Relay Assignment in Cooperative Communication Networks: Distributed Approaches Based on Matching Theory

Yitao Xu[1], Dianxiong Liu[1], Cheng Ding[1], Yuhua Xu[1] and Zongsheng Zhang[2]
[1] PLA University of Science and Technology, China
[e-mails: yitaoxu@126.com, dianxiongliu@163.com, dingchengty@163.com, yuhuaenator@gmail.com]
[2] PLA Academy of National Defense Information, China
[e-mail: Zhangzongsheng1984@163.com]
*Corresponding author: Dianxiong Liu

Received July 30, 2015; revised May 4, 2016; accepted September 26, 2016; published November 30, 2016

Abstract

In this article, we model the distributed relay assignment network as a many-to-one matching market with peer effects. We discuss two scenarios for throughput optimization of relay networks: the scenario of aggregate throughput optimization and the scenario of fairness performance optimization. For the first scenario, we propose a Mutual Benefit-based Deferred Acceptance (MBDA) algorithm to increase the aggregate network throughput. For the second scenario, instead of using the alternative matching scheme, a non-substitution matching algorithm (NSA) is designed to solve the fairness problem. The NSA improves the fairness performance. We prove that both two algorithms converge to a globally stable matching, and discuss the practical implementation. Simulation results show that the performance of MBDA algorithm outperforms existing schemes and is almost the same with the optimal solution in terms of aggregate throughput. Meanwhile, the proposed NSA improves fairness as the scale of the relay network expands.

Keywords: Relay assignment, many-to-one matching, peer effects, mutual benefit, non-substitution model

This work was supported by the Natural Science Foundation for Distinguished Young Scholars of Jiangsu Province under Grant No. BK20160034, the National Natural Science Foundation of China under Grant No. 61401508 and No. 61671473, and in part by the Open Research Foundation of National Key Laboratory of Science and Technology on Information Transmission and Dissemination Technologies in Communication Networks.

http://dx.doi.org/10.3837/tiis.2016.11.014 **ISSN : 1976-7277**

1. Introduction

With the development of wireless networks, demands of data throughput increases rapidly. The problem of spatial diversity and network data throughput optimization become the key issues of network optimization. In wireless network, source nodes with limited transmission power are disadvantageous to transmit to corresponding destination. Cooperative communication [1] is considered to be a promising approach, in which cell-edge source nodes could improve their transmission capacities with relay nodes' assisted. However, the competitive relationship exists among source nodes, and the number of relay nodes is restricted, so the problem of relay assignment is an important and timely issue.

To date, many approaches to develop the relay assignment problem have been proposed. Most of them handled the problem with centralized algorithms [2-8]. The centralized approaches always require a central controller to gather information from all nodes in the network and then make the relay assignment decisions. If the scale of wireless networks expands, optimization problems become increasingly complicated, which will cause heavy system overhead. Aiming at this problem, some distributed algorithms [9-11] have been developed, which may spend lots of time to converge. The main problem of distributed schemes facing is that source nodes do not know other source nodes' choices, which leads to the instability of relay assignment. Therefore, the equilibrium of relay assignment is a conundrum, and solving this problem with limited information exchange is our work.

In this article, the problem of relay assignment is formulated as a many-to-one matching game [12], in which the source nodes and relay nodes rank each other respectively based on the utility functions of throughput capacities. We discuss two scenarios of relay networks for different network performance requirements.

Our main contributions can be summarized as follows:

- We provide a new perspective on the problem of relay assignment, where the relay network is modeled as a many-to-one matching market with peer effects [13], and different schemes are proposed for different scenarios.
- Aiming at the aggregate throughput optimization, we propose a distributed algorithm called: Mutual Benefit-based Deferred Acceptance Algorithm (MBDA), to solve the relay selection problem in cooperative communications. The proposed MBDA overcomes the shortcoming of classic DA algorithm in the matching game [12]. Thinking highly of mutual performance among source nodes rather than the performance of single source node, MBDA remarkably improves throughput capacity of the relay network.
- Aiming at the fairness optimization of global throughput, a distributed Non-Substitution Algorithm (NSA) is proposed. We provide a novel distributed non-substitution matching scheme for matching game instead of classic substitution scheme. NSA promotes the fairness performance for the relay network. By the NSA, all source nodes in the network are considered to improve transmission data rate. The NSA solves the matching problem by suggesting unsatisfactory source nodes to apply better relay nodes. Simulation results show that relay network can tend toward stability and obtain good fairness performance fastly by the NSA.

The remainder of this paper is organized as follows. Related work is introduced in Section 2. In Section 3, we introduce the model framework of the system, including cooperative communication modes, problem formulation and the notion of peer effects. In Section 4, we introduce the proposed MBDA algorithm. We put forward the NSA algorithm and proves the convergence in Section 5. The practicability of the algorithm is discussed in Section 6, and performances of two algorithms are evaluated by experiments in Section 7. Finally, we present the conclusions in Section 8.

2. Related Work

In this section, we give a brief review of the related works on cooperative communication and some related applications of matching game theory in wireless networks.

Since Van der Meulen [14] and Cover and EL Gamal [15] pioneered the concept of cooperative communication, many related works about relay assignment problem have been studied. In [9], Cai et al. proposed a semi-distributed algorithm with a greedy algorithm methodology. Although the algorithm is an effective heuristic search, it offers no performance guarantee. A similar problem had been studied by Xu et al. [16] to minimize the total power consumption of the network. In [17], Yang et al. proposed an optimal relay assignment scheme, and the goal is to maximize the total system performance. In [11], based on stochastic learning automata (SLA), Chen et al. proposed a distributed algorithm to maximize the respective source node capacity of the relay selection network. However, this algorithm is a learning scheme and needs a long time to converge.

Matching game theory has recently attracted a lot of attention in wireless networks, such as cell association [18-21] and cooperative spectrum sharing [22, 23]. In [18], Eduard et al. applied and extended the theory of one-to-one and many-to-one matching markets to the resource allocation in wireless communications. Li et al. studied the incentive-based relay selection problem over multi-source and multi-relay wireless networks in [22]. In [23], Feng et al. studied relay-based communication schemes for cooperative spectrum sharing with incomplete information. However, these works have not considered the practical situation in wireless networks such as peer effects and many-to-one matching market, which is the model studied in this work, and we further scheme out two novel algorithms.

3. System Model and Problem Formulation

3.1 Cooperative Communication Modes

In this section, two modes of cooperation communication: Amplify-and-Forward (AF) and Decode-and-Forward (DF) [24] will be introduced.

1) Amplify-and-Forward (AF) mode: AF mode is a simple method with low-cost implementation. Under this mode, the signals from the source nodes are simply amplified and transmitted to the destination nodes by relay nodes. According to [24], the capacity of AF can be written as:

$$C_{AF}(s,r,d) = \frac{B}{2} \cdot \log_2\left(1+\gamma_{sd}+\frac{\gamma_{sr}\gamma_{rd}}{1+\gamma_{sr}+\gamma_{rd}}\right), \tag{1}$$

where B is the transmitted bandwidth, s, r and d denote the source node, relay node and destination node respectively. $\gamma_{sd}=\frac{p_s h_{s,d}}{\sigma^2}$ means the signal-to-noise-ratio at destination nodes while the signals are from source nodes, with $h_{s,d}$ indicating the channel gain between source node and destination node, p_s denotes the transmit power and σ^2 is the variance of the Gaussian noise. γ_{sr} and γ_{rd} are similar.

2) Decode-and-Forward (DF) mode: Under DF mode, the received signals are demodulated and decoded at relay nodes, and relay nodes modulate and encode signals again before transmit them to destination nodes. The capacity of DF can be written as [24]:

$$C_{DF}(s,r,d) = \frac{B}{2}\cdot\log_2\left(\min\{1+\gamma_{sr}, 1+\gamma_{sd}+\gamma_{rd}\}\right). \tag{2}$$

3) Direct Transmission: If one source node communicates with the destination node directly without using relay nodes, it is called the direct transmission, and the capacity of transmission can be written as [24]:

$$C_D(s,d) = B\cdot\log_2(1+\gamma_{sd}). \tag{3}$$

3.2 Network Model

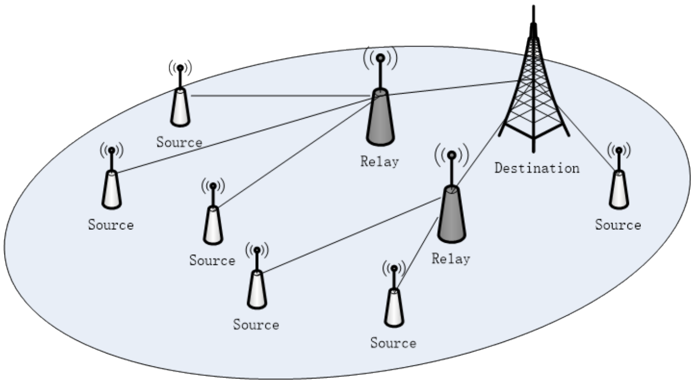


Fig. 1. A system model for multiple source nodes and relay nodes with one destination.

There are *N* source nodes, *M* relay nodes and *K* destination nodes in the relay network. We use $\mathcal{S}=\{s_1,s_2,\ldots,s_n,\ldots,s_N\}$ to denote the set of source nodes, $\mathcal{R}=\{r_1,r_2,\ldots,r_m,\ldots,r_M\}$ to denote the available *M* relay nodes, and $\mathcal{D}=\{d_1,d_2,\ldots,d_k,\ldots,d_K\}$ to denote the destination nodes. Source nodes apply relay nodes to get cooperative diversity. One source node s_n will choose direct transmission if the obtained capacities assisted by relay nodes are all lower than direct transmission. The system model is shown in **Fig. 1**, in which each source node have multiple choices to pick, and it can share the transmission resources of one relay nodes with other source nodes.

We suppose that all devices are equipped with a single antenna and work in half-duplex mode. The structure of transmission is that each frame is divided into two time slots, as shown in **Fig. 2**. One slot in one frame is used for the source node to the relay node, and the other is the relay node to the destination node. Therefore, they are unable to transmit and receive simultaneously. The capacity of s_n transmitting with d_k assisted by a relay node r_m can be written as:

$$C_R\left(\gamma_{s_n r_m}, \gamma_{s_n d_k}, \gamma_{r_m d_k}\right), \tag{4}$$

where the $C_R(\cdot)$ means that $C_R = C_{AF}$ if AF is used, and $C_R = C_{DF}$ if DF is used, that is

$$C_R(\cdot)=\begin{cases} C_{AF}(\cdot)=\frac{B}{2}log_2\left(1+\gamma_{sd}+\frac{\gamma_{sr}\gamma_{rd}}{1+\gamma_{sr}+\gamma_{rd}}\right) & for\ \text{AF} \\ C_{DF}(\cdot)=\frac{B}{2}log_2\left(min\{1+\gamma_{sr},1+\gamma_{sd}+\gamma_{rd}\}\right) & for\ \text{DF.} \end{cases} \tag{5}$$

If s_n selects the direct transmission, the capacity can be written as:

$$B\cdot log_2\left(1+\gamma_{s_nd_k}\right). \tag{6}$$

In addition, multiple source nodes equally share the time resources if they have a same relay choice. The relay nodes serve the source nodes in a frame-by-frame fashion, what can be seen in **Fig. 2**. We use $L(r_m)$ to denote the number of source nodes which use the relay node r_m. Considering the $L(r_m)$, the real data rate of one source node s_n is

$$U\left(s_n,r_m,d_k\right)=\begin{cases} \frac{1}{L\left(r_m\right)}\cdot C_R\left(\gamma_{s_nr_m},\gamma_{s_nd_k},\gamma_{r_md_k}\right),\ if\quad r_m\neq\varnothing \\ B\cdot log_2\left(1+\gamma_{s_nd_k}\right),\ if\quad r_m=\varnothing \end{cases}, \tag{7}$$

where $r_m\neq\varnothing$ means that s_n transmits to d_k with the help of relay node r_m, and $r_m=\varnothing$ means that s_n transmits to d_k directly.

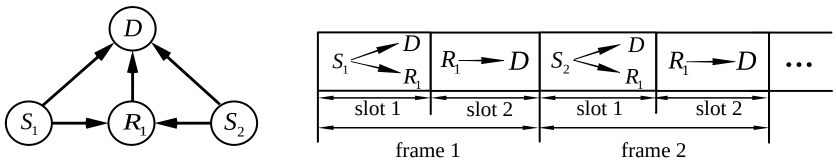


Fig. 2. A cooperative communication example of two source nodes with one relay node.

3.3 Problem Formulation

According to the network model, the problem of cooperative communication could be considered as a process of mutual selection among relay nodes and source nodes. For pairs of source-relay nodes, each source node aims to find the relay nodes offering largest capacity, so as to achieve the respective capacity requirements. In order to formalize the source-relay association problem, we define the utility function for one source node $s_n\in\mathcal{S}$ serviced by a relay node $r_m\in\mathcal{R}$ as

$$U_n\left(s_n,r_m,d_k\right). \tag{8}$$

Each relay node services source nodes connected to it and equally assign its transmission time slots. One relay node knows the information about the source nodes transmitting to it, and it prefers to connect to the source nodes with large capacity in order to maximize its own capacity. The transmission capacity of one relay node r_m can be written as

$$U_m=\sum_{n\in N}U_n\left(s_n,r_m,d_k\right)I(s_n,r_m)\ , \tag{9}$$

where $I(s_n,r_m)$ is an indicator function and equals to 1 if the source node s_n successfully connects to the relay node r_m, or else equals to 0.

On one hand, in order to obtain maximum data rates, source nodes prefer to choose relay nodes which can provide higher capacity to them. However, we can see that if plenty of source nodes transmit to one relay node simultaneously, the real capacity of source nodes obtained will be far less than the ideal value. On the other hand, relay nodes also prefer the source nodes which have high data rates. Designing a reasonable relay assignment is a contradictory problem if the number of relay nodes is limited. One relay node r_m may be the best choice for one source node s_n, but s_n may not the best applicant for r_m. Furthermore, there is inappropriate to coordinate the gobal network by central dispatch systems in large-scale systems. Accordingly, distributed approaches need to be proposed in which source nodes and relay nodes autonomously decide on the best sources-relays association, based on their individual objectives of throughput. Avoiding combinatorial complexity, we introduce a suitable tool for developing such a self-organizing configuration approach based on the matching games:

Definition 1 [25]**:** A two-sided matching game is defined by two sets of players ($\mathcal{M},\mathcal{N}$) and two preference relations $\succ_m$, $\succ_n$, permitting each player $m \in \mathcal{M}$, $n \in \mathcal{N}$ to construct preference lists over one another, i.e., to rank the players in $\mathcal{N}$ and $\mathcal{M}$ respectively.

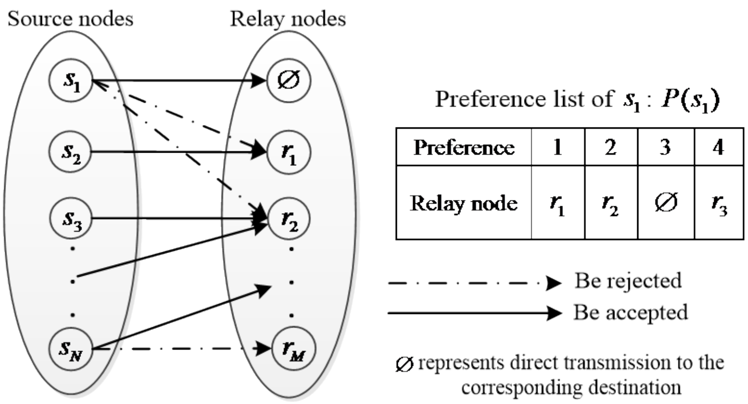
Zhao et al. in [3] pointed out that it is effective to choose the best relay node rather than multiple relay nodes participate in relay networks. Therefore, it is suitable to model the system model as the many-to-one matching market. In a many-to-one matching market model, two sets of players both individually keep preference lists so as to make best choices. One source node is allowed to connect to one relay node at most, while one relay node could keep connections with multiple source nodes simultaneously.

Definition 2 [25]**:** In the many-to-one matching model, the matching μ is a mapping relationship that is from an assemblage $\mathcal{M} \cup \mathcal{N}$ to another assemblage composed by the subaggregate of $\mathcal{M} \cup \mathcal{N}$. μ should meet the conditions for all of $m \in \mathcal{M}$, $n \in \mathcal{N}$:

(i) $\mu(n) \in \mathcal{M} \cup \{\varnothing\}$, $\mu(m) \in \mathcal{N}$; (10)

(ii) $m = \mu(n) \Leftrightarrow n \in \mu(m)$. (11)

μ represents a mapping relation in condition (i), and condition (ii) indicates the characteristics of both sides: once a source node associates with a relay node, it means the relay node accepts the source node.



Preference	1	2	3	4
Relay node	r_1	r_2	$\varnothing$	r_3

Fig. 3. An example of many-to-one matching model.

Every subset of source nodes $n \in \mathcal{N}$ in $\mathcal{M}$ are provided with strict, complete and transitive preference $P(s_n)$. An example of many-to-one matching model is shown in **Fig. 3**. The preference of source node s_1 is performed with $P(s_1) = r_1, r_2, \varnothing, r_3$. This preference list indicates that source node s_1 prefer to associate with one relay node r_1. If r_1 refuses the application from s_1, s_1 will apply to the next preferable relay node for connection, and so on. With the group of source nodes $m \subseteq \mathcal{M}$ and preference lists *P*, each source node confirms that the relay node it selected is the preferred one.

3.4 Peer Effects

In this work, the preference decision of each source node depends not only on its own choice, but also the number of other source nodes which use the same relay node. This situation impacts their obtained throughput capacity greatly. In the matching game theory, such problems are defined as peer effects [13]. Based on this case, each source node doesn't simply care about how much ideal capacity it can obtain assisted by one relay node, but also cares about how many and what kinds of source nodes will become its "peer". It means that the selection strategies of one source node will be impacted by the choices of other source nodes dynamically. For example, if only one source node s_n chooses a relay node r_m, it would get the maximal capacity that is higher than else capacity of matching results:

$$U_n(s_n, r_m, d_k) \geq \forall U(\mu_{nj}), 0 < j < M, \tag{12}$$

where μ_{nj} represents the matching between source node s_n and relay node r_j. However, if another source node has a same choice with s_n, the capacity of s_n will become as $\frac{U_n(s_n, r_m, d_k)}{2}$. If the situation $\frac{U_n(s_n, r_m, d_k)}{2} < \exists U(\mu_{nj}), (0 < j < M)$ exists, which means some matching results are better than the current matching, s_n will change its preference choice, while the new choice would trigger a new instability as well. Therefore, the strategies of relay selection will be more complicated due to the peer effects. There is a need to develop new algorithms that significantly differ from existing applications of matching theory in wireless such as [18-23], so as to find the solutions of the studied many-to-one matching game.

4. Matching Game for Aggregate Throughput Optimization

For the application of matching game in wireless network models, the classic DA algorithm [12] has been adopted or improved to solve selection problems in some literatures [18, 20, 26]. In this section, we analyze the characteristic and shortcoming of the DA algorithm in relay network. After that, MBDA will be introduced to ameliorate the aggregate performance.

4.1 The Deferred Acceptance (DA) Algorithm

DA algorithm [12] is attempting to solve a two-sided matching problem by accepting best choices and refusing the others repectively. The characteristics of DA algorithm are as follow: 1) Each relay node doesn't care about the capacity of global network, while tries to maximal its throughput selfishly; 2) Each source node submits the application, and chooses the optimal relay node; 3) Each relay node accepts the optimal source nodes to maximize its capacity, while other source nodes will not be accepted, because the goal of the relay node is to achieve the maximum utility.

Based on the characteristics above, the source nodes with largest capacity in preference lists can be matched firstly, and then the second one which doesn't collide with the first one can be matched subsequently, and so on. Finally, the rest source nodes will directly transmit to the corresponding destination. The selfish feature of the classic DA algorithm will be adverse to the global capacities. For the sake of the global capacities improvement, we propose the distributed mutual benefit-based deferred acceptance algorithm.

4.2 Proposed Mutual Benefit-based Deferred Acceptance Algorithm

In the MBDA, each source node will send a proposal to a better relay node if the source node is unsatisfied with current association. Dealing with the proposal, each relay node cares about the aggregate utility change after connection exchange of two relay nodes, which differs from the DA algorithm.

The program of MBDA algorithm is given as Algorithm 1, composed of three phases: construct relay preference lists, update the preference lists of source nodes, and output the stable matching μ. The main ideas of MBDA are as follows. Each source node sends a proposal to their preferred relay node by its own preference list, and offers the information of current association and throughput to relay node. One relay node would filter source nodes according to the information of source nodes. If the application is from one source node keeping an association but unsatisfied, the relay node will consider the aggregate utility of two relay nodes, or else it will only compare capacity of all source nodes and accept the best one. If one source node is rejected, it will update the preference list and apply to next relay node. Finally, the network outputs a stable matching for transmission. To meet the situation of dynamic network, the matching would be updated regularly.

Theorem 1: *The proposed mutual benefit-based deferred acceptance (MBDA) algorithm shown in Algorithm 1 converges to a stable matching.*

Proof: The process of the iterations could be considered as two situations. One is homeless source nodes applying to association. In this situation, only the throughput of chosen relay node need to be considered. The aggregate capacities will be promoted if the application succeeds. Another situation is applying by unsatisfied source nodes. For this situation, the aggregate capacities of two relay nodes should be considered. Similarly, if the applications succeed, aggregate capacities will be improved. Therefore, we set the process of iteration as *x*, the aggregate capacities as *y*, and the mapping relation as $y = f(x)$. This is a monotone increasing function, and *y* is limited in the networks. This function will converge to a stable value, so the proof of convergence has achieved.

A example of different matching results by two algorithms is shown in **Fig. 4**. The number in the cell of row r_m and column s_n is the achievable utility for source node s_n, when relay node r_m is exclusively assigned to it. The symbol $\varnothing$ represents the direct transmission. When the capacity of association listed as **Fig. 4(a)**, the throughput result of DA algorithm can be seen in **Fig. 4(b)**. We can see that source nodes with higher performance have higher option priority, so the result of DA is 25. Comparing with the DA, the proposed MBDA approach will lead to the matching shown as **Fig. 4(c)**. In the MBDA, source nodes s_1 and s_2 would exchange their matching relay nodes association based on **Fig. 4(b)** because of $U(s_1,\varnothing)+U(s_2,r_1)>U(s_1,r_1)+U(s_2,\varnothing)$. Similar result exists in the matching confliction between s_4 with s_5. Owing to the proposed scheme, the global throughput capacity is improved.

Algorithm 1: Mutual Benefit-based Deferred Acceptance (MBDA) Algorithm.

Data: Each relay node broadcasts its location information.
Result: Converge to a stable matching μ .

Phase I - Construct relay node preference lists.

Source nodes construct their own preference lists by the ranking value of capacity.

Source nodes apply for association with relay node according to the preference lists.

Phase II - Update the preference lists of source nodes.

Repeat: for each source node $s_n \in \mathcal{S}$ in parallel:

Relay nodes only keep connection with maximal source nodes and refuse other applicants.
Source nodes update the utilities $U_n\left(s_n, r_m, d_k\right)$ and preference list based on the current μ .

Source nodes and relay nodes are sorted by $\succ_m$ and $\succ_n$.

Homeless or unsatisfied source nodes (s_n) apply new relay nodes r_m (serving for s_i currently) in its preference list.

if s_n is a homeless source node

if $s_n \succ_m s_i$

Relay node r_m holds the new applicant.

else

Relay node r_m rejects s_n, and s_n sends a proposal to next preference relay node.

end

else if s_n is an unsatisfied source node

if the aggregate throughputs of two relay nodes can be promoted after selection exchange, that is $U(s_n, r_m) + U(s_i, r_j) > U(s_i, r_m) + U(s_n, r_j)$, where we set current matching is s_n linking with r_j and s_i linking with r_m

Source nodes exchange the selection of relay nodes.

end

end

end

Until no matching is changed at the previous round.

Phase III - Network outputs a stable matching.
Updated regularly.

Objectively, we could observe that the results of the MBDA and DA algorithm preferably assign a relay node to at most one source node to achieve the high aggregate utility. This selection tendency is similar with the result of the optimal centralized relay assignment approach [17]. The authors in [17] have pointed out and proved that for the relay assignment problem, each relay node is assigned to at most one source node which will lead to maximized total capacity. Therefore, we could observe that the result of the MBDA and DA algorithm preferably assign a relay node to at most one source node to achieve the high aggregate utility, although we allow multiple source nodes to share a common relay node in our model.

(a)

	s_1	s_2	s_3	s_4	s_5
r_1	11	10	6	6	8
r_2	7	8	4	10	9
∅	5	2	1	3	1

: Matching result

(b)

	s_1	s_2	s_3	s_4	s_5
r_1	11	10	6	6	8
r_2	7	8	4	10	9
∅	5	2	1	3	1

C_{sum}=11+2+1+10+1=25

(c)

	s_1	s_2	s_3	s_4	s_5
r_1	11	10	6	6	8
r_2	7	8	4	10	9
∅	5	2	1	3	1

C_{sum}=5+10+1+3+9=28

Fig. 4. Matching results of an example with 5 source-destination pairs and 2 relay nodes.

5. Matching Game for Fairness Optimization and Non-Substitution Model

With the characteristics of substitution and peer effects, one relay node would accept the optimal one source node. In order to maximize the global transmission capacity, maximizing each association capacity is considered in MBDA algorithms. Although the aggregate troughput of the network is improved, this matching scheme is unfair for many source nodes which are compelled to associate with the destination directly. Therefore, this model is not suitable for some communication network systems which require fairness. In order to achieve the fairness in relay network, we will bring forward the solving method.

We study the fairness optimization of global throughput in relay networks. In the classic matching game model, two-sided players will only strictly accept the best strategies for their own, the trait of which is alternative. Most of existing works [18-23] are also based on substitution preference setting, but the setting will lose efficacy when the interrelationship among the players cannot be ignored. Supposed to meet the source nodes demand, alternative relay selection system is unsuitable. It means that not only the aggregate capacities, but the improvement of respective utility should be considered in the network. For example in **Fig. 4(c)**, the method to improve respective capacity considering about s_1, s_3 and s_4 should be proposed, which is different with the traditional alternative matching game scheme for this network.

Extending the matching theory, we design a non-substitution matching model and propose a novel strategy for this model. In the wireless network with limited relay nodes, the number of source nodes is more than that of relay nodes. To meet the demand of source nodes as fair as possible, the situation of multiple source nodes connecting to one relay node simultaneously must occurs, even though this situation may reduce the sum of transmission capacity. We define this situation as non-substitution preference of matching game model. Each source node in the network is supposed to share resource with others, so as to achieve the fairness for global network system. Therefore, most of source nodes can improve their transmission utility by associating with relay nodes. To achieve this objective, we propose a novel algorithm called Non-substitution algorithm shown in Algorithm 2.

The main ideas of the Non-substitution algorithm are as follows. All source nodes in the network construct their own preference lists and apply for association with selected relay node. Relay nodes keep all of source nodes relation and give the feedback of transmission capacity to source nodes. Then, source nodes compare current utility with the throughput of direct transmission to destination node. Source node s_n will give up incumbent association and apply to next preference relay node if incumbent association is worse than direct transmission, that is $U(s_n, r_m, d_k) < U(s_n, \varnothing, d_k)$. Each homeless source node doesn't stop updating preference list until associating with the destination directly. Meanwhile, each relay node randomly urges one source node to find a better relay node. One relay node will accept the new applicant if it improves the total capacity of two relay nodes. To adapt with the dynamic wireless network, the matching would be updated regularly.

Algorithm 2: Non-Substitution Algorithm (NSA)

Data: Each relay node broadcasts its location information.
Result: Converge to a stable matching μ.

Phase I - Construct relay preference lists.
Source nodes construct their own preference lists by the ranking relay node according capacities.
Source nodes apply for association to relay nodes according to the priority list.
Relay nodes accept all of appliation and give the feedbacks of transmission information

Phase II - Update the preference lists of source nodes.
Repeat: for each source node $s_n \in \mathcal{S}$ in parallel:
Step 1. ***while*** $U(s_n, r_m, d_k) < U(s_n, \varnothing, d_k)$ ***do***
s_n gives up current association, changing the preference order.
Until $\exists\ U(s_n, r_j, d_k) \geq U(s_n, \varnothing, d_k)$, $r_j \in \mathcal{R} \bigcup \varnothing$.
end while
Step 2. For source nodes $s_n \in \mathcal{S}$ connecting to r_m, Relay node r_m randomly suggests one source node s_n to find a better relay node to settle down.
if $\exists\ U(s_n, r_j, d_k) > U(s_n, r_m, d_k)$, $r_j \in \mathcal{R} \bigcup \varnothing$
s_n applys r_j for connection.
if Aggregate capacities of two relay nodes $U(r_m) + U(r_j)$ will be improved
Relay node r_j accepts s_n.
end
end

Until no matching is changed at the previous round.

Phase III - Network outputs a stable matching.
Updated regularly.

Theorem 2: *Adopting the NSA shown in Algorithm 2, the relay assignment networks will converge to a stable matching.*

Proof: The algorithm can be considered in two parts, which are Step 1 and Step 2 shown in Algorithm 2. We analyse the Step1 firstly. Suppose that one source node s_n chooses the preferred relay node r_n initially under the ideal assume, we assume that the transmission via r_n is *K* times higher than direct transmission, that means s_n could endure *K*-1 peers at most via r_n. If the practical capacity via r_n is smaller than direct transmission, s_n will find a new relay node r_m in which the number of peers is fewer than *K*-1 at least to apply. If this adjustment lead to a new unstable in r_m, the unsatisfied source node will find a new relay selection in which the number of peers is fewer than *K*-2 at least to apply, and so on. The endurance edge of the peers' number will decrease until reach the minimum value. The worst situation is that some source nodes can endure only one peer, so the adjustment may lead them to connect to destination directly.

Analysing the Step 2, we could prove the convergence similar to Step 1. We suppose that one source node s_n chooses the preferred relay node r_n initially and s_n could endure the number of *K*-1 peers at most via r_n. If the capacity of s_n is suggested to adjust its selection, it will select one relay node in which the number of peer fewer than *K*-1. The adjustment may cause unstabitily of the new relay node r_j if the s_n causes another source node s_m's obtained data rate lower than direct transmission. The source node s_m will adjust to choose another relay node, in which the number of peer at least fewer than *K*-2. If the s_n does not cause another source node's obtained data rate lower than direct transmission, this adjustment will not cause unstabitily of the new relay node r_j. The endurance edge of the peers' number will decrease until reach the minimum value. Two steps in Algorithm 2 will mutually impel the other step and lead to the relay network convergence.□

NSA doesn't cause all source nodes to connect to the destination node directly, because in the Phase I of the proposed NSA, relay nodes accept all the demands from source nodes, and transmit information. Each source node will not give up the relay node r_m unless $U(s_n, r_m, d_k) < U(s_n, \varnothing, d_k)$ or $\exists\, \mu(s_n, r_j) \succ_n \mu(s_n, r_m)$. Nevertheless, if no choice is better than the direct transmission to the corresponding destination, one source node will select the direct transmission.

Each source node in relay network gets transmission utility improvement as much as possible by NSA. Following the distributed idea, this algorithm commendably solves the fairness problem in the relay network, and achieves global optimization of relay assignment. The relay nodes are shared effectively by source nodes to reach the global equilibration.

6. Implementation Discussion of the Proposed Schemes

In this section, we discuss the implementation of the proposed schemes and show that our schemes are practical in wireless relay networks. As shown in **Fig. 5**, the specific processes of the communication are:

1) Relay broadcast: Relay nodes regularly broadcast themselves location information.

2) MBS broadcast: In particular channel CH_0, Macrocell base station regularly broadcasts to all source nodes in the network and provides a certain time slot (duration T) opportunities for source nodes applying to relay nodes.

3) Unified access: Within the time slot ($t < T$), source nodes apply to preferred relay nodes, and relay nodes accept all of application this time period. Relay nodes give the feedback of real throughput source nodes obtained, and rank them by size of throughput.

4) Adjusting: All nodes adjust their matching by the proposed schemes.

Here, we consider and address following issues to prove that our schemes are realizable in practical wireless networks:

1) In adjusting process, multiple source nodes may apply to one relay node at the same time. Dealing with the collision, relay nodes accept applicants in order of arrival, and give the

rejected feedback to the other source nodes. The rejected source nodes receive the feedback, exploring and applying again. Similarly, relay nodes give a feedback to accepted source node. Former relay nodes don't delete source nodes until them receive replacement feedback from source nodes which make sure to leave. An example is shown in **Fig. 6**.

2) Deleting and receiving source nodes information of relay nodes don't interrelate in the NSA. If one applicant source node s_n satisfies with the capacity that one relay node r_m provided before the relay node r_m updating information, it will obtain more capacity when the relay r_m deletes some source node information which make sure to leave. Likewise, if one linking source node s_n is unsatisfied with utility relay node r_m provided already, the more dissatisfaction that new peer caused will be nothing serious.

3) For the NSA, some source nodes may enter the network in Adjusting process. The network deal with these source nodes according to the principle of Step 2 in Algorithm 2.

Fig. 5. Specific process of the communication in relay assignment network.

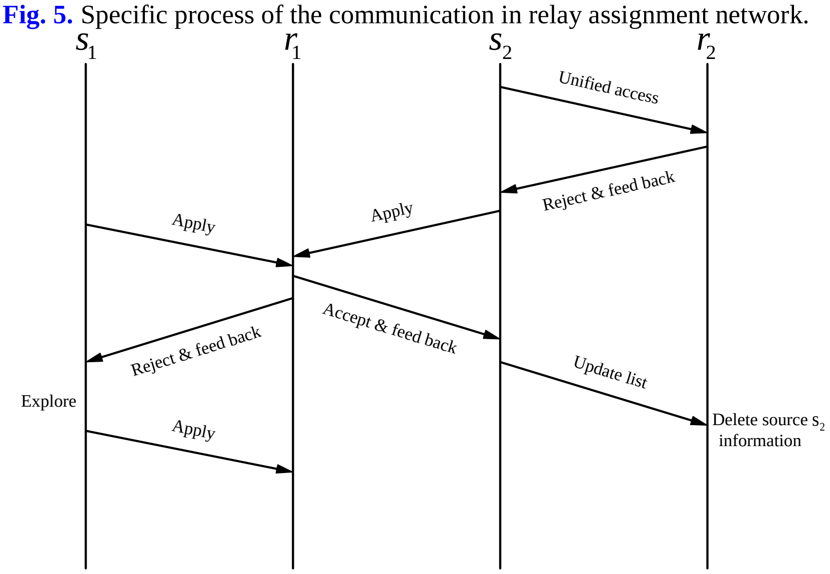


Fig. 6. An example of the application process in relay assignment network.

4) For the proposed algorithms, one relay node in the wireless network knows another relay node's information by the applicants. When the leaving source node submits the application to the new relay node, it will carry the former information to the relay node, so that the relay node could compare the information of exchange and make a choice.

5) In the wireless network, one source node knows the real capacity according to the information received. A source node would receive a physical downlink control channel (PDCCH) which contains information detailing when it connects to a relay node. The source node reports the channel information to the relay node by channel quality index (CQI), and the source node understands the modulation and coding scheme (MCS) it using [11].

In this paper, implementation of transmission model is ideal. In our future work, many-to-one models with collisions will be considered [27], and more specific models will be applied such as wireless local area networks (WLANs) [28].

7. Simulation Results

In the simulations, we use the following default settings. There is a 2000 × 2000 square area, where we assume all source nodes have a same destination. In this topology, there are series of source nodes, relay nodes and one destination node at position (1000, 1000). All source nodes transmit data to the destination, and the experimental parameters follow the simulation methodologies of 3GPP specifications [29]. The maximum transmission power of source nodes are set to 23 dBm and relay nodes are set to 30 dBm. Assume B = 10 MHz bandwidth for each channel of the system, and the noise power density of the system is -174 dBm/Hz. Without loss of generality, we adopt DF model in this paper and the results can extend to AF or hybrid mode.

7.1 The performance comparison for MBDA

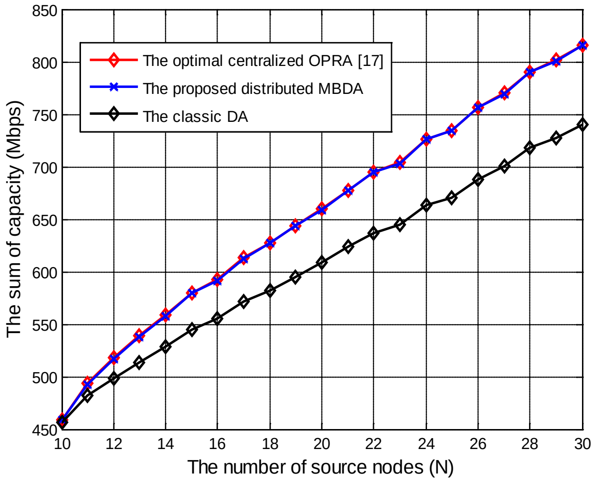
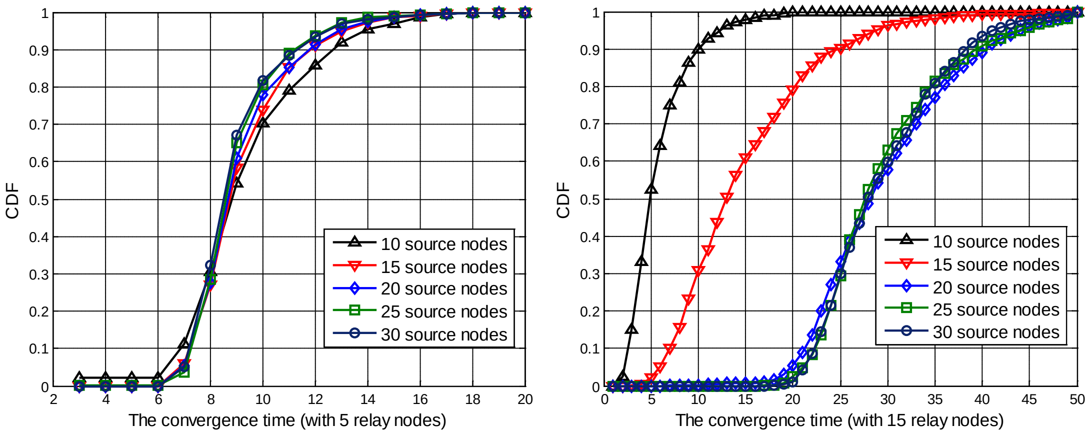


Fig. 7. Comparison of the average aggregate throughputs result from average value of 1000 times calculation (10 relay nodes with varied number of source nodes).

In this subsection, the performance of MBDA is discussed and analysed by the simulation results. In **Fig. 7**, the performances of aggregate capacities are compared between the MBDA with the classic DA approach and the optimal centralized approach (OPRA) [17]. The number of relay nodes is fixed and source nodes increases from 10 to 30. The results are obtained by independently simulating 1000 topologies and then taking the expected values. **Fig. 7** shows that, as the number of source nodes increases, the MBDA is more and better than the classic DA. Moreover, the proposed distributed MBDA is compared with the optimal centralized algorithm for all network sizes. In [17], the authors proposed a centralized algorithm (OPRA) to optimize the relay selection connection. However, the centralized OPRA requires a central controller to gather information from all nodes in the network which may cause heavy system overhead. As shown in the **Fig. 7**, the proposed distributed MBDA is almost the same with the optimal centralized OPRA for all network sizes, which validates the aggregate throughput performance of the MBDA.

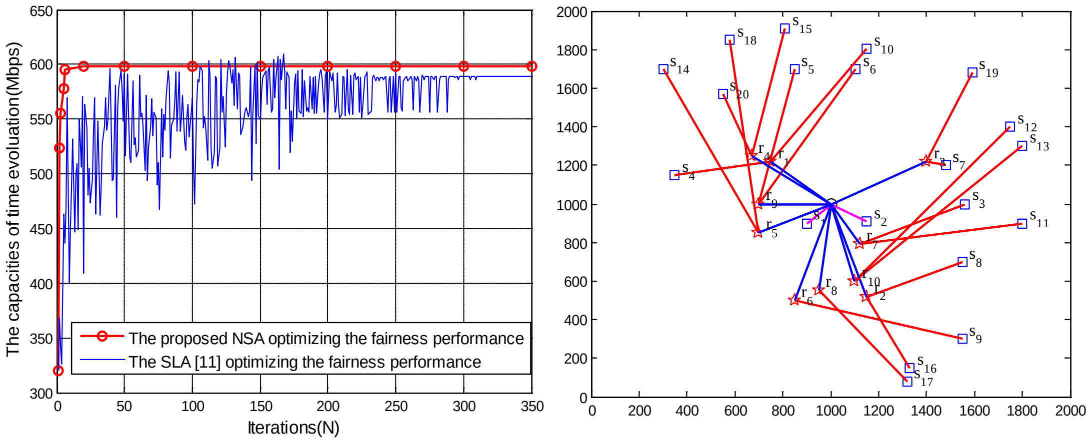
Fig. 8 represents the cumulative distribution function (CDF) for the convergence time of MBDA. The result of the proposed approach is by simulating 1000 independent trials. In this **Fig. 8 (a)** and **(b)**, we can see that, as the number of source nodes increases, the average number of iterations increases due to the increase in the number of players. With the number of nodes increases, the collisions among source nodes also increase. However, the collisions have a upper boundary finally because the relay network becomes a saturated state. **Fig. 8** demonstrates that the proposed matching approach has a reasonable convergence time that does not exceed 50 iterations for the network with 30 source nodes and 15 relay nodes. The CDF tendencies will be stable when the number of source nodes increases unceasingly. Particularly in **Fig. 8(b)**, when the number of source nodes increases from 20 to 50, the convergence time has almost not changed, which shows that the proposed MBDA is scalable to the large scale networks. The results validate the convergence of the proposed distributed MBDA.



(a) 5 relay nodes (b) 15 relay nodes

Fig. 8. The CDF of the proposed MBDA with different numbers of source nodes and relay nodes.

7.2 The performance comparison for NSA



(a) Capacity evolution results (b) The network topology and the connection by NSA.

Fig. 9. Comparison of capacities evolution and convergence speed with the network topology of 20 souce nodes and 10 relay nodes.

In this subsection, the performance of NSA is discussed and analysed with the simulation results. In **Fig. 9(a)**, the evolution result of the matching process of NSA is compared with the Stochastic Learning Automata (SLA) [11]. The SLA scheme is also a distributed algorithm. Comparing with the SLA, we could see that the proposed NSA algorithm converges faster than SLA significantly and finally achieves higher throughput than that of the SLA. **Fig. 9(b)** shows the network topology of the simulation and the corresponding relay selection results of the NSA algorithm. The connections results are represented by the solid lines. The simulation result shows that the proposed NSA can achieve a good stable matching result with a faster convergence time compared with the SLA approach.

The analyses of fairness in multiple models will be given. The Gini coefficient [30] of the proposed NSA is compared with that of the SLA [11], DA and direct transmission, and Gini coefficient is given,

$$\widehat{G} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\left|U_i - U_j\right|}{2N^2 \cdot \overline{U}}, \tag{13}$$

where U_i means the capacity source node s_i obtained, and N is the number of source nodes. The mean value is denoted by $\overline{U}$. The value of the Gini coefficient indicates the level of absolute fairness in network system, and lower value means higher fairness level. The $\widehat{G} = 0$ if all source nodes have the same throughput level.

We can see in **Fig. 10** that the performance of all schemes decreases as the number of source nodes increases, due to the ability limited of relay nodes. The values of NSA are significantly better than the DA and direct transmission among different scale of models. For example, when the number of source nodes set as 30, the value of NSA is 0.39 while the values of DA and direct transmission are higher than 0.58. Moreover, it is noted that the values of the proposed NSA is very close to that of the SLA, and the performance will be equal when the number of source node more than 29. The SLA should take a long time to converge and its throughput performance is worse than NSA. Thus, the NSA is more practical than the SLA algorithm in network systems.

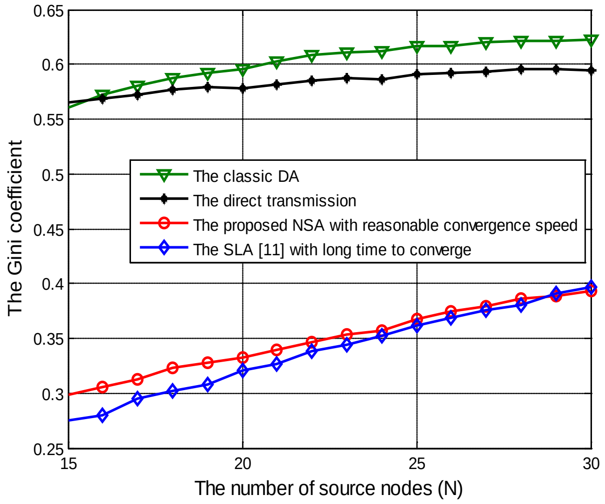


Fig. 10. The Gini coefficient of the algorithms (5 relay nodes with varied numbers of source nodes).

Moreover, Jain's fairness index (JFI) [31] is also used as the criterion of comparison among the algorithms, and JFI is:

$$V_{JFI} = \frac{\left(\sum_{n=1}^{N} U_n\right)^2}{N \cdot \sum_{n=1}^{N} {U_n}^2}. \tag{14}$$

The value of V_{JFI} indicates the level of absolute fairness in the network, and higher value means higher fairness level. The value of JFI will arrive at the largest value 1 if all source nodes obtain equal data rate.

The fairness index (JFI) of NSA, SLA [11], DA and direct transmission can be seen in **Fig. 11**. We can see that the values of NSA are significantly higher than the DA and direct transmission among different scale of models. It is noted that the JFI of the proposed NSA is very close to that of SLA, and is better than SLA when the number of source nodes more than 25. Thus, the fairness performances of the NSA are validated by different fairness criterions.

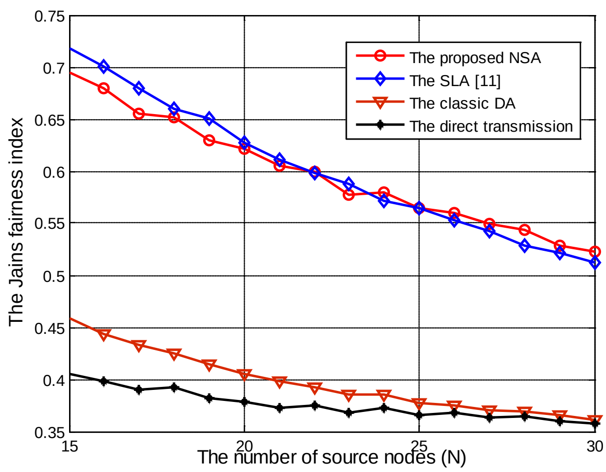
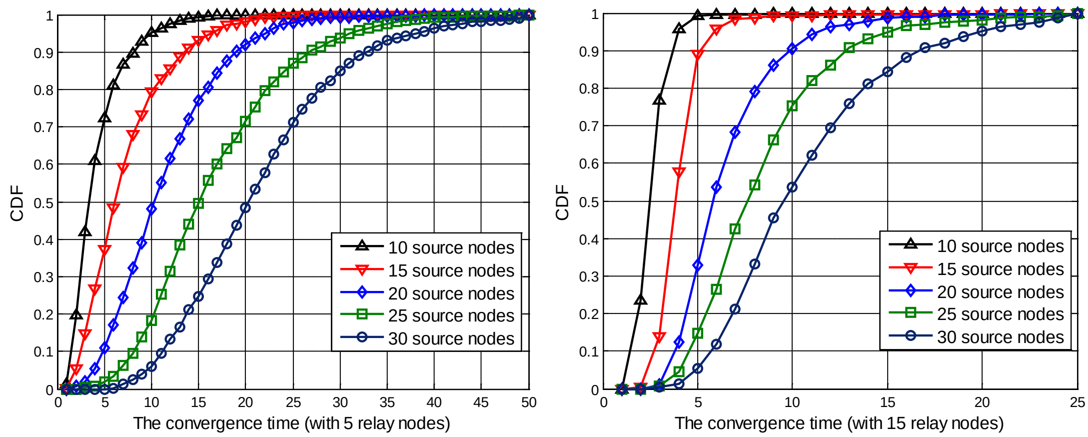


Fig. 11. The fairness index (JFI) of the algorithms (5 relay nodes with varied numbers of source nodes).



(a) 5 relay nodes (b) 15 relay nodes

Fig. 12. The CDF of the proposed NSA with different numbers of source nodes and relay nodes.

Fig. 12 shows the CDF of iterations resulting by the proposed NSA as the number of source nodes number varies, assuming 5 and 15 relay nodes respectively. In the **Fig. 12 (a)** and **(b)**, we can see that, as the number of source nodes increases, the average number of iterations increases. Due to the increase of the number of source nodes, the collisions among source nodes increase. Nonetheless, **Fig. 12** demonstrates that the proposed NSA can converge in a reasonable time, which does not exceed 25 iterations for a network with 30 source nodes and 15 relay nodes. It is noted that the convergence of the relay network with 15 relay nodes is faster than what with 5 relay nodes. This result means if the resource of relay nodes is adequate, the relay network can converge quickly.

8. Conclusion

In this paper, we presented novel, distributed relay assignment approaches for cooperative communication network. We considered competitions among relay nodes and among source nodes. We modeled the relay assignment network as a many-to-one matching market, in which a source node can choose at most one relay node, while a relay node can serve more than one source node simultaneously. Based on the theories of matching game, we developed the problem of peer effects in the cooperative communication model. Aiming at two scenarios respectively, we proposed different schemes. For aggregate throughput optimization, the MBDA algorithm was designed to solve the problem. The performance of aggregate throughput has been improved by the proposed MBDA. For fairness optimization, we pointed out that the conventional models of matching game are alternative models and not suitable for some practical network systems. Innovatively, we proposed a Non-Substitution scheme of matching game and applied it to solve the fairness optimizing problem in the relay network. Using the NSA scheme, all source nodes promote their throughput utility in balance. We have shown that the proposed two algorithms can converge to stable equilibrium. The performances and efficiencies of the proposed algorithms have been verified in the simulation results.

References

[1] A. Nosratinia, T. E. Hunter, and A. Hedayat, "Cooperative Communication in Wireless Networks," *IEEE Communications Magazine*, vol. 42, pp. 74-80, 2004. Article (CrossRef Link).

[2] P. Li, S. Guo, W. Zhuang and B. Ye, "Capacity Maximization in Cooperative CRNs: Joint Relay Assignment and Channel Allocation," in *Proc. of IEEE International Conference on Communications (ICC)*, pp. 5097-5101, 2012. Article (CrossRef Link).

[3] Y. Zhao, R. Adve and T. J. Lim, "Improving Amplify-and-Forward Relay Networks: Optimal Power Allocation Versus Selection," *IEEE Transactions on Wireless Communications*, vol. 6, no. 8, pp. 3114-3123, August 2007. Article (CrossRef Link).

[4] H. Wu, Y. Wang, C. Xiong and D. Yang, "A Novel Relay Selection Scheme with Simplified Power Allocation for Wireless Relay Networks," in *Proc. of IEEE Global Telecommunications Conference, GLOBECOM 2009.*, pp. 1-5 , 2009. Article (CrossRef Link).

[5] F. Ke, S. Feng and H. Zhuang, "Relay Selection and Power Allocation for Cooperative Network Based on Energy Pricing," *IEEE Communications Letters*, vol. 14, pp. 396-398, 2010. Article (CrossRef Link).

[6] F. He, Y. Sun, L. Xiao, X. Chen, C. Y. Chi and S. Zhou, "Capacity Region Bounds and Resource Allocation for Two-Way OFDM Relay Channels," *IEEE Transactions on Wireless Communications*, vol. 12, pp. 2904-2917, 2013. Article (CrossRef Link).

[7] H. Xu, L. Huang, H. Deng, C. Qiao, and Y. Lin, "Fairness-Aware Shared Relay Assignment for Cooperative Communications," in *Proc. of IEEE International Conference on Communications (ICC)*, pp.5700-5705, June, 2014. Article (CrossRef Link).

[8] S. Sharma, Y. Shi, Y. Hou and S. Kompella, "An Optimal Algorithm for Relay Node Assignment in Cooperative Ad Hoc Networks," *IEEE/ACM Transactions on Networking*, vol. 19, no. 3, pp. 879-892, 2011. Article (CrossRef Link).

[9] J. Cai, X. Shen, J. W. Mark and A. S. Alfa, "Semi-Distributed User Relaying Algorithm for Amplify-and-Forward Wireless Relay Networks," *IEEE Transactions on Wireless Communications*, vol. 7, pp. 1348-1357, 2008. Article (CrossRef Link).

[10] A. Bletsas, A. Khisti, D. P. Reed and A. Lippman, "A Simple Cooperative Diversity Method Based on Network Path Selection," *IEEE Journal on Selected Areas in Communications*, vol. 24, pp. 659-672, 2006. Article (CrossRef Link).

[11] Z. Chen, T. Lin and C. Wu, “Decentralized Learning-Based Relay Assignment for Cooperative Communications,” *IEEE Transactions on Vehicular Technology*, vol. 65, no. 2, pp. 813-826, Feb. 2016. Article (CrossRef Link).

[12] D. Gale and L. S. Shapley, “College Admissions and The Stability of Marriage,” *American Mathematical Monthly*, vol. 69, pp. 9–15, Jan 1962. Article (CrossRef Link).

[13] Y. Gu, W. Saad, M. Bennis, M. Debbah and Z. Han, “Matching Theory for Future Wireless Networks: Fundamentals and Applications,” *IEEE Communications Magazine*, vol. 53, pp. 52-59, 2015. Article (CrossRef Link).

[14] E. C. V. D. Meulen, “Three-Terminal Communication Channels,” *Advances in Applied Probability*, vol. 3, pp. 120-154, 1971. Article (CrossRef Link).

[15] T. Cover and A. E. Gamal, “Capacity Theorems for The Relay Channel,” *IEEE Transactions on Information Theory*, vol. 25, pp. 572-584, 1979. Article (CrossRef Link).

[16] H. Xu, L. Huang, G. Wang, T. Xu and G. Liu, “Joint Relay Assignment and Power Allocation for Cooperative Communications,” *Wireless Networks*, vol. 16, pp. 2209-2219, 2010. Article (CrossRef Link).

[17] D. Yang, X. Fang and G. Xue, “OPRA: Optimal Relay Assignment for Capacity Maximization in Cooperative Networks,” in *Proc. of IEEE International Conference on Communications (ICC) 2011*, pp. 1-6, 2011. Article (CrossRef Link).

[18] E. A. Jorswieck, “Stable Matchings for Resource Allocation in Wireless Networks,” in *Proc. of 17th International Conference on Digital Signal Processing (DSP).*, pp. 1-8, 2011. Article (CrossRef Link).

[19] N. Namvar, W. Saad, B. Maham, and S. Valentin, “A Context-Aware Matching Game for User Association in Wireless Small Cell Networks,” in *Proc. of IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pp. 439-443, 2014. Article (CrossRef Link).

[20] O. Semiari, W. Saad, S. Valentin, M. Bennis, and B. Maham, “Matching Theory for Priority-Based Cell Association in The Downlink of Wireless Small Cell Networks,” in *Proc. of IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pp. 444-448, 2014. Article (CrossRef Link).

[21] F. Pantisano, M. Bennis, W. Saad, S. Valentin, and M. Debbah, “Matching with Externalities for Context-Aware User-Cell Association in Small Cell Networks,” in *Proc. of IEEE Global Communications Conference (GLOBECOM) 2013*, pp. 4483-4488, 2013. Article (CrossRef Link).

[22] D. Li, J. Liu, Y. Xu, X. Wang and W. Chen, “Distributed Relay-Source Matching for Cooperative Wireless Networks Using Two-Sided Market Games,” in *Proc. of Global Telecommunications Conference, GLOBECOM 2009. IEEE*, pp. 1-5, 2009. Article (CrossRef Link).

[23] X. Feng, G. Sun, X. Gan, F. Yang, *et al.*, “Cooperative Spectrum Sharing in Cognitive Radio Networks: A Distributed Matching Approach,” *IEEE Transactions on Communications*, vol. 62, pp. 2651-2664, 2014. Article (CrossRef Link).

[24] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, “Cooperative Diversity in Wireless Networks: Efficient Protocols and Outage Behavior,” *IEEE Transactions on Information Theory*, vol. 50, pp. 3062-3080, 2004. Article (CrossRef Link).

[25] A. E. Roth and M. A. O. Sotomayor, “Two-Sided Matching: A Study in Game-Theoretic Modeling and Analysis,” *Cambridge University Press*, 1992. Article (CrossRef Link).

[26] Y. Y. A. Leshem and E. Zehavi, “Stable Matching for Channel Access Control in Cognitive Radio Systems,” in *Proc. of IEEE CIP*, 2010. Article (CrossRef Link).

[27] G. Wang, K. Wu and L. Ni, “CSMA/SF: Carrier Sense Multiple Access with Shortest First,” *IEEE Transactions on Wireless Communications*, vol. 13, no. 3, pp. 1692-1702, March 2014. Article (CrossRef Link).

[28] K. Wu, H. Li, L. Wang, Y. Yi, Y. Liu, D. Chen, X. Luo, Q. Zhang and L. Ni, “hJam: Attachment Transmission in WLANs,” *IEEE Transactions on Mobile Computing*, vol. 12, no. 12, pp. 2334-2345, Dec 2013. Article (CrossRef Link).

[29] G. T. 36.814, "Further Advancements for E-UTRA: Physical Layer Aspects," *Technical Specification Group Radio Access Network*, June 2009. Article (CrossRef Link).
[30] A. Sen, "On Economic Inequality," *Clarendon Press*, Oxford, 1973. Article (CrossRef Link).
[31] R. Jain, D. Chiu, and W. Haws, "A Quantitative Measure of Fairness and Discrimination for Resource Allocation in Shared Computer System," *Technical Report*, 1984. Article (CrossRef Link)

Yitao Xu received the B.S. degree in optical communications and the M.S. and Ph.D. degrees in communications and information systems from the Institute of Communications Engineering, Nanjing, China, in 1994, 2000, and 2004, respectively. He is currently a Professor with the PLA University of Science and Technology, China. His current research interests are soft-dened radio and 5G and signal processing for wireless communications.

Dianxiong Liu received the B.S. degree in School of Physics & Telecommunication Engineering, South China Normal University, Guangzhou, China, in 2014. He is currently pursuing the M.S. degree in communications and information system at College of Communications Engineering, PLA University of Science and Technology, Nanjing, China. His research interests are game theory and distributed optimization techniques for wireless communications.

Cheng Ding received the B.S. degree in Information countermeasure techniques from the School of Electronic and Optical Engineering, Nanjing University of Science and Technology, China, in 2013, and the M.S degree in the Institute of Communications Engineering, PLA University of Science and Technology, Nanjing, China, in 2016. His currently research interests include wireless relay network, learning theory and game theory.

Yuhua Xu received his B.S. degree in Communications Engineering, and Ph.D. degree in Communications and Information Systems from College of Communications Engineering, PLA University of Science and Technology, in 2006 and 2014 respectively. He has been with College of Communications Engineering, PLA University of Science and Technology since 2012, and currently as an Assistant Professor. His research interests focus on opportunistic spectrum access, learning theory, game theory, and distributed optimization techniques for wireless communications. He has published several papers in international conferences and reputed journals in his research area. He served as Associate Editor for Wiley Transactions on Emerging Telecommunications Technologies and KSII Transactions on Internet and Information Systems, and the Guest Editor of Special Issue on “The Evolution and the Revolution of 5G Wireless Communication Systems” for IET Communications. In 2011 and 2012, he was awarded Certificate of Appreciation as Exemplary Reviewer for the IEEE Communications Letters. He was selected to receive the IEEE Signal Processing Society's (SPS) 2015 Young Author Best Paper Award, and the Funds for Distinguished Young Scholars of Jiangsu Province in 2015.

Zongsheng Zhang received the B. S. degree, M. S. degree and Ph. D. degree in communications engineering and information systems from College of Communications Engineering, PLA University of Science and Technology, Nanjing, China, in 2009, 2011 and 2014, respectively. He has published over 15 papers in refereed mainstream journals and reputed international conferences and has been granted 1 patent in his research areas. His current research interests are the broad area of digital communications systems with emphasis on cognitive radio, green communications. He is now a lecturer in PLA Academy of National Defense Information, Wuhan, China.