Suitable Partner Node Selection and Resource Allocation in Cooperative Wireless Communication Using the Trade-Off Game

Oluseye A. Adeleke, Mohd. F. M. Salleh

Abstract—The performance of any cooperative communication system depends largely on the selection of a proper partner. Another important factor to consider is an efficient allocation of resource like power by the source node to help it in forwarding information to the destination. In this paper, we look at the concepts of partner selection and resource (power) allocation for a distributed communication network. A type of non-cooperative game referred to as Trade-Off game is employed so as to jointly consider the utilities of the source and relay nodes, where in this case, the source is the node that requires help with forwarding of its information while the partner is the node that is willing to help in forwarding the source node's information, but at a price. The approach enables the source node to maximize its utility by selecting a partner node based on (i) the proximity of the partner node to the source and destination nodes, and (ii) the price the partner node will charge for the help being rendered. Our proposed scheme helps the source locate and select the relay nodes at 'better' locations and purchase power optimally from them. It also aids the contending relay nodes maximize their own utilities as well by asking proper prices. Our game scheme is seen to converge to unique equilibrium.

Keywords—Cooperative communication, game theory, node, power allocation, trade-off, utility.

I. INTRODUCTION

COOPERATIVE communications have recently gained prominence and much attention as an emerging strategy for transmission for next generation or future wireless networks. The basic idea behind this concept is that partner or relay nodes can act as virtual antenna arrays in helping the source node forward its information or data to the destination node.

Through this, cooperative communication or cooperative diversity takes full advantage of the broadcast nature of wireless networks. It also exploits the spatial and multiuser diversity inherent in the traditional MIMO techniques, without each node necessarily having multiple antennas [1], [2].

The performance of cooperative communication largely depends on proper allocation of resources such as power and bandwidth, careful placement and selection of partners or relays. There are many protocols that have been devised for implementing cooperative diversity in wireless

Oluseye Adeleke is a research student in the School of Electrical & Electronic Engineering, University Sains Malaysia (USM), Nibong Tebal, Malaysia (phone: +60142577508; e-mail:oaadeleke@lautech.edu.ng).

Mohd. Fadzli Salleh is an associate professor with the School of Electrical & Electronic Engineering, University Sains Malaysia, Nibong Tebal, Pulau Pinang, Malaysia.

communications, some of which include the Amplify-and-Forward scheme, the Decode-and-Forward scheme, Estimate-and-Forward scheme and Coded cooperation. No matter the type of scheme or protocol employed in implementing cooperation, one thing that is sacrosanct is that the objective is to obtain a higher transmit diversity.

Recently, several works have dealt with the issue of partner selection and resource allocation in cooperative communications. These works are found to be in two categories namely, centralized for example, [3]-[5] and decentralized, e.g. [1], [6]-[12]. There have been more researches on the distributed systems because they are more favorable in practical terms since they require only the local information of the nodes, unlike the centralized systems which require the global channel state information, and thus incur higher signaling overhead [13]. For instance, in [6], the authors proposed a partner selection scheme for distributed systems based on limited instantaneous SNR. The authors in [7] proposed a distributed power control framework for a single-source, multiple-relay system to optimize multihop diversity.

In the last few years, game theory has grown to be a veritable tool in the analysis of distributed systems due to their autonomous and self-configuring capability. For instance, in [1] a non-cooperative game known as Stackelberg game was employed to develop a power allocation algorithm. The network is modeled as a single user, multi-relay system in which the source acts as the buyer node and the relays act as the sellers of resource (i.e. power). The authors in [14] studied and developed an auction-based power allocation scheme for a distributed cooperative network. In this work where there are many sources and only one relay, the source nodes acts as the bidders while the relay acts as the auctioneer. However, in this work we intend to improve on the resource allocation scheme developed using the Stackelberg game in which the concept of buying and selling between the source and relay nodes is used without really considering the inter-node channel conditions and the proximity of the relay nodes to either the source or destination nodes by developing a new game scheme we refer to as the Trade-Off game.

Moreover in this work, there are two main issues to be addressed regarding multiuser cooperative networks, namely, (i) among the distributed nodes, which of them can actually help in relaying and so improve the link quality of the source better, and (ii) for the nodes selected, how much power do they need to transmit? [1]. The first question leads to the

concept of partner selection, while the second is a pointer to the notion of power control, or more specifically, power allocation. It is this second question that this paper seeks to address.

The rest of this paper is organized as follows: Section II presents the background to this work. The proposed partner selection scheme is described in Section III while Section IV gives the proposed resource allocation scheme. Section V gives the results and discussion. The conclusion is given in Section VI.

II. BACKGROUND

A. Cooperative Cooperation System Model

The time division model of cooperative communication scheme is as shown in Fig. 1 (a) while the *3*-node cooperative model is shown in Fig. 1 (b), but with multiple relay nodes. The cooperative process is carried out over two-frame transmissions as shown in Fig 1 (a). For the purpose of improvement of the overall performance through diversity, the cooperation is done by sending data from the source node to the destination node in the first frame or time slot while the data is sent via the relay or partner node to the destination node in the second time slot.
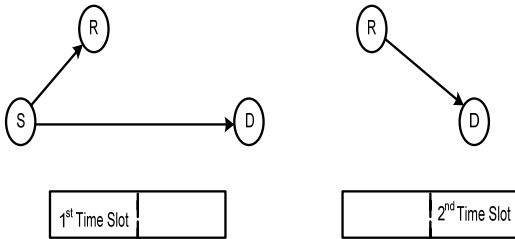

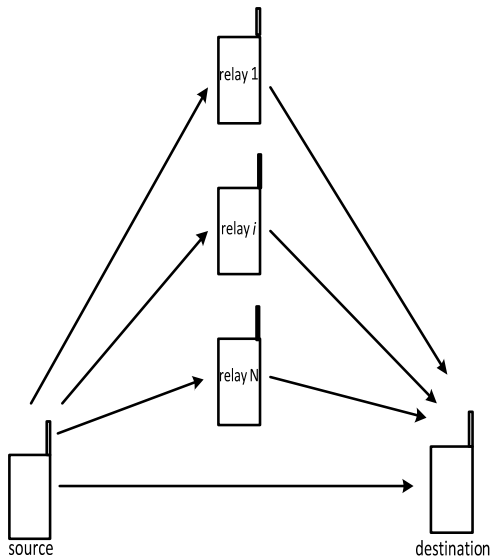Fig. 1 (a) A 3-node cooperative system model in the time division mode

Fig. 1 (b) *3* – node cooperative multi-relay communication scheme

B. Stackelberg Game

In non-cooperative games, there is the possibility of existence of hierarchy among the players in the game whereby one or more players declare and announce their own strategies prior to the other players announcing theirs. Put in another way, these other players respond or react to the strategies declared by the former players. In a hierarchical situation such as this, the declaring players can be in a position to enforce their own strategies upon the other players. As such, the player who holds this strong position which can be imposed on others is called the leader while the other players who react or respond to this leader's declared strategy are called followers. Thus a Stackelberg game is a non-cooperative leader-follower(s) game. However in some cases, there could be multiple leaders and followers [15], [16].

Given two players in a non-cooperative game which involves a leader and follower, whose strategies are respectively denoted by S_1 and S_2, whenever the leader with strategy S_1 declares to play a particular strategy $s_1 \in S_1$, the player must also react or respond accordingly with another given strategy $s_2 \in S_2$. It is also possible that the follower may have many possible reactions to a given strategy of the leader. In view of this, the following definitions are given for the Stackelberg strategy, according to [15].

Definition 1: Given a finite 2-person game, the set $R_2(s_1)$, defined for each strategy $s_1 \in S_1$ by;

$$R_2(s_1) = \{s_2 \in S_2 : u_2(s_1, s_2) \geq u_2(s_1, t), \forall t \in S_2\} \quad (1)$$

is the optimal response (or reaction) set of player 2 to the strategy $s_1 \in S_1$ of player 1.

Definition 2: In a finite game of two players, with player 1 as the leader and player 2 the follower, a strategy $s_1^* \in S_1$ is called a Stackelberg strategy (or Stackelberg equilibrium strategy) for the leader, if;

$$\min_{s_2 \in R_2(s_1^*)} u_1(s_1^*, s_2) = \max_{s_1 \in S_1} \min_{s_2 \in R_2(s_1)} u_1(s_1, s_2) \underline{\underline{\Delta}} u_1^* \quad (2)$$

In definition 2 above, the quantity u_1^* is the Stackelberg utility for the leader; this definition also applies if the player 2 is the leader and 1 the follower. However, this Stackelberg strategy proves to be a useful tool in defining equilibrium points in games that are hierarchical in their decision-making.

However, in a multiuser cooperative communication networks, modelled as a network consisting of three nodes, namely, source, relay and destination nodes, the Stackelberg game is usually employed in order to jointly consider the benefits of the source and relay nodes in cooperative communication [17]. In this case, the game is referred to as buyer-seller game instead of the former leader-follower game. Actually the buyer is the leader while the seller is the follower. This is so because it is the leader that broadcasts the desire to buy either power or bandwidth, or that requires the service of one or more of the relays to help it forward its data onward to

the destination. Thus the source is the buyer while the relay(s) is (are) the seller(s) in the game.

The Stackelberg game is divided into two levels, which are the *source node-level* game and the *partner node-level* game. In this game, it is noteworthy that each of the players involved is selfish and wishes to maximise its own benefit independent of the other players, and this is what is referred to as contention or tension among the players. Just as in normal economic concepts, the buyer (source) aims to get most benefits at the least payment, while each relay aims at earning the payment put forward by the source, which not only covers their cost for the service rendered, but also gain as much extra profit as possible [1], [17].

C. Problem Formulation and Analysis

We consider a simple cooperative model as depicted in Fig. 1(a) where there is one relay and one source node in time division mode. The schematic in Fig. 1 (b) shows a single source node, which, in our work, acts as the auctioneer and *N*-relay nodes, which act as the bidders in our proposed auction or bidding game.

In the first time slot or Phase 1 (in Fig. 1 (a)), the source node broadcasts its information, and is received by the both the partner (r) and destination (d) nodes as follows:

$$Y_{sd} = \left(P_s G_{sd}\right)^{0.5} X_s + \eta_d \tag{3}$$

$$Y_{sr_i} = \left(P_s G_{sr_i}\right)^{0.5} X_s + \eta_{r_i} \tag{4}$$

where Y_{sd} and Y_{sr} respectively represent the received signal from the source to destination, d and from source to relay, r. P_s represents the power transmitted from the source node while X_s represents the transmitted data with normalized to unit energy. G_{sd} and G_{sr} denote channel gains from s to d and from s to r respectively, and the AWG noises are given as η while the noise power is denoted by n.

During the first time slot, the SNR obtained at the destination node is given as:

$$\gamma_{sd} = \frac{P_s G_{sd}}{n} \tag{5}$$

Moreover, during the second time slot, the Y_{sr_i} is amplified and forwarded to the destination node; thus the signal received at the destination during the second time slot is given as:

$$Y_{r_i d} = \left(P_r G_{r_i d}\right)^{0.5} X_{r_i d} + \eta'_d \tag{6}$$

where $G_{r_i d}$ is the channel gain from relay to destination nodes while η'_d is the noise received during the second phase, and $X_{r_i d} = \frac{Y_{sr_i}}{\left|Y_{sr_i}\right|}$ is the signal of unit energy that the relay receives

from the source node and which it forwards to the destination node.

Now, using $X_{r_i d}$ and (2), we rewrite (4) as follows:

$$Y_{r_i d} = \frac{\left(P_{r_i} G_{r_i d}\right)^{0.5}\left(\left(P_s G_{sr_i}\right)^{0.5} X_s + \eta_r\right)}{\left(P_s G_{sr_i} + n\right)^{0.5}} + \eta'_d \tag{7}$$

and using (5), we obtain the SNR through relaying, at the destination node as follows:

$$\gamma_{sr_i d} = \frac{P_{r_i} P_s G_{r_i d} G_{sr_i}}{n\left(P_{r_i} G_{r_i d} + P_s G_{sr_i} + n\right)} \tag{8}$$

next, the achievable transmission rate at the destination node will then be obtained. From the analysis above, the source has two options in this case:

Option 1: The source node uses only the Phase1 transmission and obtains the rate:

$$C_{sd} = W \log_2\left(1 + \gamma_{sd}\right) \tag{9}$$

where W is the bandwidth of the transmitted signal from the source node

Option 2: The source node uses the two phases, and at the combining output (using MRC), achieves the following achievable transmission rate capacity $C_{sr_i d}$:

$$C_{sr_i d} = \frac{W}{2} \log_2\left(1 + \gamma_{sd} + \gamma_{sr_i d}\right) \tag{10}$$

III. PROPOSED PARTNER SELECTION SCHEME

In a cooperative communication set-up consisting of the source, partner (relay) and destination nodes, the relays are randomly distributed at different points on the network layout; from where help is required of them by the source to help it forward data or information to the destination terminal, and at the same time, the relay nodes ask different prices for helping the source node forward its data, using the economic game concept of buying and selling and trade-off. However, since these relay nodes are randomly distributed, there is the tendency that some of them would be closer to either the source node or destination node than others, and this proximity will be an important factor in the price being asked by the relay nodes. So, in the light of this, our proposed partner selection scheme will be based on three criteria unlike [1] which is based on the concept of buying and selling. These are as follows:

A. *The Proximity of the Relay Node, r_i to the Source Node*
B. *The Proximity of the Relay Node, r_i to the Destination Node*
C. *The Price Being Asked by the Relay Node for the Source Node to Pay for Forwarding Its Information to the Destination Node*

A. The Proximity of the Relay Node, r_i to the Source Node, s

We assume the source node, *s* and the destination node, *d* are separated by a distance, *x* in metres. We also assume that the relay nodes are located at different points along this path of *x* metres for the purpose of this analysis. It is also assumed that there are *N* relays available for this selection game. This is illustrated in Fig. 2. As can be seen from the illustration, if a relay node is situated at a position very close to the source node and by effect very far from the destination node, the relay node may be compelled to ask a low price from the source node so as to make it buy power from it. It would now depend on the source node to either buy power at this low price and increase its utility at the expense of the distance the signal will travel before reaching the destination or not, bringing up the concept of trade-off into the picture. It would also mean that as that relay node moves away from this location, the source node may have no more incentive to buy power from it.
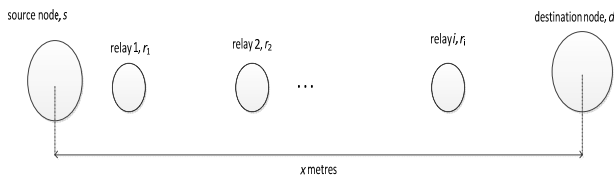

Fig. 2 Illustration of the relative distances of the relay nodes from the source and destination nodes

If we assume that relay nodes midway between the source and destination nodes are at a point $\frac{x}{2}m$ from both ends, then we can comfortably say that a relay node very close to the source node is at a distance $< \frac{x}{4}m$ from the source node end. Therefore, if the source node would select any relay node located very close to it, to enjoy the low price it would offer due to how far it is from the destination, then it would select the relay nodes located at a distance $< \frac{x}{4}m$ from the source node. The flow chart for this criterion is given in Fig. 3.
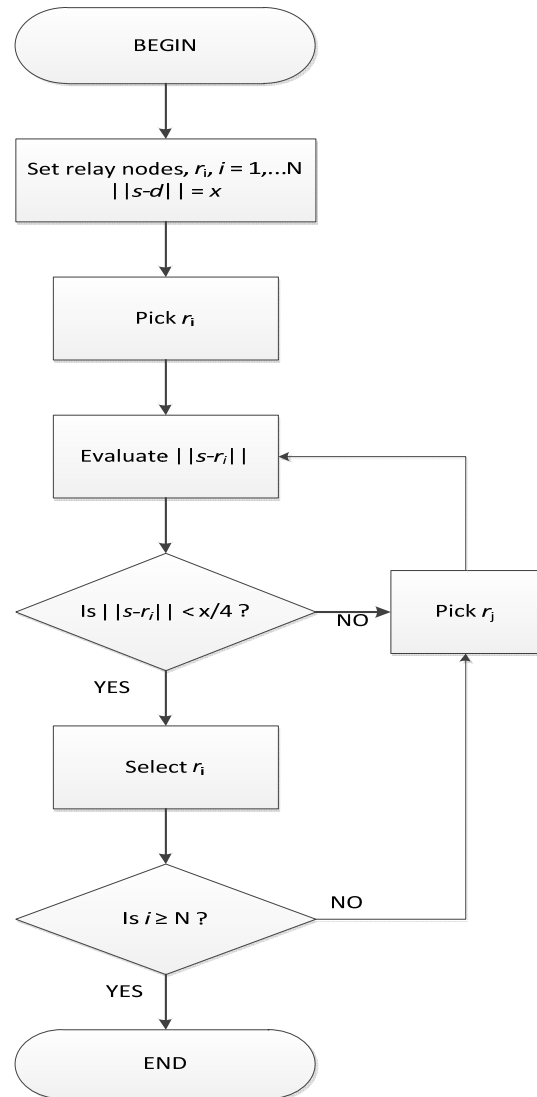

Fig. 3 Flow chart for the criteria of proximity of the relay node, r_i to the source node, *s*

B. Proximity of the Relay Node, r_i to the Destination Node, d

We still make the assumptions as we did in Fig. 2, but now we focus on the relay nodes being closer to the destination node, *d* instead of the source node, *s*. This would mean that any node whose distance from the source node is greater than $\frac{3}{4}x$ would be considered very close to the destination node; and so the source node has the choice of selecting these relays or not. As mentioned earlier, the contention for the eventually selected node will be between the relay nodes at these extreme ends: very close to the source node and very close to the destination node. In explaining what will likely happen at this location, it can be inferred from Fig. 2 that the relay node would need a little amount of power to forward the source node's data to the destination, and as such, for it to maximize its own utility or benefit, it will ask for a high price, *p* from the

source node. It will now be left for the source node to decide whether to purchase this power at such a price or not.

The flow chart of what happens in this scenario is given in Fig. 4. It is noteworthy note that L is the number of relays left after the source node has selected relays close to the source node, s in the first criterion.
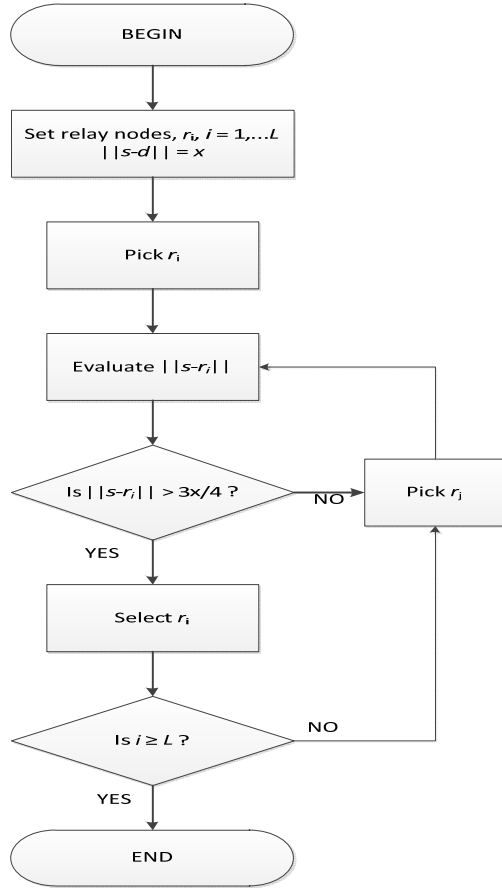

Fig. 4 Flow chart for the criteria of proximity of the relay node, r_i to the destination node, d

C. The Issue of Price

The issue of price in our proposed scheme now comes up after the first two criteria have been validated. From the relay nodes selected from the first and second criteria, we now constitute a set L_s which contains all these relay nodes, from which the final 'best' relay node would now be selected for cooperation. At this point, the contention or tension would now be among these relay nodes who are contending for the final selection by the source node.

Apart from the fact that the source node seeks the 'best partner(s)' with which to cooperate with, it also tries to maximize its utility or payoff, U_s obtainable in the game. The source node achieves this by purchasing a maximum amount of power from the selected relay – this power bought by the source is increased gradually until a maximum is reached.

This partner selection is done by observing how the utility of the source node, U_s varies with the power purchased from the relay (partner) node, P_{r_i} which is also a function of the price asked by the relay node, r_i.

From the definition of utility:

$$U_s = g\frac{\partial C_T}{\partial P_{r_i}} - \psi \qquad (11)$$

we have,

$$\frac{\partial U_s}{\partial P_{r_i}} = g\frac{\partial C_T}{\partial P_{r_i}} - p_i\frac{\partial P_{r_i}}{\partial P_{r_i}}$$

$$\frac{\partial U_s}{\partial P_{r_i}} = g\frac{\partial C_T}{\partial P_{r_i}} - p_i \qquad i = 1, 2 \ldots L_s \qquad (12)$$

(assuming that there are L_s relay nodes available for the selection game at this time)
where C_T denotes the transmission rate capacity achievable at the MRC output (which is also equal to the relation obtained in (10), with the help of the relaying partners, g refers to the gain per unit of rate, and ψ stands for the total payments paid by the source s to the relay nodes to buy power given by:

$$\psi = \sum_{i=1}^{L_s} p_i P_{r_i} \qquad (13)$$

where p_i denotes the price per unit of power being sold by relay r_i to source s, and P_{r_i} refers to the amount of power node s is buying from relay r_i.

Beginning at $P_{r_i} = 0$, if $p_i < g\frac{\partial C_T}{\partial P_{r_i}}$ for a particular relay node r_i, it is clear that $\frac{\partial U_s}{\partial P_{r_i}} > 0$ (for it would mean that $\frac{\partial U_s}{\partial P_{r_i}} = +ve$) which also means that a higher utility U_s will be obtained by the source node when a higher amount of power, P_r is bought; else, that relay r_i is exempted or excluded from participating in the game (relay exclusion criteria).

On the other hand, for selecting a particular relay that will help the source maximize its benefit in the cooperative game, the following algorithm is given as the criterion:

1. $C_T = \dfrac{W}{2} \log_2\left(1 + \gamma_{sd} + \gamma_{sr_id}\right)$

2. $\gamma_{sr_id} = \dfrac{P_{r_i} P_s G_{r_id} G_{sr_i}}{n\left(P_{r_i} G_{r_id} + P_s G_{sr_i} + n\right)}$

3. Initial: Set $P_{r_i} = 0$; $g=gain\ per\ unit$ $of\ rate$;

4. $i = 1, 2, ...N;$

5. For all i, $p_i = c_i$;$initial\ price$

Evaluate $g\,\dfrac{\partial C_T}{\partial P_{r_i}}$;

If $c_j \le g\,\dfrac{\partial C_T}{\partial P_{r_j}}$;

then r_j is selected;

else;

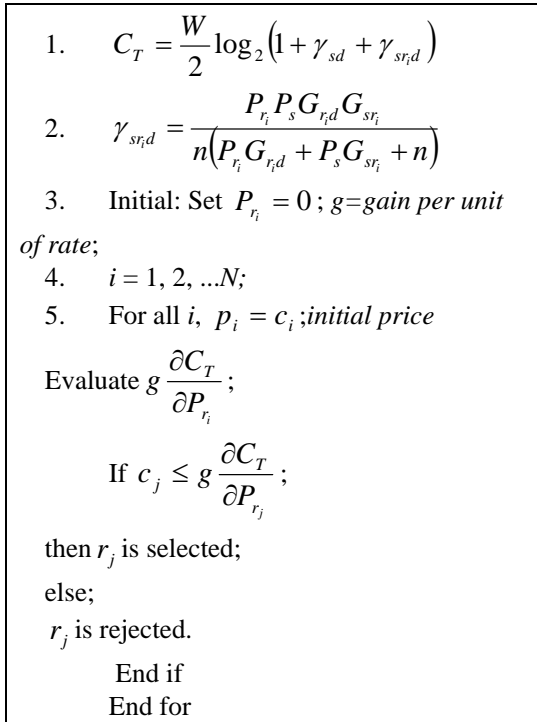r_j is rejected.

      End if

      End for

Fig. 5 Pseudocode for relay selection based on the criterion of price

The relay node selection strategy based on the utility obtainable by the source node as a result of the price announced by the relay node and the power the source node is able to buy from it is shown in the flow chart of Fig. 6.
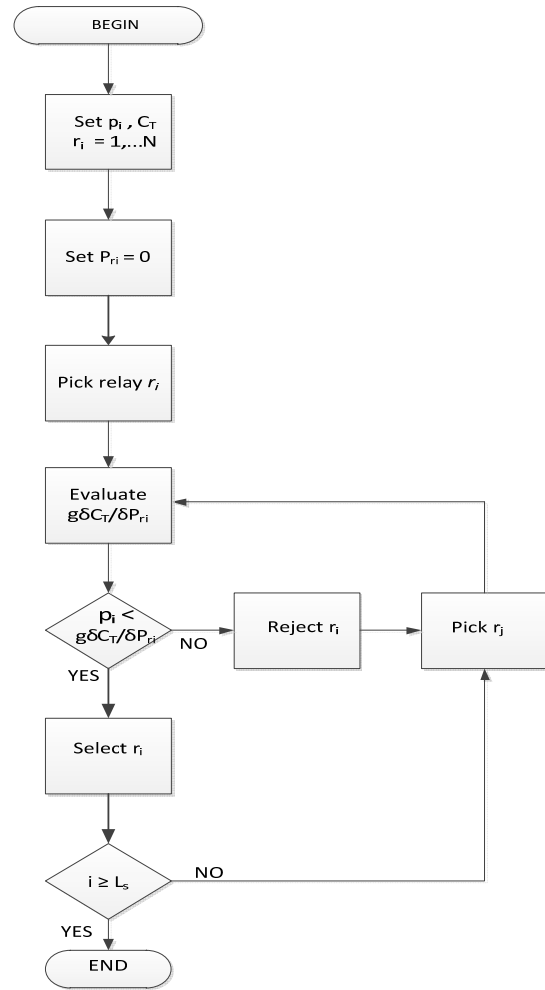

Fig. 6 Flow chart for selecting a suitable partner node based on price and power purchased

IV. PROPOSED RESOURCE ALLOCATION SCHEME

In a cooperative communication set-up consisting of the source, partner (relay) and destination nodes, the relays are randomly distributed at different points on the network layout; from where help is required of them by the source to help it forward data or information to the destination terminal, and at the same time, the relay nodes ask different prices for helping the source node forward its data, using the economic game concept of buying and selling and trade-off.

Technically speaking, the source node cannot choose all the available nodes as partners or relays. Some are rejected while others are selected. For instance, any node with a bad channel condition will definitely be rejected since it will not guarantee good throughput, notwithstanding the price tag on it. So, it is this partner selection that this section of this paper is devoted to. The question we wish to proffer solutions to is that, how is this selection of partner(s) carried out in a distributed network? The subsections that follow describe two levels of this game, which are the source node-level and relay node-level games.

A. Source Node-Level Game

Modeling the source node as buyer of resource, for example, power is aimed at making the buyer obtain the most benefits at least possible payments, similar to what happens in normal business concept of buying and selling. The source, *s* has its utility function defined as [1]:

$$U_s = gC_T - \psi \qquad (14)$$

where C_T denotes the transmission rate capacity achievable at the MRC output, with the help of the relaying partners, *g* refers to the gain per unit of rate, and ψ stands for the total payments paid by the source *s* to the relay nodes to buy power, given by:

$$\psi = \sum_{i=1}^{N} p_i P_{r_i} \qquad (15)$$

where p_i denotes the price per unit of power being sold by relay r_i to source *s*, and P_{r_i} refers to the amount of power node *s* is buying from relay r_i. And because the source node will want to maximise its resource, an optimization problem is formulated thus:

$$\max U_s = gC_T - \psi \text{ s.t. } P_{r_i} \geq 0 \qquad (16)$$

for a single-relay case, the optimization problem is given as:

$$\max U_s = gC_T - p_1 P_{r_1}, \text{ s.t. } P_{r_i} \geq 0 \qquad (17)$$

while it becomes:

$$\max U_s = gC_T - (p_1 P_{r_1} + p_2 P_{r_2}), \text{ s.t. } P_{r_i} \geq 0 \qquad (18)$$

for a two-relay case and for *n*- relay case, it becomes:

$$\max U_s = gC_T - \sum_{i=1}^{n} p_i P_{r_i}, \text{ s.t } P_{r_i} \geq 0 \qquad (19)$$

B. Relay Node-Level Game

Every relay node in the cooperative process is seen as a seller of resources, who seeks to sell its resources, for example, power in this case, and also targets, not only receiving the payment for the cost of forwarding data to the destination node for the source node, but also earning much profit from the deal.

Then just as in the buyer's case, the utility of the relay node r_i will be given as [1]:

$$U_{r_i} = p_i P_{r_i} - a_i P_{r_i} \qquad (20)$$

where a_i is a parameter denoting the cost of the power for forwarding data by the relay *i*. Also, since the relay will also try to maximize its opportunity, the optimization problem is written thus

$$\max U_{r_i} = (p_i - a_i)P_{r_i}, \text{ s.t. } p_i > 0, \forall i \qquad (21)$$

From the above discussions, it can be seen that the two games, the buyer-level and seller-level games are aimed at (i) selection of partners by the source node (ii) deciding the optimal price p_i to maximize the partners' (relays') profits or utility, U_{r_i}; and (iii) getting the corresponding optimal power that will be consumed to maximize its (source's) utility U_s. It is also noteworthy that only two signals are necessary to exchange data between the source and relays. These are the price p_i and knowledge of the amount of power P_{r_i} the source would buy from the relay or that the relay node would sell to the source node.

Actually, apart from the fact that the source node seeks the 'best partner(s)' with which to cooperate with, it also tries to maximise its utility or payoff, U_s obtainable in the game. The source node achieves this by purchasing a maximum amount of power from the selected relay – this power bought by the source is increased gradually until a maximum is reached.

After selecting all the 'suitable' partners for the cooperation, what is next is how to allocate resource to these selected relay nodes. This is important in that in any power-limited network, there is the need to ascertain the optimal power that can be allocated, or in our work, the optimal power that can be sold or bought by either the relay node or source node respectively. This is the major focus of this work.

In the event that the suitable partner(s) located to the destination node has/have been selected by the source node and a selected node set constituted as:

$$L_{s1} = \{r_1, r_2, r_3, ... r_{L_s}\}$$

where L_{s1} denotes the number of selected partner nodes (based on the second criteria for selection discussed earlier), there is the need to compute the optimal value of the resource (in this case, power) that the partner can offer the source node to enable it maximize its utility. This is known as the optimum resource or simply optimum power allocation, in case of power as the metric; so, in this work, an optimum power allocation scheme is developed for the cooperative scheme. The execution of this scheme is however preceded by the partner selection scheme developed in the previous section.

Recall that during the partner selection scheme, it is the variation of the source node's utility *U* to the power *P* of the partner node that gives rise to the criteria for the selection of suitable partner(s) for the source node after the first two selection criteria based on proximity to the source and destination nodes have been considered. That is:

$$\frac{\partial U_s}{\partial P_{r_i}} = g\frac{\partial C_T}{\partial P_{r_i}} - p_i = 0 \qquad (22)$$

where g is the gain per unit of rate at the output of the MRC (receiving end) and p_i is the price per unit of power bought by the source node:

$$C_T = W\log_2\left(1+\left(\gamma_{sd}+\gamma_{rd}\right)\right)$$
$$C_T = W\log_2\left(1+\gamma_{sd}+\gamma_{rd}\right)$$

for a one-relay system and

$$C_T = W\log_2\left(1+\gamma_{sd}+\sum_{r_i\in L_s}\gamma_{rd}\right) \qquad (23)$$

For L_{s1} selected relays

$$\text{So, } gC_T = gW\log_2\left(1+\gamma_{sd}+\sum_{r_i\in L_s}\gamma_{r_id}\right) \qquad (24)$$

for computational simplicity, or to reduce computational complexity, we assume:

$$W^{'} = \frac{gW}{In2} \text{ ; and } 1+\gamma_{sd} = D$$

We thus have

$$gC_T = gW\log 2\left(D+\sum_{r_i=1}^{L_s}\gamma_{r_id}\right) \qquad (25)$$

$$= W^{'}In\left(D+\sum_{r_i=1}^{L_s}\gamma_{r_id}\right) \qquad (26)$$

$$= W^{'}InD + W^{'}In\left(1+\gamma^{'}_{tot}\right) \qquad (27)$$

where $\gamma^{'}_{tot}$ is the total SNR for all the partner-destination channels in the cooperative network.

$$\text{i.e } \gamma^{'}_{tot} = \sum_{r_i=1}^{L_s}\gamma^{'}_{r_id} = \frac{1}{D}\sum_{r_i=1}^{L_s}\gamma_{r_id} \qquad (28)$$

$$\text{and } \gamma^{'}_{r_id} = \frac{\alpha_i}{1+\frac{\beta_i}{P_{r_i}}} = \frac{\alpha_i\cdot P_{r_i}}{P_{r_i}+\beta_i} \qquad (29)$$

where $\alpha_i = \dfrac{E_{sd}h_{sd}^{2}}{N_o+E_{sd}h_{sd}^{2}}$ and $\beta_i = \dfrac{E_{sd}h_{sr}^{2}+N_o}{h_{rd}^{2}}$

Recall that:

$$M = \sum_{r_i\in L_s}p_iP_{r_i} = p_1P_{r_1} + p_2P_{r_2} + ...p_{N_s}P_{r_{N_s}} \qquad (30)$$

Substitute (27) and (23) into (19),

$$\frac{\partial U_s}{\partial P_{r_i}} = \frac{W^{'}}{\left(1+\sum_{k=1}^{N_s}\frac{\alpha_kP_{r_k}}{P_{r_k}+\beta_k}\right)}\frac{\alpha_i\beta_i}{\left(P_{r_i}+\beta_i\right)^2} - p_i = 0 \qquad (31)$$

rearranging (28), we have:

$$\frac{p_i}{\alpha_i\beta_i}\left(P_{r_i}+\beta_i\right)^2 = \frac{W^{'}}{\left(1+\sum_{k=1}^{N_s}\frac{\alpha_kP_{r_k}}{P_{r_k}+\beta_k}\right)} \qquad (32)$$

From (29), it is seen that for any partner i on the LHS, the RHS is the same, so

$$\frac{p_i}{\alpha_i\beta_i}\left(P_{r_i}+\beta_i\right)^2 = \frac{p_j}{\alpha_j\beta_j}\left(P_{r_j}+\beta_j\right)^2 \qquad (33)$$

where i, j represent two different partners in the selected partners set.
Solving (12),

$$p_i\alpha_j\beta_j\left(P_{r_i}+\beta_i\right)^2 = p_j\alpha_i\beta_i\left(P_{r_j}+\beta_j\right)^2$$

$$\sqrt{\frac{p_i\alpha_j\beta_j}{p_j\alpha_i\beta_i}}\left(P_{r_i}+\beta_i\right) = \left(P_{r_j}+\beta_j\right)$$

$$\Rightarrow P_{r_j} = \sqrt{\frac{p_i\alpha_j\beta_j}{p_j\alpha_i\beta_i}}\left(P_{r_i}+\beta_i\right) - \beta_j \qquad (34)$$

We then substitute (31) into (26) and simplify to obtain

$$\gamma^{'}_{r_jd} = \left(\frac{\alpha_j}{1+\frac{\beta_j}{P_{r_j}}}\right) = \left(\alpha_j - \sqrt{\frac{p_j\alpha_i\beta_i}{p_i\alpha_j\beta_j}}\frac{\alpha_j\beta_j}{\left(P_{r_i}+\beta_i\right)}\right) \qquad (35)$$

Recalling also from (26) that $\gamma^{'}_{tot} = \sum_{i=1}^{N_s}\gamma^{'}_{r_id}$, we have from (32),

$$
\gamma_{tot} = \begin{bmatrix} \left[\alpha_1 - \sqrt{\dfrac{p_1\alpha_i\beta_i}{p_i\alpha_1\beta_1}}\dfrac{\alpha_1\beta_1}{(P_{r_i}+\beta_i)}\right] + \left[\alpha_2 - \sqrt{\dfrac{p_2\alpha_i\beta_i}{p_i\alpha_2\beta_2}}\dfrac{\alpha_2\beta_2}{(P_{r_i}+\beta_i)}\right] + \\[2mm] \left[\alpha_1 - \sqrt{\dfrac{p_3\alpha_i\beta_i}{p_i\alpha_3\beta_3}}\dfrac{\alpha_3\beta_3}{(P_i+\beta_i)}\right] + ... \\[2mm] ... + \left[\alpha_1 - \sqrt{\dfrac{p_{N_s}\alpha_i\beta_i}{p_i\alpha_{N_s}\beta_{N_s}}}\dfrac{\alpha_{N_s}\beta_{N_s}}{(P_{r_i}+\beta_i)}\right] \end{bmatrix} \quad (36)
$$

Substituting (33) into (29), and after some manipulations, we have,

$$
\begin{bmatrix} \left(1+\sum_{j=1}^{N_s}\alpha_j\right)\left[\sqrt{\dfrac{p_i}{\alpha_i\beta_i}}\left(P_{r_i}+\beta_i\right)\right]^2 - \\[3mm] \sum_{j=1}^{N_s}\sqrt{p_j\alpha_j\beta_j}\left[\sqrt{\dfrac{p_i}{\alpha_i\beta_i}}\left(P_{r_i}+\beta_i\right)\right]-W' \end{bmatrix} = 0 \quad (37)
$$

which is a quadratic function in P_{r_i}

Therefore, for a selected partner, the optimum power allocation or consumption to enable the source node maximize its utility is given as follows:

$$
P_{r_i} = \begin{bmatrix} \dfrac{\sqrt{\dfrac{\alpha_i\beta_i}{p_i}}}{2\left(1+\sum_{j=1}^{N_s}\alpha_j\right)}\left(\sum_{j=1}^{N_s}\sqrt{p_j\alpha_j\beta_j}+\sqrt{\left(\sum_{j=1}^{N_s}p_j\alpha_j\beta_j\right)^2+4\left(1+\sum_{j=1}^{N_s}\alpha_j\right)W'}\right)-\beta_i \end{bmatrix} \quad (38)
$$

The solution in (35) is actually a general solution for the optimum power allocation for the selected partner, which is also seen to be the global optimum to the optimization problem in (13). However, the value may be negative if for instance the channel condition is poor or too high a price is asked by the partner node which might be unaffordable by the source node. So the optimum power allocation is modified as follows:

$$
P_{r_i}^{opt} = \max(P_{r_i}, 0) \quad (39)
$$

where P_{r_i} is the solution of (35)

Now to the issue of the optimal price that the relay can ask: We substitute (35) into (18), giving us:

$$
\max U_{r_i} = (p_i - a)P_{r_i}^{opt}\left(p_1,...p_2,...p_i,...p_{L_s}\right), \\ p_i > 0, \forall i \quad (40)
$$

Being a game of tension among the relay nodes, trade-off thus exists between the utility U_{ri} of the relay node and the price p_i as can be seen in (37). As discussed earlier, if a relay node is located very close to the destination node, there is every tendency for it to ask a high price from the source node

so as to maximize its own utility; therefore, there should be an optimal price for the relay node to ask for. Aside that, this optimal power isalso affected by the prices of the other relay nodes, since this is a game in which the source node only chooses the beneficial relay nodes as cooperating partners.

Thus, differentiating the relay node's utility U_{r_i} with respect to price p_i, we obtain:

$$
\frac{\partial U_{r_i}}{\partial p_i} = (p_i - a)\frac{\partial U_{r_i}}{\partial p_i} + P_{r_i}^{opt} \quad \forall r_i \ i \in L_s \quad (41)
$$

Equating (38) to zero gives:

$$
(p_i - a)\frac{\partial U_{r_i}}{\partial p_i} + P_{r_i}^{opt} = 0 \quad (42)
$$

Solving (39) for p_i gives the optimal price a relay node can ask for, under the circumstance that the channel condition is good and that the relay node is in the proximity of the destination node. So this optimal price is denoted by:

$$
p_i^{opt} = p_i^{opt}(n, \{G_{sr}\}, \{G_{rd}\}) \quad (43)
$$

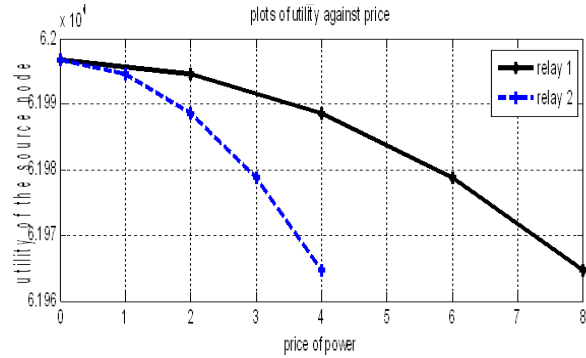## V. RESULTS AND DISCUSSION

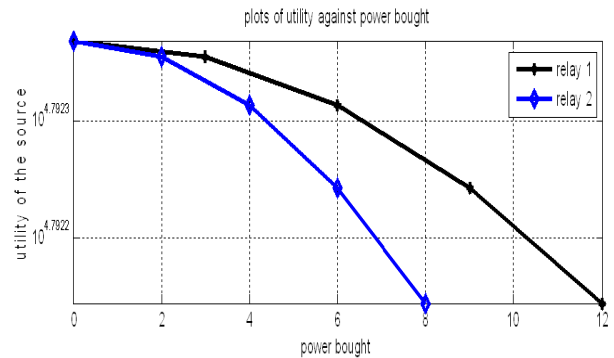Fig.7 Plots showing the variation of the source utility with the unit price of power

Fig. 8 Plots of variation of the utility of the source node with the power bought from the relay node

The relay selection criteria for a distributed network analyzed above is discussed as follows: Given that the total number of nodes is N (in this work $N = 2$). At the start of the game, the source initially chooses $P_r = 0$, $i = 1, 2 \ldots N$ and all relay nodes available set their own prices initially as $p_i = c_i$, for all i. If for a particular relay, say j, $c_j \leq g \dfrac{\partial C_T}{\partial P_{r_j}}$, then relay j is selected by the source even while $P_{r_j} = 0$, else it is rejected.

However, Figs. 7 and 8 show the interactions between the unit price of power and the utility of the source node on one hand; and between the power bought from the relay and the utility of the source node on the other hand. At a low price, the source node is willing to buy more power, thus enhancing its utility while also boosting the utility of the relay node as well, because it is the seller of the power. But as it can be seen from the plots (Fig.7), as the price announced by the relay nodes begins to increase, the utility enjoyed by the source by being able to buy power also begins to reduce. Moreover, as it is seen that the source tends to derive more utility from relay 1 than from relay 2, the source would select relay 1 as its cooperative partner.

A similar trend is noticeable in Fig. 8. As the power bought increases in amount, the utility of the source also begins to reduce. Reason for this is that as the source node continues to buy more power, the relay will also want to increase its own utility by increasing its price, which will compel the source node to buy less power, and thus have its utility reduced.
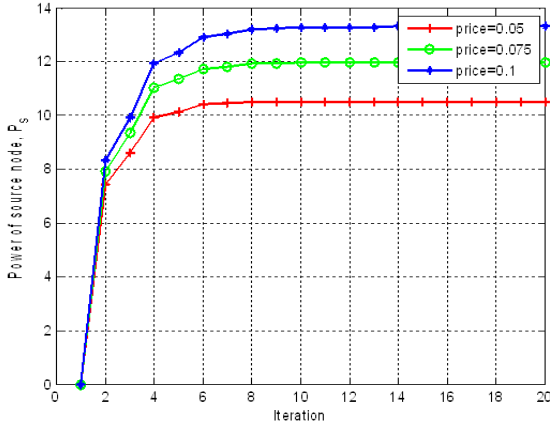

Fig. 9 Plots showing the convergence of the source node power to the Nash equilibrium
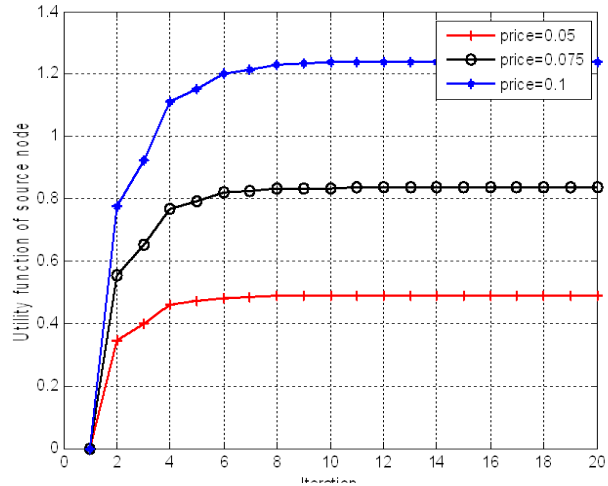

Fig. 10 Plots showing the convergence of the source node's utility to the Nash equilibrium

In Figs. 9 and 10, we see how the power of the source node and the source node's utility both converge to the Nash equilibrium. Fig. 9 shows for the power bought by the source node while Fig. 10 is for the utility of the source node which, as can be observed, increases as the price is varied upwards. One of the unique metrics used in game-theoretic analyses is the Nash equilibrium, which is a solution concept in this type of game, i.e., non-cooperative game involving two or more players in the game. So this convergence to equilibrium further validates our proposed scheme.

VI. Conclusion

In this paper we have proposed new game-theory based partner selection and power allocation schemes. We have modeled a cooperative wireless network as a non-cooperative game scenario in which the source node is the buyer and the relay nodes are the sellers of power. We observe that the approach enables the source node to maximize its benefit (or utility) by selecting a partner node based on (i) the channel conditions between the partner node and destination node, (ii) the proximity of the partner node to the source and destination nodes, and (iii) the price the partner node will charge for the help being rendered. Our proposed scheme helps the source locate and select the relay nodes at 'better' locations and purchase power optimally from them. It also aids the contending relay nodes maximize their own benefits or utilities as well by asking proper prices. Our game scheme is seen to converge to the unique Nash equilibrium.

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Oluseye A. Adeleke obtained his Master's degree in Electronic and Electrical Engineering from the Ladoke Akintola University of Technology, Ogbomoso Nigeria in the year 2008 and is currently a research student in the areas of user cooperation and game theory at the University Sains Malaysia (USM), Nibong Tebal, Penang, Malaysia. He is a registered student member of the Institute of Electrical and Electronics Engineers (IEEE) and of the Communications Society (ComSoc). He is also a member of the Institute of Electronics, Information and Communication Engineers (IEICE), and of the Nigeria Society of Engineers (NSE).

Mohammed Fadzli Salleh is an associate professor in the School of Electrical and Electronic Engineering, University Sains Malaysia, Pulau Pinang, Malaysia. He is a registered member of the Institute of Electrical and Electronic Engineers (IEEE) and the Institute of Information, Electronics and Communication Engineers (IEICE).