SUITABLE PARTNER SELECTION IN A DECENTRALISED COOPERATIVE COMMUNICATION VIA THE *BUYER-SELLER* GAME

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ABSTRACT

The performance and efficiency of a cooperative diversity scheme depend, largely on proper allocation of resources like power and bandwidth. Another important factor to consider is the selection of a proper partner by the source node to help in forwarding information to the destination. In this letter, we look at the concept of relay selection for a distributed communication networks, rather than the more common centralized system where precise channel state information data has to be available at the base station. Also coded cooperation is used as the cooperative scheme rather than the more common amplify-and-forward or decode-and-forward system. A type of game known as non-cooperative game is employed in this analysis so as to jointly consider the utilities of the source and relay nodes, where in this case, the source is the buyer while the relay is the seller. The approach enables the source to maximize its benefit (or utility) by selecting to buy power from the relay that would enable it do so. Results show that at a low price, the source node buys more power from the relay, which also increases the utility of the relay itself. It also shows that among a set of relays competing for the attention of a source node, the source will only select a partner (relay) that gives it the highest utility in terms of the resource, i.e power. In this paper, partner and relay are used interchangeably.

Keywords coded cooperation, cooperative communication, game theory, power, utility, relay selection

1 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 (Beibei, Zhu, & Liu, 2009), (Elfituri, Hamouda, & Ghrayeb, 2009).

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 communications, some of which include the Amplify-and-Forward scheme, Decode-and-Forward scheme, Estimate-and-Forward scheme and Coded cooperation. But the coded cooperation scheme is usually preferred to others because of its capability to address the limitations of the others (Hunter & Nosratinia, 2006), (Hunter & Nosratinia, 2002b). Coded cooperation is a cooperation scheme that incorporates channel coding in the cooperative process.

There have been works that utilized game theory in cooperative communications (Cao, Zhao, & Jing, 2012) (Afghah, Razi, & Abedi, 2010) (Hua & Junhu, 2008) (Nazir & Rajatheva, 2010) (Beibei et al., 2009) (Hunter & Nosratinia, 2002a). In the work of Cao *et al* (Cao et al., 2012), the authors consider a multi-user single-relay wireless network, where the relays get paid for helping to forward data to the destination terminal. In that work, the interaction between source and relay is modelled as a two-level Stackelberg game, in order to solve the issue of relay power allocation via pricing. In (Elfituri et al., 2009), the authors propose a stochastic game-theoretic model for cooperative packet forwarding to provide an efficient cooperative solution for nodes to achieve better power and throughput performance.

Jiang and Ruan, in (Hua & Junhu, 2008) propose a distributed algorithm based on the Stackelberg strategy for power control in wireless networks. In (Nazir & Rajatheva, 2010), the issue of relay selection is dealt with. Here the authors present an algorithmic approach to solve the problem of relay selection using the techniques from optimization and game theory. Among all these past works, the one most related to this current research is the one by Wang *et al* (Beibei et al., 2009) where distributed relay selection and power control using the Stackelberg game concepts are considered. As in (Beibei et al., 2009) and (Nazir & Rajatheva, 2010), the relay – source interaction is modeled as a two-level game to jointly consider the benefits of the source and relay nodes. In this situation, the source acts as the buyer while the relay nodes act as the sellers in the game.

However, all these works base their cooperation on the amplify-and-forward cooperative scheme which main demerit has been that noise and other propagation impairments are also amplified and forwarded with the original information (Afghah et al., 2010). In view of this, the major contribution of this work is to correct this error by incorporating channel coding in selecting suitable cooperating partners with the aid of non-cooperative game theory in a cooperative network.

The rest of this paper is organized as follows: Section II gives the cooperative system model while Section III gives the relay selection scheme being proposed. In Section IV, results are discussed while the paper is concluded in Section V.

2 Coded Cooperation System Model

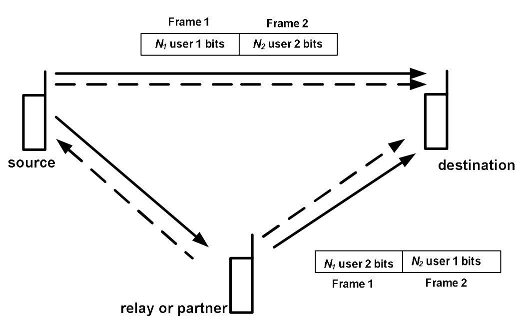

Fig.1 A 3 – node coded cooperative communication scheme

The process of cooperation for a 3-node (source, relay and destination nodes) 2-user (source and relay nodes) coded cooperative scheme is fully described in (Hunter & Nosratinia, 2006), (Almawgani & Salleh, 2010). The first frames (N_1) are transmitted from the source node to the destination node directly, while the second frames (N_2) are forwarded to the destination node via the partners or relay node(s). As mentioned earlier, coding is introduced into the cooperative process in order to control the errors inherent in the system.

3 Proposed Partner Selection Scheme

First, we obtain the channel capacity for a coded cooperative scheme, from the Claude-Shanon's theorem on information theory. After some computations, the channel capacity for a coded cooperation scheme is given as

$$C_T = W\log_2\left(1 + 2R\gamma_{sd}(n) + 2\frac{R}{(L_s+1)}\left(\gamma_{sd}(n) + \sum_{i=1}^{L_s}\gamma_{r_i d}\right)\right) \quad (1)$$

where W = bandwidth, R = code rate L_s = number of relays for cooperation, γ = channel SNR and the subscripts sd and $r_i d$ refer to the source node – destination node and relay node – destination node respectively.

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

$$U_s = gC_T - \psi \quad (2)$$

where $\psi = \sum_{i=1}^{L_s} p_i P_{r_i}$ is the total payment paid to the relay nodes by the source node (3)

Since $\psi = p_i P_{r_i} + p_i P_{r_i} + \ldots$, (2) can be written as follows:

$$U_s = gC_T - p_i P_{r_i}$$

To obtain how the utility of the source node *s* varies with the purchased power by the relay nodes, we obtain the derivatives as follows:

$$\frac{\partial U_s}{\partial P_{r_i}} = g\frac{\partial C_T}{\partial P_{r_i}} - p_i\frac{\partial P_{r_i}}{\partial P_{r_i}} \quad (4)$$

Yielding $\frac{\partial U_s}{\partial P_{r_i}} = g\frac{\partial C_T}{\partial P_{r_i}} - p_i$ i = 1, 2 ... L_s (assuming that there are L_s relay nodes participating in the game) where C_T denotes the transmission rate capacity achievable at the maximal ratio combiner (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 made by the source node *s* to the relay nodes to buy power, as defined earlier 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 node r_i is exempted or excluded from participating in the game (relay node exclusion criteria).

The algorithm of the proposed partner selection algorithm using the Buyer-Seller game scheme is given as follows:

Algorithm for the proposed Scheme

1. Set $P_{r_i} = 0$; *g* is given; C_T is also known;
2. $i = 1, 2, ...N;$
3. For all *i*, set $p_i = c_i$;
4. Evaluate $g\frac{\partial C_T}{\partial P_{r_i}}$;
5. If $c_j \le g\frac{\partial C_T}{\partial P_{r_j}}$;
6. then r_j is selected;

   else;
7. r_j is rejected.

4 Results and Discussion

The proposed scheme for selecting the most suitable cooperating partner in a coded diversity scheme using the concept of buying and selling has been described. Since the partners (or relay nodes) are located at different points on the network, and all of them cannot be selected by the source node, game theory becomes the veritable tool to use in helping the source in determining the best among the partnering nodes that would enable it maximize its utility. At a low price charged by a partner or relay node, the source node tends to buy more power from it. But as this price increases, there is the propensity that the source node would look away from that partner and seek another with a lower price. This is illustrated in Fig. 3 and Fig. 4.

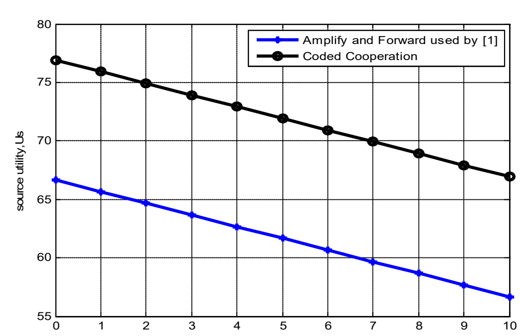

Fig. 2 Plots showing the comparison of the source utility using the amplify and forward scheme in [1] with that using the coded cooperation scheme

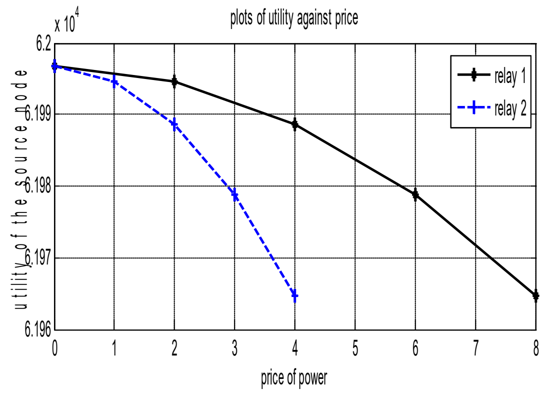

Fig. 3 Plots showing the variation of the source utility with the unit price of power

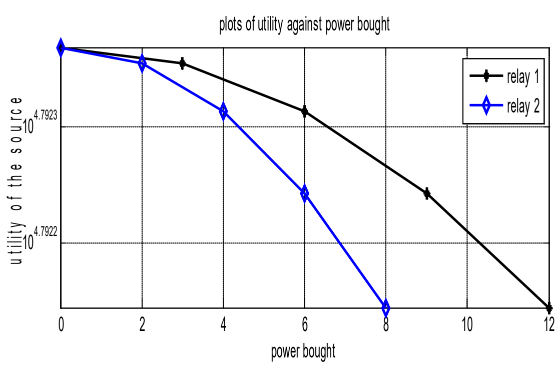

Fig. 4 Plots of variation of the utility of the source node with the power bought from the relay node

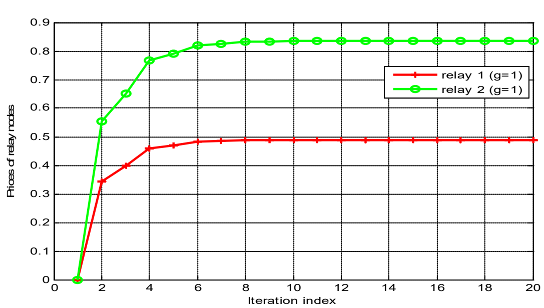

Fig. 5 Observance of convergence speed using the relay node's prices versus iteration index, with two relay nodes in the system

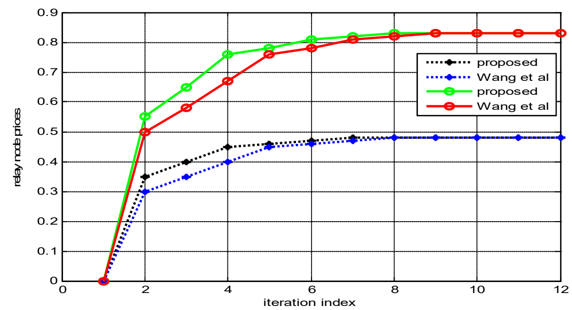

Fig. 6 Plots comparing the convergence speeds of the proposed game scheme with the scheme in Wang et al [1] for a 2-relay node network

In Fig. 2, we show the plots of total payment by the source node against the source utility, using both the amplify and forward scheme, used for the partner selection scheme in [1] and the coded cooperation which is being proposed in this work for partner selection. In the plots, it is seen that the utility of the source decreases as the total payment increases. This is because the total payment is a function of the unit price announced by the prospective partners; and as this price increases, the source would buy less from that partner.

It can also be seen from the plots that, using the coded cooperation, the source utility is higher than when the amplify and forward scheme is used. This is because the amplify and forward scheme, as mentioned earlier, tends to amplify the noise and other impairments, leading to poor channel conditions, and as such hindering the source node from making a partner selection which would increase its utility. This thus corroborates our proposition in this work – partner selection in a coded cooperative system

In Fig. 3, the plots showing how the source utility varies with the price of power are shown. At a low price announced by the relay, the source is willing to buy more power from it, leading to a high source's utility and by extension, more utility for the relay as well. But as the price goes up, the utility decreases, since the source tends to reduce the amount of power bought. It is also seen here that the source would select relay 1, since it gives it more utility than relay 2. A similar situation is described in Fig. 4.

Fig. 5 shows plots for observing the convergence to equilibrium of the relay nodes' prices. Here we see plots of the prices of relay nodes against the iteration index. It can be seen from the figure with two relay nodes, that the proposed trade-off scheme has fast convergence to equilibrium. Less than 10 iterations are needed for the price to converge, with two relay nodes in the network, and given that $g = 1$, where g is as defined earlier in the earlier section, as gain per unit of transmission rate.

Fig. 6 shows a comparison of the convergence for the proposed scheme with that in a related work by Wang et al [1]. In the figure, it is seen that the proposed scheme converges faster than the previous work, which confirms that this proposed scheme outperforms the previous related work.

5 Conclusion

In this paper, we have proposed a partner selection scheme for a coded cooperative scheme based on a type of non-cooperative game known as the Stackelberg game. Power is used as the 'trading' parameter. This work is an improvement over the work in [1] where the amplify-and-forward scheme is used as the cooperative scheme. Our work is also seen to converge to equilibrium.

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