Heuristic Relay Assignments for Green Relay Assisted Device to Device Communications

Tao Han, Student Member, IEEE, and Nirwan Ansari, Fellow, IEEE
Advanced Networking Laboratory
Department of Electrical and Computer Engineering
New Jersey Institute of Technology, Newark, NJ, 07102, USA
Email: {th36, nirwan.ansari}@njit.edu

Abstract—Device to device (D2D) communications is a promising concept to improve data rates and the energy efficiency of mobile networks. User devices (UEs) participated in D2D communications may increase their own data rates by retrieving the content from their neighboring peers instead of from the base stations. Meanwhile, UEs may drain their batteries while performing as content providers and transmitting the content to their peers. Increasing the data rates of D2D communications is desirable to alleviate the UEs’ power consumption. In this paper, we propose a novel green relay assisted D2D communication architecture, in which the relay nodes powered by green energy are deployed to increase the data rates of D2D communications. However, achieving the optimal relay assignment for green relay assisted D2D communications is challenging. We propose a heuristic green relay assignment algorithm which maximizes the minimum data rates of the D2D pairs while considering the green load capacity of the relay nodes. We show that the proposed algorithm approximates the optimal solution with low computational complexity, and validate its performance by using simulation results.

I. INTRODUCTION

Owing to the direct impact of greenhouse gases on the earth environment and the climate change, the energy consumption of Information and Communications Technology (ICT) is becoming an environmental and thus social and economic issue. Mobile networks are among the major energy hogs of communication networks. Therefore, greening mobile networks is crucial to reducing the carbon footprints of ICT. On the other hand, with the rapid development of mobile networks and user devices (UEs), Internet applications, e.g., web browsing and video streaming, are gradually migrated to mobile networks. As a result, mobile traffic is forecasted to increase exponentially. The increasing mobile traffic not only congests mobile networks, but also intensifies their energy consumption.

Mobile data offloading, which is referred to as utilizing complementary network communication techniques to delivery mobile traffic, is a promising technique to alleviate congestion and reduce the energy consumption of mobile networks [1]. Deploying small cell base stations (BSs), e.g., pico-BSs and femto-BSs, can efficiently offload mobile traffic from macro BSs, thus reducing traffic congestion and the power consumption of cellular networks [2], [3]. However, the lack of cost-effective backhaul connections for small cell BSs often impairs the performance of the small cell BSs in term of traffic offloading. Recently, device to device (D2D) communications as an underlay to cellular networks have been proposed to offload mobile traffic from BSs. For example, by enabling D2D communications, some UEs download content from BSs while the other UEs may retrieve the content through D2D connections from their peers. In this way, D2D communications alleviate traffic congestion and reduce the energy consumption of mobile networks. However, UEs are battery-powered devices, and therefore the energy consumption is a premium concern for UEs to participate in D2D communications. Given UE’s transmission power and the size of the content, the energy consumption involved in delivering the content to another UE is determined by the data rates of the D2D communication link between the UEs. With a higher link data rate, delivering the same content requires less transmission time, and therefore consumes less energy. Thus, increasing data rates of D2D communications is desirable to incentivize UEs to participate in D2D communications as content providers.

In this paper, we propose a novel D2D communication architecture: green relay assisted D2D communications as shown in Fig. 1. Here, we define the UE which delivers the content as the source node while the UE which retrieves the content as the destination node. In green relay assisted D2D communications, we introduce green relay node to increase the link data rate of D2D communications by leveraging cooperative communications [4]. Green relay assisted D2D communications exhibits several advantages: 1) the green relay

Fig. 1. Green relay assisted D2D communications.

This work was supported in part by NSF under grant no. CNS-1147602 and no. CNS-1218181.
nodes can forward the source nodes’ information and increase the transmission data rate between the source and destination nodes, 2) performing as relays, the green relay nodes do not require backhaul connections, 3) the green relay nodes are powered by renewable energy, e.g., solar energy and wind energy, thus not requiring on grid power supplies, 4) the green relay nodes can cache the popular content and enable localized content delivery [5], 5) the green relay node can facilitate the service and peer discovery and the D2D communications session management [6]. We investigate to utilize the green relay nodes to enhance the data rates of D2D communications. In order to enhance the data rates between the source and destination nodes, the green relay nodes should be properly assigned to the source-destination (SD) pairs. Different from traditional relay assignment problems, which assume a relay node is assigned to at most one SD pair, a green relay node can be assigned to multiple SD pairs to increase their data rates. In practical implementations, a green relay node can be a powerful small cell BS but being configured as a relay node. Therefore, a green relay node is able to handle multiple transmissions simultaneously. Hence, a green relay node may be assigned to multiple SD pairs. In addition, since green relay nodes are powered by green energy, green relay node assignments should also consider the availability of green energy in the relay nodes. We propose a heuristic green relay assignment (GRA) algorithm to optimize the relay assignments in green relay assisted D2D communications. The GRA algorithm maximizes the minimum data rates of the SD pairs under the green energy constraint.

II. RELATED WORK

In this section, we briefly overview the related works, which can be classified into two categories. The first one maximizes the utilization of green energy in cellular networks, and the second one optimizes relay assignments in cooperative communications.

A. Optimize green energy utilization

Green energy techniques, in which green energy such as sustainable biofuels, solar and wind energy is able to power BSs, can save the on-grid energy consumed by BSs and reduce the CO2 footprints. Ericsson Inc. [7] has developed a wind-powered tower for BSs of cellular networks. To maximize the utilization of renewable energy, Zhou et al. [8] proposed the HO (Hand Over) parameter tuning algorithm and the power control algorithm to guide mobile users to access the BSs with renewable energy supply. Han and Ansari [9] proposed an energy aware cell size adaptation algorithm named ICE, which balances the energy consumption among BSs powered by green energy, and enables more users to be served with green energy. Considering a network with multiple energy supplies, Han and Ansari [10] also proposed to optimize the utilization of green energy, and reduce the on-grid energy consumption for cellular networks by the cell size optimization.

B. Relay assignments in cooperative networks

Many efforts have been made on studying the relay assignment problem in cooperative communications. Bletsas et al. [11] proposed a distributed relay node selection scheme which selects the relay nodes based on the instantaneous channel condition at the relay nodes. Zhao et al. [12] studied the performance of the cooperative communications system where a source node communicates with a destination node with the help of multiple relay nodes, and showed that choosing one best relay node is sufficient to maintain full diversity order. Wang et al. [13] proposed a game theory based relay selection algorithm for multiuser cooperative communication networks. Sharma et al. [14] studied the relay assignment problem in cooperative ad hoc networks, and proposed a relay assignment algorithm to maximize the minimum data rate among all the SD pairs. While these works investigate the relay assignment problem with different network settings and optimization objectives, they all assume a relay node is assigned to at most one source SD pair. Yang et al. [15] extended the relay assignment problem to consider a relay node being assigned to multiple SD pairs. The authors proposed to maximize the summation of the data rates of all SD pairs, and proved that it is necessary to assign one relay node to only one SD pair in order to achieve the optimal solution. As a result, the proposed algorithm is still to assign a relay node to only one SD pair.

In green relay assisted D2D communications, the relay assignment should incentivize UEs to participate in D2D communications as content providers. Therefore, we aim to maximize the minimum data rates of all SD pairs. With a different optimization objective, the property derived by Yang et al. [15] does not hold. Therefore, we propose the GRA algorithm to enable a relay node being assigned to multiple SD pairs. In addition, since green relay nodes are powered by renewable energy, the proposed relay assignment algorithm also considers the availability of green energy while determining the relay assignments.

III. SYSTEM MODEL

In this paper, we consider a wireless network consisting of 2N UEs and M green relay nodes, and the UEs form N SD pairs. Denote $\mathcal{R} = \{r_1, r_2, \cdots, r_M\}$, $\mathcal{S} = \{s_1, s_2, \cdots, s_N\}$, and $\mathcal{D} = \{d_1, d_2, \cdots, d_n\}$ as the sets of the green relay nodes, the source nodes and the destination nodes, respectively. We assume that orthogonal channels are available in the network, e.g., OFDMA, to avoid interference [14]. We assume all the nodes can only either transmit or receive at a time.

A. Communication Model

Denote $p^s_\mu$ and $p^r_\nu$ as the transmission power of the $i$th source node and the $j$th relay node, respectively. If a node $\mu$ is transmitting a signal to the node $\nu$ with power $p_\mu$, the perceived signal noise ratio (SNR), $\gamma_{\mu \nu}$, at the receiving node is

$$\gamma_{\mu \nu} = \frac{p_\mu}{N_0 ||\mu, \nu||^\alpha}.$$  \hspace{1cm} (1)

Here, $N_0$ is the white noise, $||\mu, \nu||$ is the Euclidean distance between node $\mu$ and $\nu$, and $\alpha$ is the path loss component [15].

In green relay assisted D2D communications, the SD pairs can either transmit data directly or transmit via a green relay
node. If the $i$th SD pair transmits data directly, the achievable data rate is

$$C_D(s_i, d_i) = W \log_2(1 + \eta_{s_i, d_i}). \quad (2)$$

Here, $W$ is the available bandwidth. The SD pair can also transmit via a green relay node with either the Amplify-and-Forward (AF) or Decode-and-Forward (DF) cooperative communication mode. In this paper, we adopt the DF cooperative communication mode. Cooperative communications is illustrated in Fig. 2. In the first time slot, the source node broadcasts the data. Both the destination node and the relay node receive the data. In the second time slot, the relay node forwards the received data to the destination node. For DF cooperative communications, the green relay node decodes the data received in the first time slot, and transmits the decoded data to the destination in the second time slot [16]. Based on DF cooperative communications, the achievable data rate of the $i$th SD pair via the $j$th green relay node is

$$C_{DF}(s_i, r_j, d_i) = \frac{W}{2} \min(\log_2(1 + \eta_{s_i, r_j}), \log_2(1 + \eta_{s_i, d_i} + \eta_{r_j, d_i})). \quad (3)$$

B. Traffic Model

We assume that the traffic generated from the $i$th source node is according to a Poisson process with the average rate equaling to $\lambda_i$, and the traffic loads have a general distribution with average traffic load of $l_i$. The traffic load generated from the $i$th SD pair in the $j$th green relay node is

$$\rho_{i,j} = \frac{\lambda_i l_i \eta_{i,j}}{C_{DF}(s_i, r_j, d_i)} \quad (4)$$

Here, $\eta_{i,j}$ is an indicator function. If $\eta_{i,j} = 1$, the $i$th SD pair transmits via the $j$th green relay node. The average traffic load in the $j$th green relay node is

$$\rho_j = \sum_{i \in S} \rho_{i,j}. \quad (5)$$

This value of $\rho_j$ indicates the fraction of time BS $j$ is busy. Assuming the green relay node serves SD pairs according to the round-robin fashion. Then, the green relay node realizes a M/G/1-processor sharing (PS) queue [17]. If the $j$th green relay node is assigned to multiple SD pairs, the effective data rate of the $i$th SD pair transmitting via the $j$th relay node is

$$C_{ef}(s_i, r_j, d_i) = C_{DF}(s_i, r_j, d_i)(1 - \rho_j). \quad (6)$$

C. Energy Model

In green relay assisted D2D communications, the relay nodes are powered by green energy generated by their solar panels. Owing to the disadvantages of “banking” green energy [18], we do not assume that green energy can be stored. The relay node’s power consumption consists of two parts: the static power consumption and the dynamic power consumption [19]. The static power consumption is the power consumption of a relay node without any traffic load. The dynamic power consumption refers to the additional power consumption caused by traffic load on the relay node, which can be well approximated by a linear function of the traffic load [19]. Denote $c_j^g$ as the static power consumption of the $j$th relay node. Then, the $j$th relay node’s power consumption can be expressed as

$$c_j = \beta_j \rho_j + c_j^g. \quad (7)$$

Here, $\beta_j$ is a linear coefficient which reflects the relationship between the traffic load and the dynamic power consumption in the $j$th relay node. Denote $e_j$ as the energy generation rate in the $j$th relay node. Define the green load capacity as the maximum traffic load that the relay node can support with a given green energy generation rate. Denote $\rho_j^g$ as the green load capacity of the $j$th relay node. If $e_j \leq c_j^g$, which indicates the relay node does not have enough green energy to be turned on, then $\rho_j^g = 0$; otherwise,

$$\rho_j^g = \min\left(\frac{e_j - c_j^g}{\beta_j}, 1 - \epsilon\right). \quad (8)$$

Here, $\epsilon$ is small positive number to guarantee $\rho_j^g < 1$.

D. Problem Formulation

In green relay assisted D2D communications, we aim to maximize the minimum data rate of SD pairs by optimizing the relay assignment. Thus, the green relay assignment problem can be formulated as

$$\max_{\eta} \min_{i \in S} C(s_i, d_i) \quad (9)$$

subject to:

$$\sum_{j \in R} \eta_{i,j} = 1, \quad (10)$$

$$0 \leq \rho_j \leq \rho_j^g. \quad (11)$$

Here,

$$\eta = \begin{pmatrix}
\eta_{1,1}, & \eta_{1,2}, & \cdots, & \eta_{1,M} \\
\eta_{2,1}, & \eta_{2,2}, & \cdots, & \eta_{2,M} \\
\vdots, & \vdots, & \ddots, & \vdots \\
\eta_{N,1}, & \eta_{N,2}, & \cdots, & \eta_{N,M}
\end{pmatrix}. \quad (12)$$

$C(s_i, d_i)$ is the effective data rate of the $i$th SD pair. The constraint (10) indicates a SD pair is assigned to at most one green relay node. The constraint (11) is to guarantee the total power consumption is not larger than the available green energy. The above optimization problem is a mixed integer quadratic constraint problem, which is challenging to solve. A brute-force search, in the worst case, requires $O(M^N)$ iterations to find the optimal green relay assignments. The
computational complexity of the brute-force search increases exponentially with respect to the number of the SD pairs in the network, and is thus not practical for real time applications.

IV. A HEURISTIC GREEN RELAY ASSIGNMENT ALGORITHM

In this section, we propose a heuristic green relay assignment (GRA) algorithm which approaches the optimal solution with low computational complexity. Denote $\hat{\eta}$ as a relay assignment derived by the $(\hat{\eta}, flag) = \text{new\_relay\_search}(s_i, \eta)$ algorithm. flag is an indicator which tells whether $\hat{\eta}$ is a better relay assignment or not. If $flag = 1$, $\hat{\eta}$ is a better assignment. The GRA algorithm, as is shown in Algorithm 1 below, starts with an initial green relay assignment, in which each green relay is assigned to one source node. Then, GRA adjusts the green relay assignment to increase the minimum data rate of the SD pairs during each iteration. Specifically, in each iteration, GRA finds the SD pair, $(s_i, d_i)$, with the minimum data rate and searches for a new green relay assignment to increase the data rate of the SD pair. If a new assignment is found, GRA starts another iteration. Otherwise, GRA checks whether $\hat{\eta}$ as a relay assignment derived by the alternative relay assignment, which solves the relay assignment problem. Suppose we want to find a better relay node. The GRA algorithm clears the markers of the SD pair, $(s_i, d_i)$, assigned to the relay node with the minimum data rate, and under current relay assignment, $s_i$ can only be assigned to $d_i$. If it fails, then $s_i$ is marked, and the algorithm tries to find a better relay assignment. If $s_i$ is marked, the algorithm checks whether $s_i$ can be assigned to $d_i$. If it is successful, a new assignment, $\hat{\eta}$, is found; otherwise, the algorithm checks whether $s_i$ can be assigned to other relay nodes to enable $s_i$ to join $r_2$. In this example, $s_1$ and $s_4$ can only be assigned to $d_2$. $C_D(s_3, d_3) < C(s_1, d_1)$, and $C_D(s_4, d_4) < C(s_1, d_1)$. Therefore, $s_3$ and $s_4$ cannot be removed from $r_2$. $s_5$ has an alternative relay, $r_1$. Then, the recursive algorithm calls itself but with $s_5$ as the input to check whether $s_5$ can be successfully assigned to $r_1$. Suppose it is not successful, then $r_2$ is marked, and the algorithm tries to offload load traffic from unmarked relay nodes to $r_2$. Then, the algorithm checks whether $s_1$ can be successfully assigned to $r_3$ following the same procedures. If it fails, then $s_1$ cannot find a better relay node. The GRA algorithm clears the markers on all the relay nodes and tries to remove $s_2$ from $r_1$ following the same procedures.

There are two key innovations in the proposed heuristic GRA algorithm. The first one is the relay node marking mechanism, which reduces the computational complexity on solving the relay assignment problem. Suppose we want to search a new relay assignment for $s_1$, without the relay node marking mechanism, it requires $M^N$ iterations in the worst case. With the marking mechanism, the GRA algorithm only checks $M$ relay nodes in the worst case. However, the marking mechanism may deteriorate the performance of the algorithm. For example, suppose in the optimal relay assignment, $s_5$ is assigned to $r_1$ and $s_1$ is assigned to $r_2$. If this is the case, with the marking mechanism, the GRA algorithm may fail to find the optimal solution. To reduce the probability of such failure, we introduce the traffic offloading mechanism, which tries to

Algorithm 1 The Heuristic GRA Algorithm

Step 1: Initial relay assignment;
Step 2: Set flag = 0; find $i = \arg\min_{j \in S} C(s_j, d_j)$;
$(\hat{\eta}, flag) = \text{new\_relay\_search}(s_i, \eta)$;
if (flag == 1) then
$\eta = \hat{\eta}$;
Go to step 2;
else
Step 3:
if ($s_i$ share a relay node with other SD pairs) then
Find $S_k = \{j \mid \eta_{j,k} = 1, \hat{\eta}_{i,k} = 1, j \neq i, j \in S\}$
for $j = 1$ : $|S_k|$ do
Clear the markers;
$(\hat{\eta}, flag) = \text{new\_relay\_search}(s_j, \eta)$;
if (flag == 1) then
$\eta = \hat{\eta}$, and break;
end if
end for
if (flag == 1) then
Go to step 2;
end if
end if
end if
Return $\eta$;

Fig. 3. An illustrative example for the recursive algorithm.

for a specified source node. Since Algorithm 2 is a recursive algorithm, we denote $\hat{\eta}$ as an intermediate relay assignment during the recursions. We use an example shown in Fig. 3 to illustrate the recursive algorithm. Suppose $s_1$ is the source node with the minimum data rate, and under current relay assignment, $s_1$ and $s_2$ share the green relay node, $r_1$. GRA first tries to find a better relay assignment for $s_1$. The dotted lines in the figure indicate the alternative relay nodes for a source node. Given $s_1$ and $\eta$, the recursive algorithm finds $s_1$ having two alternative relays, $r_2$ and $r_3$. Since $s_1$ is to be assigned to either $r_2$ or $r_3$, the traffic load on $r_1$ is reduced. Therefore, $r_1$ may be assigned to other source nodes. To increase the possibility that $s_1$ can successfully join $r_2$ or $r_3$, the recursive algorithm firstly tries to offload traffic from $r_2$ and $r_3$, and then offloads traffic from other relays. After that, $r_1$ is marked to avoid being searched again. If $r_2$ is not marked, the algorithm checks whether $s_1$ can be assigned to $r_2$ successfully. If it is successful, a new assignment, $\hat{\eta}$, is found; otherwise, the algorithm checks whether $s_1$ can be assigned to other relay nodes to enable $s_1$ to join $r_2$. In this example, $s_1$ and $s_4$ can only be assigned to $r_2$. $C_D(s_3, d_3) < C(s_1, d_1)$, and $C_D(s_4, d_4) < C(s_1, d_1)$. Therefore, $s_3$ and $s_4$ cannot be removed from $r_2$. $s_5$ has an alternative relay, $r_1$. Then, the recursive algorithm calls itself but with $s_5$ as the input to check whether $s_5$ can be successfully assigned to $r_1$. Suppose it is not successful, then $r_2$ is marked, and the algorithm tries to offload load traffic from unmarked relay nodes to $r_2$. Then, the algorithm checks whether $s_1$ can be successfully assigned to $r_3$ following the same procedures. If it fails, then $s_1$ cannot find a better relay node. The GRA algorithm clears the markers on all the relay nodes and tries to remove $s_2$ from $r_1$ following the same procedures.

Here, a successful assignment means that the assignment increases the minimum data rates of SD pairs in the network.
offload traffic from the unmarked relay nodes to the marked ones. Thus, when \( r_1 \) is marked, the GRA algorithm offloads traffic from the unmarked node, e.g., \( r_2 \). As a result, \( s_5 \) may be offloaded to \( r_1 \), and \( s_1 \) can be assigned to \( r_2 \) successfully. Thus, the optimal assignment is obtained. In each iteration, the computational complexity of the offloading mechanism in the worst case is \( O(N^M) \). Since a SD pair has a choice of up to \( M \) relay nodes, on each relay node, the SD pair can have \( N \) different data rates, the total data rate improvements an individual SD pair can have is limited by \( NM \). Therefore, the computational complexity of the heuristic GRA algorithm is \( O(M^2N(M+3)) \). If we fix the total number of the green relay nodes deployed in an area, then the computational complexity of the heuristic GRA algorithm is polynomial with respect to the number of the SD pairs.

**Algorithm 2 (\( \tilde{\eta}, \text{flag} \) = new relay search(\( s_i, \eta \)))**

Set \( \text{flag} = 0, \tilde{\eta} = \eta \);
Find \( \mathcal{R}_k = \{ k | C_{DF}(s_i, r_k, d_i) > \min_{j \in S} C(s_i, d_i), k \in \mathcal{R} \} \);
if \((C_{DF}(s_i, r_k, d_i) > \min_{j \in S} C(s_i, d_i), \forall k \in \mathcal{R}) \) then
  if \( (\tilde{\eta} = \eta, \exists j \in \mathcal{R}) \) then
    Add SD pairs to the \( j \)th relay, and update \( \eta \);
    end if
  else
    Find \( \mathcal{S}_k = \{ j | \eta_{j,k} = 1, \eta_{i,k} = 1, j \neq i, j \in \mathcal{S} \} \);
    for \( j = 1 : |\mathcal{S}_k| \) do
      \( (\tilde{\eta}, \text{flag}) = \text{new relay search}(s_j, \eta) \);
      if \( \text{flag} == 1 \) then
        \( \tilde{\eta} = \eta \), and break;
      end if
    end for
  end if
end if
for \( k = 1 : |\mathcal{R}_k| \) do
  if \( (r_k \) is not marked) then
    Mark the relay, \( r_k \).
    if \( (s_i \) can be assigned to \( r_k \) then
      Update \( \eta \), set \( \text{flag} = 1 \), break;
    else
      Add SD pairs to the \( j \)th relay, and update \( \eta \);
    end if
  end if
end if
if \( \text{flag} == 0 \) then
  Add SD pairs to the \( j \)th relay, and update \( \eta \);
  Set \( \tilde{\eta} = \eta \);
end if

end for

V. **SIMULATION RESULTS**

Simulations are set up to evaluate the performance of the proposed GRA algorithm in green relay assisted D2D communications. We consider a wireless network in which SD pairs are randomly distributed in a 1000m × 1000m square area. In the simulation, we adopt two green relay deployments as shown in Fig. 4. The first deployment is utilized to compare the performance of the proposed GRA algorithm, the brute-force search, and the ORA algorithm [14]. In this relay deployment, we only consider four green relay nodes to reduce the running time of the brute-force search. The second deployment is utilized to evaluate the performance of the GRA algorithm versus different numbers of users and various green load capacities. In the simulations, the transmission power of the source node and the green relay node is \( 500mW \) and \( 4W \), respectively. The path loss exponent \( \alpha = 4 \), the available bandwidth for each channel \( W = 10MHz \), and the white noise \( N_0 = 10^{-10} \). We assume \( \lambda d_i = 0.4Mbps \), \( \forall i \in \mathcal{S} \).

Fig. 5 compares the minimum data rate of the SD pairs under the proposed GRA algorithm, the brute-force search, and the ORA algorithm [14]. We assume the green load capacity is 1 for all the green relay nodes. As shown in the figure, the proposed GRA algorithm approximates the optimal solution resulted from the brute-force search. One reason for the performance gap between the GRA algorithm and the brute-force search is that during the traffic offloading procedure, the GRA algorithm may not correctly offload traffic to enable a better relay assignment. For example, as shown in Fig. 3, when GRA searches a better relay assignment for \( s_1 \), \( r_1 \) may offload traffic from \( r_2 \) and \( r_3 \). Suppose either \( s_3 \) or \( s_6 \) can be offloaded to \( r_1 \) and offloading \( s_6 \) to \( r_1 \) will enable a better relay assignment for \( s_1 \). However, since GRA offloads the source node sequentially, \( s_3 \) is offloaded to \( r_1 \) which disables \( s_1 \) from obtaining a better relay assignment. The minimum data rates under the ORA algorithm is lower than that of under the GRA algorithm because the ORA algorithm only considers assigning one relay node to only one SD pair.

Fig. 6 and 7 compare the minimum data rates of the SD pairs and the total data rates of the network under the GRA algorithm and the ORA algorithm, respectively. In the simulation, we assume the green load capacity is 1 for all the green relay nodes. As shown in Fig. 6, as the number of
the SD pairs increases, the minimum data rates under both algorithms converge to the same value. This is because as the number of the SD pairs increases, the traffic loads on the relay nodes become heavier. Owing to the heavy traffic, transmitting via relay nodes may not increase the SD pairs’ data rate. Therefore, the minimum data rate of the SD pairs is the direct transmission data rate of certain SD pair. Thus, both GRA and ORA result in the same minimum data rate. However, owing to allowing a relay node to be assigned to multiple SD pairs, as shown in Fig. 7, the total data rates of the network under GRA is much higher than that of under ORA.

Fig. 8 shows the minimum data rate of the SD pairs versus the green load capacity of the relay nodes. In the simulation, $M = 5$, $N = 15$. We assume all the relay nodes have the same green load capacity. As shown in the figure, as the green load capacity increases, the minimum data rate of the SD pairs increases. However, when the green load capacity is larger than 0.7, the minimum data rate of the SD pair almost keeps constant. This indicates that the green load capacity of the green relay nodes no longer limits the performance of the network in the term of the minimum data rate.

VI. CONCLUSION

In this paper, we have proposed novel green relay assisted SD communications, and have designed a heuristic green relay assignment algorithm to maximize the minimum data rate of the SD pairs. The proposed GRA algorithm approximates the optimal solution with low computational complexity. In addition, GRA is green energy aware, and optimizes the relay assignment with the consideration of the green load capacity of the relay nodes.

REFERENCES