RUE until the DUE receive the content while one RUE can serve multiple DUEs simultaneously. One RUE and the DUEs it serves forms a coalition, and the collection of the coalitions is represented as $\mathcal{S}^{\mathcal{R}} = \{s_1^r, \ldots, s_M^r\}$ where s_m^r represents the coalition constructed by RUE$_m$ and the DUEs it serves.

If DUE_n is served by RUE_m, the path loss of the channel between them is denoted as $h_{m,n}^t = d\left(w_m^t - w_n^t\right)^{-\alpha}$. Assuming all RUEs have equal transmission power P_r, then the SNR DUE_n receives at time slot t will be

$$\gamma_{m,n}^t = \frac{P_r h_{m,n}^t}{N_0}, \tag{4}$$

and the corresponding AR will be

$$r_{m,n}^t = \frac{B}{|s_m^r| - 1} \log_2\left(1 + \gamma_{m,n}^t\right), \tag{5}$$

where $|s_m^r| - 1$ indicates the number of DUEs that served by RUE_m.

Hence, the latency of DUE_n served by RUE_m will be

$$t_{m,n} = \sum_{t=t_m+1}^{t_{\max}+t_m} O\left(L - r_{m,n}^t * \tau\right), \tag{6}$$

For the CUEs, since their QoE constraint cannot be satisfied if they are served by the RUEs, they will be served also by the BS directly with a low guaranteed rate λr_{th} introduced in Sect. 2.2.

Therefore, the number of time slots of one CUE getting the content is

$$t_c = \frac{L}{\lambda r_{th}} \tag{7}$$

2.2 Quality-of-Experience Model

In order to reasonably optimize the average delay of all users receive the content in our proposed scenario, we present one QoE model for the users considering their data rates and device types in this section. In the literature, the mean opinion score (MOS) model [12] is usually used to measure the QoE of wireless users as shown in Fig. 2, where QoE is categorized into five levels according to the users' sensitivity to the AR. The mapping between a user's AR and his/her MOS value is given by

$$\bar{r} = \frac{\lambda r_{th} - r_{\min}}{r_{\max} - r_{\min}}, \tag{8}$$

where $\bar{r}$ is the MOS value, r_{th} is the lowest average rate that guarantees users' QoE, λ is the diameter length of the user's device which also influence the user's

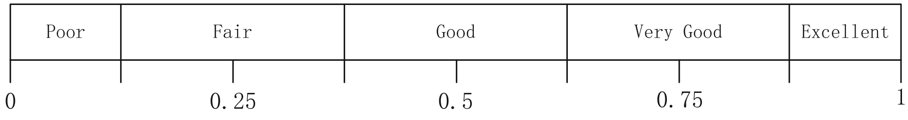

Fig. 2. Mean opinion score model

MOS value, $r_{\max}$ and $r_{\min}$ are the maximum and minimum average rates to get the content in the system, respectively.

Before the users are classified into RUEs, DUEs and CUEs, the minimum and maximum average rates of the system can be calculated as follows.

$$r_{\min} = \min\left\{\min_{m} \frac{1}{t_m}\sum_{t=1}^{t_m} r_m^t \ , \ \min_{m,n} \frac{1}{t_{m,n}} \sum_{t=t_m+1}^{t_{\max}+t_m} r_{m,n}^t\right\}, \quad (9)$$

$$r_{\max} = \max\left\{\max_{m} \frac{1}{t_m}\sum_{t=1}^{t_m} r_m^t \ , \ \max_{m,n} \frac{1}{t_{m,n}} \sum_{t=t_m+1}^{t_{\max}+t_m} r_{m,n}^t\right\}. \quad (10)$$

In Eqs. (9) and (10), the users represented by m m and n will traverse the set $\mathcal{U}$.

Then given $\bar{r}$ and λ, r_{th} can be expressed as

$$r_{th} = \frac{\bar{r}r_{\max} + (1-\bar{r})r_{\min}}{\lambda}. \quad (11)$$

The maximum number of time slots to get the content guaranteeing users' QoE can be expressed as

$$t_{\max} = \frac{L}{\lambda r_{th}} = \frac{L}{\bar{r}r_{\max} + (1-\bar{r})r_{\min}}. \quad (12)$$

2.3 Problem Formulation

Given this system model, our goal is to minimize the total latency of all the users acquiring the content while guarantee the QoE of each user. Suppose that after the users submit the content requirement to the MVNO, their current locations are also reported. By using machine learning, the MVNO can estimate their locations in a period in the future. Then the problem includes RUEs selection and the DUEs association problems can be formulated as follows.

$$\begin{aligned} &\min_{\mathcal{U}^{\mathcal{R}},\mathcal{S}^{\mathcal{R}}} \frac{1}{|\mathcal{U}|}\left(\sum_{m\in\mathcal{U}^{\mathcal{R}}} t_m + \sum_{s_m^r\in\mathcal{S}^{\mathcal{R}}}\sum_{n\in s_m^r} t_{m,n} + \sum_{c\in\mathcal{U}^{\mathcal{C}}} t_c\right) \\ &s.t. \quad r_m^t \geq \lambda r_{th}, \forall t\in[1,t_m], \\ &\qquad\quad r_{m,n}^t \geq \lambda r_{th}, \forall t \in [t_m+1, t_n^{\max}+t_m]. \end{aligned} \quad (13)$$

In (13), the constraints guarantee that in each time slot the ARs of RUEs and DUEs must meet their QoE.

3 Optimal Solution to RUEs Selection and Long-Term Users Association

The optimal solution of the joint RUE selection and DUE association problem in Eq. (13) can only be obtained by traversal. However, as the number of users increases, the complexity of the traversal algorithm will explode. In order to find a sub-optimal solution with low complexity, we divide the problem solving process into two steps. First, we select a subset of users to act as RUEs based on the set criteria. Then, the DUEs served by each RUE and the CUEs served by the BS are determined by the coalition formation game based algorithm.

3.1 Selection of RUEs

To guarantee the QoE of users, we set the first criterion for selecting RUEs: the users that cannot meet their QoE when BS transmits the content to them with P_0 and a proprietary RB are classified as CUEs. Moreover, the RUEs should have high potential to help minimize the total latency of the system. In other words, a potential RUE should be the one that close to BS during the reception of the content and close to the users it will serve after caching the content. Therefore, in algorithm for RUEs selection, we use the sum number of time slots used by users to receive the content from BS and distribute it to other users as the other criterion for selecting RUEs.

The proposed RUEs selection algorithm is mainly composed of three steps: (i) apply the first selection criterion to all users and divide some users into CUEs; (ii) BS directly serves remaining users with P_0 and a proprietary RB if the number of remaining users doesn't exceed K, otherwise the next step is continued; (iii) apply the second selection criterion to the remaining users and select K users with the best expected performance to act as RUEs. The algorithm for RUEs selection is shown in Algorithm 1.

Algorithm 1. RUEs Selection

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for u $\in \mathcal{U}$ **do**
  Calculating the value of t_u which is the number of time slots BS used to transmit the content to every user with P_0 and a proprietary RB.
  if $t_u > \frac{L}{\lambda r^{th}}$ **then**
    The user will be divided into $\mathcal{U}^{\mathcal{C}}$ and served by BS directly.
  end if
end for
if $|\mathcal{U}| - |\mathcal{U}_{\mathcal{C}}| \leq \mathcal{K}$ **then**
  The remaining users will be divided into $\mathcal{U}^{\mathcal{R}}$ and served by BS with P_0 and an exclusive RB.
else
  for u $\in \mathcal{U} \backslash \mathcal{U}_{\mathcal{C}}$ **do**
    Calculating the value of $t_u + \frac{1}{|\mathcal{U} \backslash \mathcal{U}_{\mathcal{C}}|-1} \sum_{n \in \mathcal{U} \backslash \mathcal{U}_{\mathcal{C}} \backslash u} \sum_{t=t_u+1}^{t_{\max}+t_u} O(L - B \log_2(1+\gamma_{u,n}^t) * \tau)$.
  end for
  The K users that with minimal value are selected as RUEs.
end if

3.2 DUEs Association

After RUEs are selected and received the content, they will select users to serve according to the distance between them during the process of transmission. Here, coalition formation game, which is a powerful analytical tool to study the behavior of rational players when they may cooperate with each other, is used to solve the DUEs association problem. A coalition $s_m^r \subseteq \mathcal{S}^{\mathcal{R}}$, which is consisted of one RUE and some DUEs, is a non-empty subset of $\mathcal{S}^{\mathcal{R}}$. RUEs are divided into disjoint coalitions and one DUE can only access one RUE until him/her gets the content. Thus, $\forall i, i' \in \{1, 2, \ldots, M\}$ and $i \neq i'$, it is clear that $\cup s_i^r = \mathcal{S}^{\mathcal{R}}$ and $s_i^r \cap s_{i'}^r = \emptyset$.

The coalition formation game can be defined as a triplet $(\mathcal{T}, \mathcal{P}, \mathcal{V})$, where $\mathcal{T}$ represents the users set defined as $\mathcal{U}^{\mathcal{R}} \cup \mathcal{U}^{\mathcal{D}}$, $\mathcal{P}$ represents a collection of coalitions which can be seen as a partition of $\mathcal{T}$, and $\mathcal{V}$ represents the value of coalitions. The utility of DUE and coalition are denoted as $\mathcal{V}_n$ and $\mathcal{V}(s_m^r)$, respectively. According to the MOS model that we mentioned in Sect. 2, user's QoE is closely related to delay, and the reduction of delay will increase user's QoE. Thus we define $\mathcal{V}(n)$ as the reciprocal of delay to receive the content, which can be calculated as

$$\mathcal{V}_n = \frac{1}{t_{m,n}}, \tag{14}$$

where $t_{m,n}$ has been calculated in Eq. (6).

Similarly, we define $\mathcal{V}(s_m^r)$ as the reciprocal of the average delay of users in coalition s_m^r, which can be calculated as

$$\mathcal{V}(s_m^r) = \begin{cases} \frac{|s_m^r|-1}{\sum\limits_{n \in s_m^r} t_{m,n}}, \text{if } |s_m^r| \geq 1, \\ 0, \text{otherwise.} \end{cases} \tag{15}$$

The necessary condition for users to join a coalition is that the users can get the content from RUE in the coalition in up to $t_{\max}$ time slots. Intuitively, we can find the optimal coalition structure by traversing all possible formation. However, the complexity of such a primitive calculation will show an exponential growth trend as the increases of DUEs. Therefore, we proposed a suboptimal solution to solve the coalition formation game using the concept of defection order. The defection order of the DUE_n served by RUE_m can be represented as

$$s_{m'}^r \triangleright s_m^r = \begin{cases} \mathcal{V}_n\left(s_{m'}^{r,new}\right) > \mathcal{V}_n\left(s_m^r\right), \\ \\ t_{m,n'} \leq t_{\max}, \forall DUE_{\text{n}} \in s_{m'}^r, \\ \\ \mathcal{V}\left(s_{m'}^{r,new}\right) + \mathcal{V}\left(s_m^{r,new}\right) \\ > \mathcal{V}\left(s_{m'}^r\right) + \mathcal{V}\left(s_m^r\right), \end{cases} \tag{16}$$

where $s_{m'}^r$ is the coalition in $\mathcal{S}^{\mathcal{R}}$ except for s_m^r; $\mathcal{V}_n(s_m^r)$ indicates the utility of DUE_n in coalition s_m^r; $s_{m'}^{r,new} = s_{m'}^r \cup DUE_{\text{n}}$ while $s_m^{r,old} = s_m^r \backslash DUE_{\text{n}}$; $\triangleright$ indicates $s_{m'}^r$ is better than s_m^r for DUE_n.

The defection order lists three necessary conditions based on users' QoE constraint: (i) DUE$_n$ in $s^r_{m'}$ is more profitable than in s^r_m; (ii) the participation of DUE$_n$ will not violate the QoE constraint of DUEs originally in $s^r_{m'}$; (iii) the defects of DUE$_n$ will increase the utility of $\mathcal{S}^{\mathcal{R}}$. The corresponding algorithm, which MVNO uses to find the optimal association between RUEs and DUEs, is proposed in Algorithm 2.

Algorithm 2. The Long-term Coalition Formation Game

Initial Stage
The network is partitioned by RUEs, CUEs and candidate users which may become DUEs or CUEs in a non-cooperative way.
Coalition Formation Stage
repeat
  for u $\in \mathcal{U} \backslash \mathcal{U}^{\mathcal{C}} \backslash \mathcal{S}^{\mathcal{R}}$ **do**
    Calculating the value of $t_{m,n}$ defined in Eq. (6) for each $m \in \mathcal{U}^{\mathcal{R}}$.
    if $min\ t_{m,n} > t_{\max}$ **then**
      The user will be divided into $\mathcal{U}^{\mathcal{C}}$.
    else
      The user submit application to the RUE that can transmits the content to it with minimal value of $t_{m,n}$.
    end if
  end for
  The user which won't cause the users connected it cannot satisfy their QoE and maximize the value of $\mathcal{V}(s^r_m)$ defined in Eq. (15) will join in s^r_m.
until All users in $\mathcal{U} \backslash \mathcal{U}^{\mathcal{R}}$ served by RUEs or BS.
repeat
  for All DUEs in $\mathcal{S}^{\mathcal{R}}$ **do**
    if The defection order defined in Eq. (16) is satisfied **then**
      The DUE transfers to the coalition that ensures its maximum utility.
    end if
  end for
until The defection of one DUE can only cause the change of $\mathcal{S}^{\mathcal{R}}$ doesn't exceed ε which is equal to 0.01.

The goal of Algorithm 2 is to reach a stable coalition partition, where no DUE will defect. The proposed long-term coalition formation game is composed of two stages: initial stage and coalition formation stage. Initially, the network is partitioned in a non-cooperative way. The coalition formation procedure is performed in the second stage: (i) all users who have not determined their access schemes send access requests to the access point that can provide maximum average receiving rate, and then each RUE will associate with users that maximize utility of the coalition from the users sent access requests to him/her; (ii) DUEs traverse all coalitions and join the coalition that can maximize its utility according to defection order. After the long-term coalition formation game, users will decide to become DUEs or CUEs according to the distance to RUEs in future time slots.

In the following Theorem 1, we prove the convergence of the coalition formation game.

Theorem 1. *The proposed long-term coalition formation game based algorithm is convergent.*

Proof. The convergence of the long-term coalition formation game based algorithm is guaranteed due to the fact that: (i) the total number of possible partitions with overlapping coalitions is finite when the total number of users is finite in this system; (ii) the transition from a coalition to another coalition leads to the increase of individual utility; (iii) the game contains mechanism to prevent the users to re-visit a previously formed coalitional structure with the set of ε.

4 Simulation Results and Analysis

In this section, the proposed algorithms in Sect. 3 are evaluated based on a data-driven numerical simulation, and the results are compared with two other baseline schemes. The first baseline scheme is called short-term optimal scheme, which MVNO will select RUEs and corresponding DUEs according to their locations at the beginning of each time slot. The second baseline scheme is called non-cooperative scheme, which all users are served by BS directly.

4.1 Experiment Setup

We assume some users that require same popular content are uniformly and randomly distributed in a $500\,\mathrm{m} \times 500\,\mathrm{m}$ square area. There is one BS at the center of the square area. At the beginning of each time slot, users move to new locations and unmoved during the time slot. We set all users' transmission power to 6 dBm, the BS's transmission power to 43 dBm, the power of background additive white Gaussian noise to an average of -120 dBm (at all access points), the λ to 1, the locations prediction interval to 1 s [13], the duration of one time slot to $\tau = 1$ ms, the bandwidth of one RB to 180 kHz, the path loss exponent to $\alpha = 3$.

4.2 Numerical Results

Based on the setup, we compare the average number of time slots used by users with the variety of L when $|\mathcal{U}| = 30$ and the number of RBs is 20, the results of which are depicted in Fig. 3. Obviously, the advantage of Long-term Optimal Algorithm (LOA) we proposed isn't obvious when the value of L is small. As the value of L increases, the average number of time slots used by D2D users in our algorithm increase slowly and the advantage of the algorithm is outstanding when the value of L is large. It's due to the fact that, users can receive the content in very few time slots when the value of L is small and LOA can't show its advantage. When the value of L is relatively large, the users in Short-term

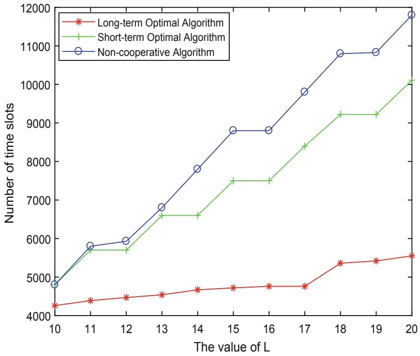

Fig. 3. The average number of time slots varies with the value of L

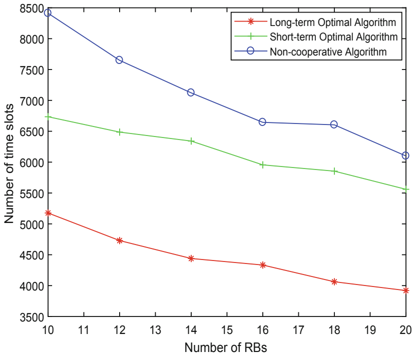

Fig. 4. The average number of time slots varies with the number of RBs

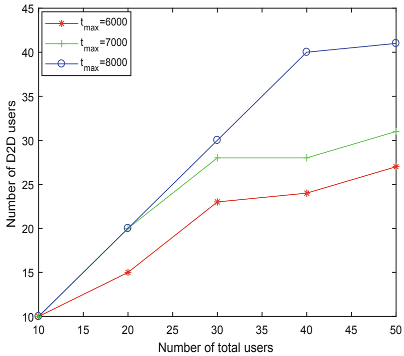

Fig. 5. The number of D2D users varies with the number of total users

Optimal Algorithm (SOA) switch the associated nodes between time slots and bring much switching loss. In Non-cooperative Algorithm (NA) with the worst performance, all users connect with BS and can't perform the distance advantage between users. We further assess the performance of the proposed algorithm, in Fig. 4, by increasing the number of RBs when $|\mathcal{U}| = 20$ and the value of L is 10 Mb. Figure 4 shows that, at all values of the number of RBs, the LOA yields a significant advantage over LOA and NA. When the number of RBs is small, the LOA has better performance. The reason for this result is the less spectrum resources there is, the more important the excellent relay is. In Fig. 5 we set different value for $t_{\max}$ when the value of L is 10 Mb and the number of RBs is 10. The results of Fig. 5 shows how the number of D2D users varies with the number of total users that require the content. From the Fig. 5, we can see that by adjusting the value of $t_{\max}$ the proportion of D2D users can be controlled.

5 Conclusions

In this paper, we integrated long-term D2D communication into cognitive WVN and studied the joint RUEs selection and DUEs association problem from a long-term perspective. Specifically, we have proposed long-term RUEs selection algorithm to choose users act as RUEs and long-term coalition formation game to determine the association relationship of D2D users. Comparing with the existing related works, in this paper we determine the RBs allocation scheme and D2D users' association relationship from a long-term perspective. Numerical results have shown that the proposed scheme yields notable gains relative to both short-term optimal scheme and non-cooperative scheme. The future work will continue to study the issues raised in this work when there are multiple base stations and different users reuse spectrum resources.

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