Sensors & Transducers, Vol. 158, Issue 11, November 2013, pp. 127-134

Sensors & Transducers

http://www.sensorsportal.com

Distributed Relay Selection and Power Allocation Using Stackelberg and Auction Games in Multi-user Multi-relay Networks

Erqing ZHANG, Sixing YIN, Liang YIN, Shufang LI
School of Information and Communication Engineering,
Beijing University of Posts and Telecommunications, Beijing, 100876, China
Tel.: 86+18801110165
E-mail: sxhd2004@126.com

Received: 3 September 2013 /Accepted: 25 October 2013 /Published: 30 November 2013

Abstract: This paper focuses on the problem of distributed relay selection and power allocation problem in a multi-user multi-relay network, aims to maximize users' achievable rate while consume less power of relays which are selected for helping users transmit information. At first, we use the auction game theory to choose the relays for each user preliminarily, then for each user and the selected relays, we model the interaction between them as a two-level Stackelberg game, the relays modeled as the service provider and the users modeled as customers who will buy power from the providers. Based on this game model, we get the relays at relatively better locations for each user and the optimal power need to buy from them. Otherwise, as the users will not exchange information between themselves, we recalculate the power allocated to each user for relays the power users buy from it exceeds the maximizing transmit power. Simulation results show the effectiveness of our proposed scheme. *Copyright © 2013 IFSA.*

Keywords: Distributed relay selection, Power allocation, multi-user multi-relay network, Stackelberg game, Auction game.

1. Introduction

In recent years, cooperative communication [1-2] has been proposed as an emerging transmit strategy to spread the whole coverage and increase system reliability which has been widely used in wireless networks. Generally, in such a network, all nodes can act as the relay nodes to help each other's transmission to their destinations. In this way, cooperative communication can efficiently takes advantages the broadcasting nature of wireless communication networks, as well as the inherent multiuser and spatial diversities. However, in a practical application, especially in commercial networks, the nodes usually represent different interest groups, e.g., service providers and clients. Thus, the practical problems appear such as when and whether to cooperative, which mainly depends on their own available radio resources and traffic loads. Extremely, the selfish user would occupy the available resources as much as possible to maximize its own benefit rather than to share them with others.

According to the description mentioned above, how to analyze the behaviors of ration users in wireless networks has become an urgent need to be addressed. Recently, it has been proved that game theory can be a promising tool in solving the resource allocation problem of cooperative communication network due to its natural and flexible represents of how the autonomous nodes interact and cooperate with each other and has been used in modeling the interactions in different network layers among users with various benefits [3]. There have been volumes of existing literatures based on game theory on the decision-making problems on when, whether and how to cooperate in wireless networks. In [4], the problem of cooperation among energy constrained nodes in wireless ad hoc networks was addressed and Generous TIT-FOR-TAT (GTFT) scheme was proposed to solve this problem based on the historical statistics. The author of [5] proposed a pricing algorithm that encourages forwarding among autonomous nodes through a reimbursing forwarding scheme for multi-hop wireless networks. Based on the results in [5], a pricing game that stimulates cooperative diversity among selfish nodes in commercial wireless ad hoc networks was studied in [6].

The research results abovementioned were based on an asymmetric structure model between the source and relay nodes. The source node has the opportunity to get the relay's help while the relay node cannot get benefit from the source, that is, the roles of the two nodes are unequal, making it hard to fully reveal the rational behaviors between all nodes, particularly in cases when both nodes only have limited radio resources. In addition, the works in [4-6] are based on "non-cooperative game," which is mainly focused on each node's individual utility rather than the utility of the whole system. In contrast, the schemes based on "cooperative game" [7-10] can achieve general pareto-optimal performance and maximize the whole system payoff while satisfying the fairness requirements.

There are also some works studying the relay selection, bandwidth and power allocation based on game theory in cooperative communication networks. In [11], the behaviors of selfish nodes in the case of random access and power control are examined. In [12] and [13], a two user network where each user can also work as a relay for the other is studied. By employing a two-user bargaining game, fair bandwidth allocation [12] and power allocation [13] are found from Nash bargaining solution. In [14] and [15], the relay power allocation and pricing problem in the downlink of multi-user single-relay and single-user multi-relay wireless network is studied respectively. The interaction between the users and the relay is modeled as a two-level Stackelberg game, the optimal relay power price that maximizes the relay revenue is derived analytically. Motived by [15], we use Stackelberg and auction games model to solve the relay selection and power allocation problem in a multi-user multi-relay network which all the users can do the game process simultaneously. Simulation results show the advantage of our scheme compared with other existing algorithms.

The rest of this paper is organized as follows. In Section II, the system model is given and in Section III, the interaction between each user and the selected relays which can be obtained by utilizing the auction game theory can be modeled as a two-level Stackelberg game where the relays and users are modeled as the service provider and customers, respectively. In section IV, simulation results are demonstrated and the conclusion of the whole paper is given in Section V.

2. System Model

Consider a wireless network where there are N users communicating with their destinations with the help of M relays as shown in Fig. 1. Denote that the channel power gain from user i to its destination i (direct link) as h_i, the channel power gain from user i to relay j as f_{ij} and the channel power gain from relay j to its destination i as g_{ji} respectively. Amplify-and-forward (AF) cooperation protocol is employed in this system.

The cooperative transmission process consists of two phases: in phase 1, user i broadcasts its information to both the relays and its corresponding destination i, and in phase 2, relays which receive the information of user i will amplify this information and forward it to the corresponding destination i. All the users will adopt the two phase cooperative transmission way, the difference is that the relays which help to transmit information are different due to different users.

In phase 1, the received signals at destination i a nd relay j can be denoted by $y_{i,i}$ and $y_{i,j}$, respectivel y, which can be expressed as

$$y_{i,i} = \sqrt{P_i h_i}\, x + \eta_{i,i} \tag{1}$$

and

$$y_{i,j} = \sqrt{P_i f_{i,j}}\, x + \eta_{i,j}\,, \tag{2}$$

where x denotes the broadcast information symbol with unit energy from user i to its corresponding destination i and relay j, $\eta_{i,i}$ and $\eta_{i,j}$ are the additive white Gaussian noises (AWGNs

The rate of the direct transmission from user i to its corresponding destination i without relay nodes' help is

$$R_{i,i} = W\log_2\left(1 + \frac{\Gamma_{i,i}}{\Gamma}\right), \tag{3}$$

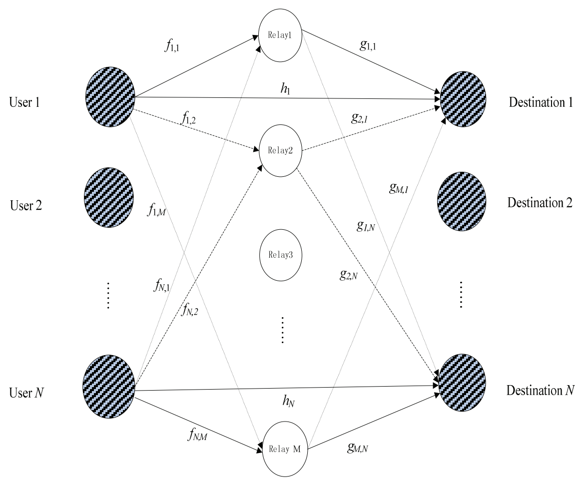


Fig. 1. Multi-user multi-relay network.

where W is the bandwidth for transmission and Γ is a constant representing the capacity gap, $\Gamma_{i,i}$ is the SNR of the direct transmission from user i to destination i and can be expressed by

$$\Gamma_{i,i} = \frac{P_i h_i}{\sigma^2}, \tag{4}$$

where P_i denotes the transmit power at user i.

In phase 2, relay j amplifies $y_{i,j}$ and forwards it to corresponding destination i with transmitted power P_j and the received signal at destination i is

$$y_{j,i} = \sqrt{P_j g_{j,i}} x_{j,i} + \eta_{j,i}, \tag{5}$$

where

$$x_{j,i} = \frac{y_{i,j}}{\left|y_{i,j}\right|} \tag{6}$$

is the transmitted signal from user i to corresponding destination i that is normalized to have unit energy and $\eta_{j,i}$ is the received noise. Substituting (2) into (6), Eq. (5) can be rewritten as follows

$$Y_{j,i} = \frac{\sqrt{P_j g_{j,i}}\left(\sqrt{P_i f_{i,j}} X + \eta_{i,j}\right)}{\sqrt{P_i f_{i,j} + \sigma^2}} + \eta_{j,i}, \tag{7}$$

where P_j denotes the transmit power at relay j. Utilizing (7), the relayed SNR for user i, which is helped by relay j, can be expressed as

$$\Gamma_{i,j,i} = \frac{P_i P_j f_{i,j} g_{j,i}}{\sigma^2\left(P_i f_{i,j} + P_j g_{j,i} + \sigma^2\right)} \tag{8}$$

By (4) and (8), the reception rate of destination from user i by maximal-ratio combining (MRC) detector with relay j is

$$R_{i,j,i} = \frac{W}{2}\log_2\left(1 + \frac{\Gamma_{i,i} + \Gamma_{i,j,i}}{\Gamma}\right) \tag{9}$$

For user i, the relay nodes help for transmitting constitute a set, which is denoted by L_i, where $L_i = \left\{r_1, \cdots, r_{L_i}\right\}$, then the rate of destination i is

$$R_{i,j,i} = \gamma_L W \log_2\left(1 + \frac{\Gamma_{i,i} + \sum j\Gamma_{i,j\in L_i,i}}{\Gamma}\right), \tag{10}$$

where γ_L denotes a bandwidth factor.

3. Problem Formulation and Energy-efficient Power Allocation for SU

In this section, in order for efficient utilization of the cooperative diversity in multiuser networks, two fundamental problems on resource allocation are studied. They are the relay selection and power allocation problems. Owing to the nodes in multiuser cooperative wireless networks belong to different authorities and act selfishly, the distributed resource allocation is adopted where the only local knowledge of channel information is needed. Initially, incentives need to be provided by the users to relays in order to relay the information of users. Consequently, the users need to choose the optimal relay for maximizing their own benefits. Thus, a distributed resource allocation scheme utilizing the Stackelberg-game-based scheme in our scenario can be formulated as follows.

3.1. Problem Formulation

Consider there are many users transmit information simultaneously, the users will not exchange any information between each other and they can get every relay for help. The problem of interest is to select appropriate relays for each user to maximize its achievable rate and decrease the power of whole relays consumed as much as possible, auction game theory is used to find the relays for each user preliminarily. Suppose each relay is the object for sale and N users are bidders. For each relay j, assume the power helping each user is equal at first, i.e., $P_j = P_{unit}$, and for user i, if power P_i is given, the rate of the direct transmission $R_{i,i}$ and with relay j 'help $R_{i,j,i}$ can be calculated, $R_{i,j,i} - R_{i,i}$ will be the price of user i to compete for relay j as the value shows the ability of relay j for helping user i transmit information. Then the whole prices of N bidders competing for relay j is denote as $\mathbf{X}^j = \left(R_{1,j,1} - R_{1,1}, R_{2,j,2} - R_{2,2}, \cdots, R_{N,j,N} - R_{N,N} \right)$, and relay j will choose the bidders with highest $N^{'}\left(N^{'} \le N \right)$ prices to provide help. Then for each relay, we can find $N^{'}$ users for help at first, in other words, for each user, there are $M^{'}\left(M^{'} \le M \right)$ relays can provide help. Given the $M^{'}$ relays, the Stackelberg game model will be used to help user i to buy the optimal amount of power from relays and also helps the selected relays maximize their own utilities by asking the optimal prices.

Stackelberg game is divided into two levels: the users play the buyer-level game and the relays play the sell-level game. The users aim to achieve the best performance with relay nodes' help with the least reimbursements to them while the relays aim to earn as much as benefits from spending their own transmission power in helping the users forward its information. Both of the two sub-game perfect Nash equilibriums can be found using the backward induction method.

From the above, we assume the number of relays which can provide help for user i to be $M_i^{'}\left(r_{L_i} = M_i^{'} \right)$, denoted by $\mathbf{r}_i = \left\{ r_{i,1}, r_{i,2}, \cdots, r_{i,M_i^{'}} \right\}$, the power the relays spend to transmit information is denoted as $\mathbf{P} = \left\{ P_{i,1}, P_{i,2}, \cdots, P_{i,k}, \cdots, P_{i,M_i^{'}} \right\}$. The price per unit of power selling from relay node L_i is denoted as $\mathbf{P}_i = \left\{ p_{i,1}, p_{i,2}, \cdots, p_{i,k}, \cdots, p_{i,M_i^{'}} \right\}$. Then the utility function of all the users denoted by U_S is

$$U_S = \sum_{i=1}^{N} a_i R_i - \sum_{i=1}^{N} \sum_{k=1}^{M_i^{'}} p_{i,k} P_{i,k} \tag{11}$$

In (11), the first part denotes all the users' achievable rate with the relay nodes' help, a_i denotes user $i's$ gain per unit of rate at the MRC output. The second part denotes the total payments paid by the whole users to relay nodes.

The relay nodes' utility function denoted by U_R is

$$U_R = \sum_{i=1}^{N} \sum_{k=1}^{M_i^{'}} \left(p_{i,k} - c_{i,k} \right) P_{i,k}, \tag{12}$$

where $c_{i,k}$ denotes the cost of power for relaying data.

Formula (11) is the sum of N single user's utility essentially, so we can find each user's maximizing utility and get the optimal solution of (11).

For user i, the utility function can be written as:

$$U_i = a_i R_i - \sum_{k=1}^{M_i^{'}} p_{i,k} P_{i,k} \tag{13}$$

and the utility function of relay nodes for helping user i is

$$Q_i = \sum_{k=1}^{M_i^{'}} \left(p_{i,k} - c_{i,k} \right) P_{i,k} \tag{14}$$

By derivation of U_i, we can get

$$\frac{\partial U_i}{\partial P_{i,k}} = a_i \frac{\partial R_i}{\partial P_{i,k}} - p_{i,k} \tag{15}$$

If $p_{i,k} < a_i \frac{\partial R_i}{\partial P_{i,k}}$, then $\frac{\partial U_i}{\partial P_{i,k}} > 0$, it means that user i will obtain a larger utility by increasing $P_{i,k}$. Now we will determine the final relay nodes for user i further, according the relay rejection criteria in [15], all the relay nodes in $\mathbf{r}_i$ set their initial prices $p_{i,k} = c_{i,k}$, if $p_{i,k} \ge a_i \frac{\partial R_i}{\partial P_{i,k}}$, then relay $r_{i,k}$ will be rejected by user i. With the relay rejection criteria, user i excludes the least beneficial relay nodes at the very beginning and it is proved that the relays are fixed and will not change after the game is played. Then the final relay nodes for helping user i are denoted by $\mathbf{r}_i = \left\{ r_{i,1}, r_{i,2}, \cdots, r_{i,M_i^{'}} \right\}$.

After the relay selection, the optimal power that user i need to buy from the selected relay nodes in $\mathbf{r}_i$ when achieves game equilibrium will be calculated. Suppose γ_L in (10) equal to 1 and let (15) equal to 0, according (7), (8) and 10), we can get

$$P_{i,k}^{*} = \sqrt{\frac{A_{i,k} B_{i,k}}{p_{i,k}} \frac{Y + \sqrt{Y^2 + 4XW^{'}}}{2X}} - B_{i,k}, \tag{16}$$

where k is the k_{th} relay of $\mathbf{r}_i$, $A_{i,k} = \frac{P_i f_{i,r_{i,k}}}{\Gamma \sigma^2 + P_i h_i}$, $B_{i,k} = \frac{P_i f_{i,r_{i,k}} + \sigma^2}{g_{i,r_{i,k}}}$, $X = 1 + \sum_{j \in \mathbf{r}_i} A_{i,j}$, $Y = \sum_{j \in \mathbf{r}_i} \sqrt{p_{i,j} A_{i,j} B_{i,j}}$.

The optimal price that each relay in $\mathbf{r}_i$ sells to user i can be got by

$$p_{i,k} = c_{i,k} - \frac{P_{i,k}^{*}}{\partial P_{i,k}^{*} / \partial p_{i.k}} \tag{17}$$

3.2. Problem Solving

Since there are N users, if they transmit information at the same time, N game processes happens simultaneously. For users will not exchange information among themselves, each user will only know how much power he buys from the relay, as one relay can help many relays, it can't be guaranteed that the sum of optimal power each user buys lower than the maximum transmit power of the relay, so in connection with the relay node which the users it helps buy the power larger than prescribed power, the power the relay node allocates to each user need to be re-calculated.

Suppose any relay, the set of the users it helped is denoted as $\mathbf{u}_m = \{u_1, u_2, \cdots, u_m\}$, according to (16), we can get the optimal power allocated to each user, denoted as $\mathbf{P}_m = \{P_{u_1}, P_{u_2}, \cdots, P_{u_m}\}$. Since the utility function (13) is concave in $P_{i,k}$ [1, property 1], U_i will decrease as $P_{i,k}$ is decreasing, in order to reduce the power buying from relay m, but maximize U_S as much as possible, since U_S is the sum of $U_i, (1 \le i \le N)$ so we just need to find the relay node m that U_i is not varying obviously with the decrease of $P_{i,k}$. According to (15), for users in $\mathbf{u}_m$, we calculate $\frac{\partial U_i}{\partial P_i}, i \in \mathbf{u}_m$, then we sorted $\frac{\partial U_i}{\partial P_i}$ in descending order of the value of $\frac{\partial U_i}{\partial P_i}$, assume $\frac{\partial U_1}{\partial P_1} \ge \frac{\partial U_2}{\partial P_2} \ge \cdots \ge \frac{\partial U_m}{\partial P_m}$, we decrease the power of user $u_m(P_m^*)$ at first, if the sum of optimal power all users buy is still larger than the maximum transmit power of the relay m, then we will decrease the power of user $u_{m-1}(P_{m-1}^*)$ until the sum of the optimal power all users buy is lower than the maximum transmit power of the relay m, then we get the whole utility of all the users U_S.

The whole relay selection and power allocation process is summarized as follows

1) Preliminarily Relay Selection: choose the first $N'(N' \le N)$ users to use i_{th} relay for helping transmitting information using auction game theory.

2) Determine which relays will be help for each user according 1).

3) Using formula $p_{i,k} \ge a_i \frac{\partial R_i}{\partial P_{i,k}}$ to determine the final relays to help for each user.

4) Calculate the optimal power each user buys from the corresponding relays and the optimal price that each relay sells to the user using formula (16) and (17) respectively.

5) Find the relays that the sum of the optimal power that users buy is larger than the maximum transmit power of it and decrease the power of user with the smallest $\frac{\partial U_i}{\partial P_i}$ until the whole power is smaller than the maximum transmit power of the relay.

6) Calculate the whole utility of all the users U_S.

4. Performance Analysis

In this section, the simulation results are given which demonstrates the reliability and effectiveness of the proposed distributed relay selection and power allocation based on Stackelberg and auction games in our scenario.

Fig. 2 illustrates utility of each user with relay's different prices. Considering the interference between users, the system adopts TDMA for each user to transmit data, the channels are assumed to be Rayleigh fading. Suppose N =5, M =20 and the capacity gap is set to be $\Gamma = 1$. We suppose all the users undergo the same game process and take one of them for simulating. We can see from the figure that our proposed scheme the utility of each user will be increasing as the price of each relay is growing, but when the price of the relay is higher than a threshold, the utility of the user will be decreasing, it means that the proposed scheme converges to a better local optimum value and also there exists a optimal price for the relays. Moreover, user's utility will increase as the value of M' is growing, it's because that as growing of the value of M', there will be more relays to help the user to transmit information, it will improve user's utility.

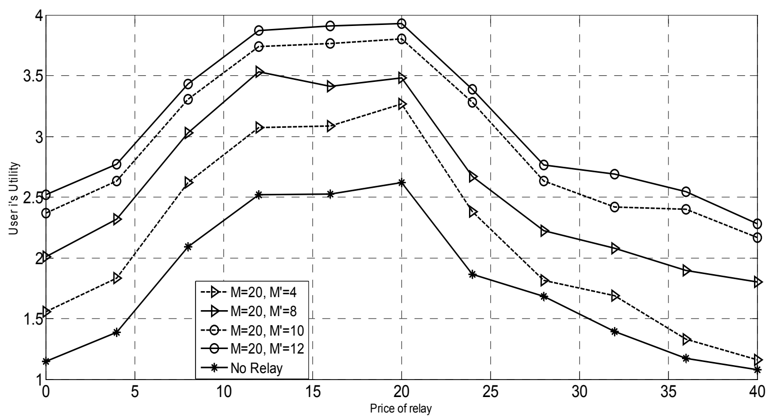


Fig. 2 Average utility of each user with relay's different prices.

5. Conclusions

In this paper, we propose a novel distributed relay selection and power allocation scheme in a multi-user multi-relay network, aims to maximize users' achievable rate while consume less power of relays which are selected for helping users transmit information. The auction game is adopted to solve the relay selection problem for each user, then we model the interaction between the users and relays as a two-level Stackelberg game, and the relays modeled as the service provider and the users modeled as customers who will buy power from the providers. The simulation results validate the reliability and effectiveness of our proposed scheme. Further study may focus on the EE optimization with the imperfect channel sensing and energy harvesting for each SU.

Acknowledgements

This work is supported by the grants from the Major State Basic Research Development Program of China (973 Program) (No.2011CB302900), the National Science and Technology Major Project (No.2012ZX03003006) and the National Natural Science Foundation of China (No. 61139001).

References

[1]. J. N. Laneman, G. W. Wornell, and D. N. C. Tse, An efficient protocol for realizing cooperative diversity in wireless networks, in *Proceedings of the IEEE ISIT,* Washington, DC, June 2001, p. 294.

[2] T. E. Hunter and A. Nosratinia, Cooperation diversity through coding, in *Proceedings of the IEEE ISIT,* Lausanne, Switzerland, June 2002, p. 220.

[3] V. Srivastava, J. Neel, A. B. Mackenzie et al., Using game theory to analyze wireless ad hoc networks, *Commun. Surveys Tuts.,* Vol. 7, No. 4, Forth Quarter 2005, pp. 46–56.

[4] V. Srinivasan, P. Nuggehalli, C.-F. Chiasserini, and R. R. Rao, An analytical approach to the study of cooperation in wireless ad hoc networks, *IEEE Trans. Wireless Commun.,* Vol. 4, No. 2, March 2005, pp. 722–733.

[5] O. Ileri, S.-C. Mau, and N. B. Mandayam, Pricing for enabling forwarding in self-configuring ad hoc networks, *IEEE J. Sel. Areas Commun*., Vol. 23, No. 1, Jan. 2005, pp. 151–162.

[6] N. Shastry and R. S. Adve, Stimulating cooperative diversity in wireless ad hoc networks through pricing, in *Proceedings of the IEEE ICC,* Istanbul, Turkey, June 2006, pp. 3747–3752.

[7] D. Grosu, A. T. Chronopoulos, and M.-Y. Leung, Load balancing in distributed systems: An approach using cooperative games, in *Proceedings of the IPDPS,* April 2002, pp. 52–61.

[8] Z. Han, Z. Ji, and K. J. R. Liu, Fair multiuser channel allocation for OFDMA networks using Nash bargaining solutions and coalitions, *IEEE Trans. Commun.,* Vol. 53, No. 8, August 2005, pp. 1366–1376.

[9] Z. Han, T. Himsoon, W. Siriwongpairat, and K. J. R. Liu, Energy efficient cooperative transmission over multiuser OFDM networks: Who helps whom and how to cooperate, in *Proceedings of the IEEE Wireless Commun. Netw. Conf.,* New Orleans, LA, Vol. 2, March 2005, pp. 1030–1035.

[10] R. Mazumdar, L. G. Mason, and C. Douligeris, Fairness in network optimal flow control: Optimality of product forms, *IEEE Trans. Commun*., Vol. 39, No. 5, May 1991, pp. 775–782.

[11] A. B. MacKenzie and S. B. Wicker, Game theory and the design of self-configuring, adaptive wireless networks, *IEEE Commun. Mag.,* Vol. 39, November 2011, pp. 126–131.

[12] Z. Zhang, J. Shi, H.-H. Chen, M. Guizani, and P. Qiu, A cooperation strategy based on Nash Bargaining Solution in cooperative relay networks, *IEEE Trans. Veh. Technol.,* Vol. 57, No. 4, July 2008, pp. 2570–2577.

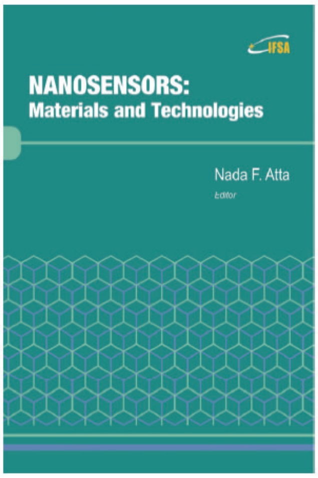
[13] G. Zhang, H. Zhang, L. Zhao, W. Wang, and L. Cong, Fair resource sharing for cooperative relay networks using Nash bargaining solutions, *IEEE Commun. Lett.,* Vol. 13, No. 6, June 2009, pp. 381–383.

[14] Q. Cao, H. V. Zhao, and Y. D. Jing, Power Allocation and Pricing in Multi-User Relay Networks Using Stackelberg and Bargaining Games, *IEEE Trans. Vehicular Technology,* Vol. 61, No. 7, September 2012, pp. 3177-3190.

[15] B. Wang, Z. Han, and K. J. Ray Liu, Distributed relay selection and power control for multiuser cooperative communication networks using Stackelberg game, *IEEE Trans. Mobile Comp*., Vol. 8, July 2009, pp. 975-990.

___

Contents:


IFSA
NANOSENSORS:
Materials and Technologies
Nada F. Atta
Editor