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A Game-Theoretic Approach for Power Allocation in Bidirectional Cooperative Communication

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Abstract—**Cooperative communication exploits wireless broadcast advantage to confront the severe fading effect on wireless communications. Proper allocation of power can play an important role in the performance of cooperative communication. In this paper, we propose a distributed game-theoretical method for power allocation in bidirectional cooperative communication networks. In this work, we consider two nodes as data sources who want to cooperate in sending data to the destination. In addition to being data source, each source node has to relay the other's data. We answer the question: How much power each node contributes for relaying other node's data? We use Stackelberg game which is an extensive-form game to find a solution to this problem. The proposed method reaches equilibrium in only one stage. It is shown that there are more benefits when bidirectional cooperation is done between node pairs who are closer to each other. Simulation results show that the proposed method leads to fair solution and the nodes farther to the destination should contribute more power to cooperate with others.**

Keywords- Cooperative communication, Distributed power allocation, Game theory, Stackelberg game

I. INTRODUCTION

One of the disruptive effects in wireless communication is the fading effect. Spatial diversity is a way for compensating this effect. It is performed by utilizing multiple antennas in receiver. In some networks like sensor networks, where the nodes' sizes are so small that using multiple antennas with appropriate distance between them is not practical, spatial diversity cannot be applied. Cooperative communication [1] , [2] exploits wireless broadcast advantage (WBA) for solving this problem. It uses the other nodes in the network to relay the data from source node thereby creating virtual multiple antennas to confront the fading effect.

Resource allocation is one of the most important challenges in cooperative communication. Power and bandwidth are mostly considered as shared resources among nodes in cooperative communication. In this paper, we focus on power allocation. Several works have studied resource allocation in cooperative networks in recent years. These methods are divided into two major categories: centralized and distributed.

Considering centralized methods category, in [3], the authors examined optimal user matching (bidirectional cooperation) and power management to maximize cooperative diversity energy gain for wireless networks. In [4], the relay selection and power allocation problem is solved in a network to expand wireless network lifetime. The authors of [5] investigated power allocation to minimize outage probability. In [6], the authors proposed an optimal algorithm for power allocation and relay selection in a cooperative network to minimize power consumption.

In some networks, nodes are autonomous or do not belong to the same authority. Rationally, for each of these nodes only its own performance is important, i.e. nodes are selfish. For such networks, distributed methods that consider the selfish behavior of nodes should be used. Considering distributed methods, in [7], two auction-based methods are used for distributed relay selection and power allocation. The authors of [8] proposed a pricing game that stimulates cooperation among selfish nodes using reimbursements to relays. In [9] the bidirectional cooperation problem for bandwidth sharing between nodes is solved. It utilizes Nash bargaining solution to determine the amount of bandwidth each node contributes in cooperation assuming fixed power for nodes. In [10] distributed resource allocation for multiuser cooperative network is performed using Stackelberg game [11]. It assumes one source node and a number of relay nodes and answers two questions: who will be the relays and how much power each of them consumes for relaying source node data? In this work, source node pays for the relay nodes service and does not give them any service.

In this paper, we focus on performing power allocation for two source nodes who want to have bidirectional cooperation. That is, both of nodes want to send data to a common destination and cooperate with each other in data transmission. The first benefit of bidirectional scheme is that, it is applicable in a large variety of networks where a number of source nodes want to send data to a common destination. One of the well-known samples of these networks is wireless LAN where various users like laptops and mobiles want to have two-way communications with an access point. Another benefit of this scheme is that it does not involve virtual money payment procedures. Making such payments is still a challenge in decentralized networks [12]. In this method, there is a trade of transmission power between nodes. Since every node has a power supply for its own data transmissions, the power trade in bidirectional scheme is easily applicable. Furthermore, in this process, the payment for the relaying service is paid at the same time as the service is received. That is, when a node retransmits the other node's data, the node receiving the service pays back the favor by forwarding the other node's data.

In a bidirectional cooperative communication scheme, the main question is how much power each node contributes for sending other node's data. In this paper, we propose a game-theoretical method that answers this question. Stackelberg game is applied which is a simple extensive-form game. Its solution is a Nash equilibrium for the game. When nodes are in Nash equilibrium none of them has any incentive for unilateral deviation. Therefore, considering nodes' selfishness, solving the problem with a game that reaches Nash equilibrium is very precious. In this work, power allocation for cooperation is done. Moreover, we have optimized the power transmitted for self data in non-cooperative mode.

The rest of this paper is organized as follows: in section II, system model and problem formulation is introduced. Next, in section III, the problem is analyzed and the power allocation for bidirectional cooperative communication problem is performed. In section IV, simulation results are illustrated and the results are analyzed. Finally, we conclude the paper in section V.

II. System model and Problem Formulation

A. System Model

In this work, nodes utilize the Amplify and Forward (AF) protocol for cooperation. The model includes a common destination and two nodes as data sources who want to cooperate in sending data to the destination. Source nodes are called node1 and node2. In addition to being data source, each source node has to relay the other's data. First we consider the case where node1 is the data source and node2 is the relay.

At the first step, node1 sends its data. Received signals at destination and node2 are $y_{1,d}$ and $y_{1,2}$.

$$y_{1,d}(t) = \sqrt{P_{11}G_{1d}}x_1(t) + n_{1d}(t) \quad (1)$$

$$y_{1,2}(t) = \sqrt{P_{11}G_{12}}x_1(t) + n_{12}(t) \quad (2)$$

Here, P_{11} is the power that node1 consumes to broadcast its data, $x_1(t)$ is the signal transmitted from node1 with unit energy, G_{1d} and G_{12}, are the path gain of node1-destination and node1-node2 channels respectively. $n_{1d}(t)$ and $n_{2d}(t)$, are Additive White Gaussian Noise (AWGN) added to data signal. The SNR received from direct path at the destination is

$$SNR_{1d} = \frac{G_{1d}P_{11}}{\sigma^2} \quad (3)$$

Where σ^2 is the noise power. Without loss of generality, the noise power is assumed constant for all channels.

At the second step, node2 retransmits node1 data and signal $y_{2,d}$ is received at the destination.

$$y_{2,d}(t) = \sqrt{P_{21}G_{2d}}x_{21}(t) + n_{2d}(t) \quad (4)$$

Here, G_{2d} is the path gain of node2-destination channel. Node2 forwards node1 data with the power P_{21} and $n_{2d}(t)$ is the additive noise component. x_{21} is the normalized $y_{1,2}$ i.e. it has unit energy. As calculated in [1], relay path SNR for node1 data at the destination is

$$SNR_{12d} = \frac{G_{12}G_{2d}P_{11}P_{21}}{\sigma^2(G_{12}P_{11}+G_{2d}P_{21}+\sigma^2)} \quad (5)$$

Assuming a MRC receiver at the destination, the achieved rate for node1 data resulted from direct path and relay path is [1]

$$R_{12d} = \gamma W\, log_2(1 + SNR_{1d} + SNR_{12d}) \quad (6)$$

Where γ is the bandwidth factor. W is the total bandwidth exploited by node1 and node2.

In a similar way, the achieved rate for node2 data at the destination is

$$R_{21d} = \gamma W\, log_2(1 + SNR_{2d} + SNR_{21d}) \quad (7)$$

Where direct path and relay path SNRs for node2 data at the destination can be expressed as

$$\mathrm{SNR}_{2d} = \frac{\mathrm{G}_{2d}\mathrm{P}_{22}}{\sigma^2} \quad (8)$$

$$SNR_{21d} = \frac{G_{21}G_{1d}P_{22}P_{12}}{\sigma^2(G_{21}P_{22}+G_{1d}P_{12}+\sigma^2)} \quad (9)$$

In above formulas, G_{2d} and G_{21}, are the path gain of node2-destination and node2-node1 channels respectively. P_{22} is the power that node2 uses to send its data. Node1 forwards node2 data with the power P_{12}.

B. Problem Formulation

We use game theory to perform power allocation in bidirectional cooperation communication problem.

The utility of node1 is defined as follows:

$$U_1 = aR_{12d} - (cP_{11} + P_{12}) \quad (10)$$

Where a indicates the gain per unit of achieved rate at the destination. c is a parameter for controlling node's tendency for cooperation. By increasing c, node1 is encouraged to cooperate more and vice versa. Utility function consists of two parts. The first part is the achieved rate at the destination which is node1's profit. The second part is the cost that node1 pays in the game. It effectively is the power node1 consumes for sending its own data and relaying node2's data.

Because of symmetry, Node2 utility is defined in a similar way:

$$U_2 = aR_{21d} - (cP_{22} + P_{21}) \quad (11)$$

For relating P_{12} and P_{21}, an α parameter is defined:

$$P_{12} = \alpha P_{21} \quad (12)$$

P_{21} and α are considered as decision parameters of the game, i.e. two source nodes negotiate the amount of these two variables to determine cooperation level. By substituting P_{12} from (12), the optimization problem for node1 can be formulated as

$$max_{\{P_{11},P_{21}\}}\, U_1 = aR_{12d} - (cP_{11} + \alpha P_{21}) \quad (13)$$

And the optimization problem for node2 is

$$max_{\{P_{22},\alpha\}}\, U_2 = aR_{21d} - (cP_{22} + P_{21}) \quad (14)$$

Note that node1 determinesP_{21} i.e. node1 tells node2 that I want you to consume P_{21} Watt power for relaying my data. On the other hand, node2 determines α which means node2 tells node1 to consume α multiples of P_{21} Watt power for relaying node2's data.

In optimizing node1 utility, two different problems are faced. Determining P_{11} in order to maximize U_1 is an optimization problem, while determining P_{21} is a game problem. The reason is that its value not only influences node1's utility, but also influences node2's utility. Therefore, it is not a simple optimization problem. In a similar discussion for node2, it is obvious that determining P_{22} is an optimization problem and determining α is a game problem. Hence, there exists three different problems, two optimization problem for determining P_{11} and P_{22} and a game for determining P_{21} and α.

III. Analytical Results

In this section, optimization problems solution is mentioned first. Then the Stackelberg game, which is used for game analysis, is introduced. Finally the game solution is declared.

A. Optimization Problems

Before starting the game, the value of P_{11} and P_{22} is determined to maximize nodes' utilities. This is done assuming non-cooperative nodes. In the non-cooperative scheme, it can be deduced from formula (10), that node1's utility is

$$U_1 = a\gamma W\, log_2\left(1 + \frac{G_{1d}P_{11}}{\sigma^2}\right) - cP_{11} \tag{15}$$

In order to find P_{11}^*, which maximizes the above utility, derivative of U_1 is taken with respect to P_{11},

$$\frac{\partial U_1}{\partial P_{11}} = W'\frac{G_{1d}}{\sigma^2+G_{1d}P_{11}} - c \tag{16}$$

Where W' is

$$W' = \frac{a\gamma W}{ln\, 2} \tag{17}$$

By equating equation (16) with zero, it is concluded that

$$P_{11}^* = \frac{W'}{c} - \frac{\sigma^2}{G_{1d}} \tag{18}$$

In a similar way for node2, it can be seen that

$$P_{22}^* = \frac{W'}{c} - \frac{\sigma^2}{G_{2d}} \tag{19}$$

Deduced optimized P_{11}^* and P_{22}^* are assumed constant in game analysis section.

B. Stackelberg Game

Stackelberg game is an extensive-form game which is used to describe the competition between two players who want to compete on the amount of their outputs. The players of the game are called "leader" and "follower". In this game, the leader moves first and the follower observes the leader's action before doing its action. Here, player2 is assumed to be leader and player1 is assumed to be follower. q_2 and q_1 are respectively the leader and follower actions. The credible Nash equilibrium of this game is as follows. In Nash equilibrium, player1's strategy is to choose, for each q_2, the level of q_1 that solves $max_{q_1'}\, U_2\,(q_2, q_1')$. The solution of this maximization problem is called follower's reaction function $q_1 = r_1(q_2)$. Nash equilibrium forces player1's action to be the solution of $max_{q_2}\, U_2\,(q_2, r_1(q_2))$.

C. Game Analysis

Optimization problems for determining P_{11} and P_{22} were solved in section III-A. Therefore, the optimization problems (13) and (14) leads to a game as follows.

$$max_{P_{21}}\, U_1 = aR_{12d} - (cP_{11} + \alpha P_{21}) \tag{20}$$

$$max_{\alpha}\, U_2 = aR_{21d} - (cP_{22} + P_{21}) \tag{21}$$

By using Stackelberg game, the above game is solved.

Node1 is assumed as "Stackelberg follower" and node2 is supposed to be "Stackelberg leader". First, the follower side solution is studied and then the leader side solution is considered.

C.1 Follower Side Solution

As explained in section III-B, in Stackelberg game, follower observes the leader action and then chooses her action. Therefore, in this section, the α parameter is known and the follower should choose P_{21} in a way that maximizes its utility. In mathematical words, optimization problem (20) should be solved.

By taking derivative of U_1 in equation (20) with respect to P_{21} and equating it with zero, the action of node2 action can be found

$$\frac{\partial U_1}{\partial P_{21}} = a\frac{\partial R_{12d}}{\partial P_{21}} - \alpha = 0 \tag{22}$$

Above equation solution which is follower's reaction function, can be found in [9]

$$P_{21} = r_1(\alpha) = \frac{\alpha A_1B_1 + \sqrt{(\alpha A_1B_1)^2 + 4\alpha A_1B_1W'(1+A_1)}}{2\alpha(1+A_1)} - B_1 \tag{23}$$

Where $A_1 = \frac{G_{12}P_{11}}{\sigma^2+G_{1d}P_{11}}$ and $B_1 = \frac{\sigma^2+G_{12}P_{11}}{G_{2d}}$.

Obtained P_{21} is a decreasing function of α [9] and it is shown next that there exists a value α_0 that $r_1(\alpha_0) = 0$. Hence, for $\alpha > \alpha_0$, $r_1(\alpha)$ becomes negative. Since transmitted power cannot be negative, this is not logical and can't be used. So the action which node2 chooses is

$$P_{21}^* = max\{r_1(\alpha), 0\} \tag{24}$$

In order to find α_0, first the formula (23) is written in a simpler way,

$$P_{21} = \frac{W'}{k_2}\left(1 + \frac{\sqrt{(\alpha+k_2)^2 - k_2^2}}{\alpha}\right) - B_1 \tag{25}$$

Where $k_2 = 2W'(1 + A_1)/(A_1B_1)$.

To find α_0, the equation $P_{21}(\alpha) = 0$ should be solved. With some straight calculations

$$\alpha_0 = \frac{2k_2}{k_3^2 - 1} \tag{26}$$

Where $k_3 = (2 + A_1)/A_1$.

Notice that if the leader chooses α in range $\alpha \in (0, \alpha_0)$, the follower will choose positive value for P_{21} and so the cooperation between two nodes occurs. In contrast, if the leader chooses α outside this range, the follower will choose $P_{21} = 0$ and consequently, the nodes won't cooperate. Therefore, the range $\alpha \in (0, \alpha_0)$ is the cooperation region.

C.2 Leader Side Solution

For the leader side, as mentioned in section III-B, the solution of $max_{q_2} U_2\left(q_2, r_1(q_2)\right)$ should be found. By substituting q_2 with α , the optimization problem $max_\alpha u_2\left(\alpha, r_1(\alpha)\right)$ should be solved. Note that this is an optimization problem that only has an independent variable α. The problem in the extensive form is

$$max_\alpha U_2 = aR_{21d}(\alpha) - \left(cP_{22} + P_{21}(\alpha)\right) \tag{27}$$

Where $R_{21d}(\alpha)$ is

$$R_{21d}(\alpha) = \gamma W \log_2\left(1 + \frac{G_{2d}P_{22}}{\sigma^2} + \frac{G_{21}G_{1d}P_{22}\alpha P_{21}(\alpha)}{\sigma^2(G_{21}P_{22} + G_{1d}\alpha P_{21}(\alpha) + \sigma^2)}\right) \tag{28}$$

and $P_{21}(\alpha)$ is the reaction function of follower expressed in (23).

Solving optimization problem (27) leads to the following equation solution,

$$a\frac{dR_{21d}}{d\alpha} = \frac{dP_{21}}{d\alpha} \tag{29}$$

Because of complex dependency of $R_{21d}(\alpha)$ and $P_{21}(\alpha)$ on variable α, solving above optimization problem and finding precise optimizer of U_2 is very difficult. Therefore, in order to find an approximate solution for the above optimization problem, two estimations for functions $R_{21d}(\alpha)$ and $P_{21}(\alpha)$ are used. These estimations are second order polynomials.

- Rate Estimation

Property: $R_{21d}(\alpha)$ is a concave function of α.

First it is shown that $R_{21d}(\alpha)$ is an increasing function of $P_{12} = \alpha P_{21}$. Because of the monotonic behavior of logarithm function, it is sufficient to show that the relay path SNR is an increasing function of P_{12} . Intuitively, this conclusion is obvious. Because by increasing P_{12}, which is the power node1 consumes for relaying node2 data, it is expected that the SNR resulted from relay path will increase. In mathematical form, by taking derivative of formula (9) with respect to P_{12},

$$\frac{\partial SNR_{21d}}{\partial P_{12}} = \frac{G_{21}G_{1d}P_{22}\sigma^2(G_{21}P_{22} + \sigma^2)}{\sigma^4(G_{21}P_{22} + G_{1d}P_{12} + \sigma^2)^2} \tag{30}$$

Which is positive for all values of P_{12} and so relay path SNR is an increasing function of P_{12}.

Now, it is shown that $P_{12}(\alpha) = \alpha P_{21}(\alpha)$, is a concave function of α. By inserting P_{21} from equation (25), $P_{12}(\alpha)$ is

$$P_{12}(\alpha) = \frac{W'}{k_2}\left(\alpha + \sqrt{(\alpha + k_2)^2 - k_2^2}\right) - \alpha B_1 \tag{31}$$

By taking derivative of $P_{12}(\alpha)$ with respect to α,

$$\frac{dP_{12}}{d\alpha} = \frac{W'}{k_2}\left(1 + \frac{\alpha + k_2}{\sqrt{(\alpha + k_2)^2 - k_2^2}}\right) - B_1 \tag{32}$$

By taking derivative again,

$$\frac{d^2P_{12}}{d\alpha^2} = \frac{-W'k_2}{[(\alpha + k_2)^2 - k_2^2]^{\frac{3}{2}}} \tag{33}$$

The above formula is negative for all values of $\alpha > 0$. Hence, P_{12} is a concave function of α. From the above conclusions, it is proved that $R_{21d}(\alpha)$ is a concave function of α.

The next question is whether there exists a point $\alpha = \alpha_R^*$ for which $R_{21d}(\alpha)$ function obtains a local maximum? The answer is yes. As aforementioned, $R_{21d}(\alpha)$ is a concave function of α. Therefore, the α at which $dR_{21d}(\alpha)/d\alpha = 0$, is a maximizer of $R_{21d}(\alpha)$. Because $R_{21d}(\alpha)$ is a monotonic function of P_{12}, this maximum occurs when $dP_{12}/d\alpha = 0$. By equating equation (32) with zero,

$$\frac{\alpha + k_2}{\sqrt{(\alpha + k_2)^2 - k_2^2}} = k_3 \tag{34}$$

By squaring both sides and rearranging the result,

$$\alpha_R^* = \frac{k_2k_3}{\sqrt{k_3^2 - 1}} - k_2 \tag{35}$$

Here, α_R^* is where $R_{21d}(\alpha)$ achieves its absolute maximum.

As shown in equation (29), the optimization problem solution is where the derivative of $R_{21d}(\alpha)$ and $P_{21}(\alpha)$ with respect to variable α are equal with a constant factor a. As mentioned before, $dP_{21}/d\alpha$ is always negative. Therefore, in order to meet relation (29), $dR_{21d}/d\alpha$ should be negative. Consequently, optimizer of U_2 occurs for $\alpha > \alpha_R^*$. Also, for $\alpha > \alpha_0$ nodes won't cooperate. Thus, if the solution happens in the range $\alpha \in (\alpha_R^*, \alpha_0)$, nodes will cooperate and if the solution doesn't occur in that range, the nodes won't cooperate. Note that, it can be simply deduced from equations (26) and (35) that α_R^* is less than α_0 . Therefore, it is sufficient that the estimation of functions be reliable in the range $\alpha \in (\alpha_R^*, \alpha_0)$.

According to the above discussions, it seems suitable to estimate $R_{21d}(\alpha)$ with a second order polynomial which takes its maximum at point $\left(\alpha_R^*, R_{\alpha_R^*}\right)$ and passes $\left(\alpha_0, R_{\alpha_0}\right)$. $R_{\alpha_R^*}$ and R_{α_0} are $R_{21d}(\alpha_R^*)$ and $R_{21d}(\alpha_0)$ respectively. Note that, R_{α_0} is non-cooperative rate and we call it $R_{non-coop}$. Second order polynomial estimation can be described as

$$R_{21d}(\alpha) \cong a_R\alpha^2 + b_R\alpha + c_R \tag{36}$$

By applying the above constraints to polynomial estimation, polynomial coefficients become

$$a_R = \frac{R_{non-coop} - R_{\alpha_R^*}}{(\alpha_0 - \alpha_R^*)^2} \tag{37}$$

$$b_R = -2\alpha_R^* a_R \tag{38}$$

$$c_R = R_{non-coop} - a_R\alpha_0^2 - b_R\alpha_0 \tag{39}$$

- Power Estimation

As mentioned before, $P_{21}(\alpha)$ is a decreasing function of α and coincides α-axis at point α_0. In order to have a suitable estimation for this function in the range $\alpha \in (\alpha_R^*, \alpha_0)$, a second order polynomial is considered which takes its minimum at point $(\alpha_0, 0)$ and passes $(\alpha_R^*, P_{\alpha_R^*})$, where $P_{\alpha_R^*}$ is $P_{21}(\alpha_R^*)$. The second order polynomial estimation can be described as

$$P_{21}(\alpha) \cong a_P(\alpha - \alpha_0)^2 \tag{40}$$

By applying the above constraints to polynomial estimation, polynomial coefficient becomes

$$a_P = \frac{P_{\alpha_R^*}}{(\alpha - \alpha_0)^2} \tag{41}$$

By using the proposed estimations for functions in equation (29), the approximate solution of optimization problem for leader side is

$$\alpha^* = \frac{b_R a + 2a_P\alpha_0}{2(a_p - a_R a)} \tag{42}$$

The introduced Stackelberg game is run in a way that at first the leader, node2, determines α from formula (42). In order to calculate α, it is necessary that follower sends parameters k_2, k_3 and $P_{\alpha_R^*}$ to leader. After calculating α and declaring it to the follower, follower calculates P_{21} from formula (24) and declares it to the leader. The (α^*, P_{21}^*) pair is the cooperation power allocation. Simulation results show that the approximate solution of leader side, α^*, is very close to exact solution. Therefore, the (α^*, P_{21}^*) pair is very close to Nash equilibrium.

IV. Numerical Results

To investigate the performance of the proposed algorithm for power control in bidirectional cooperation, an appropriate scenario is considered and figures are derived from analytical results. Since nodes in this work have the same utility functions, it seems suitable to fix a node at a location and evaluate the results by changing the location of the other node. By doing this, the fixed node profit achieved from cooperative communication, can be analyzed for different partner positions.

It is assumed that the nodes are located on x-y plane, where destination is located at (0m,0m) and node2 is fixed at (100m,-20m). Node1 is moving on the line $y = 20m$, for x between -200m to 300m. We refer to node1 as mobile node and node2 as fixed node. A discussion about how to choose the leader and the follower in the network is provided at the end of this section. Parameter a is assumed 10^{-8}, transmission bandwidth is $W = 10MHz$, bandwidth factor is $\gamma = 0.5$, cooperation factor is $c = 1.2$ and noise power is $\sigma^2 = 10^{-9}$. Path loss exponent is considered to be 2.

By running the game with above parameters the value of the optimized P_{22}, using equation (19) is 0.06W.

P_{mf}, the power that mobile node consumes for relaying fixed node data, is sketched in figure 1. It is seen that, P_{mf} takes its maximum value, when the mobile node is located near the fixed node.

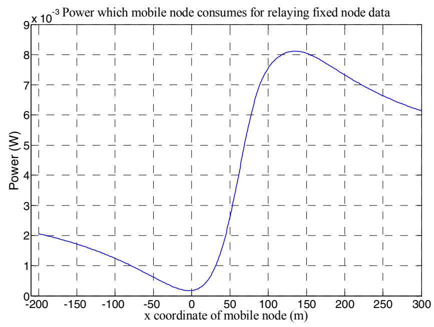

Figure 1. power that mobile node consumes for relaying fixed node data

Therefore, when the partner node is closer to the source node, the cooperation level is more.

In figure 2, α is sketched for different location of mobile node. α is the ratio of powers that each node consumes for relaying the data of the other node,

$$\alpha = \frac{P_{12}}{P_{21}} = \frac{P_{mf}}{P_{fm}}$$

Where P_{fm} is the power that fixed node consumes for relaying mobile node data. The dashed curve is the approximate α obtained from equation (42) and the solid curve is the exact α obtained from global search for optimizing utility in (27). It is seen that approximate solution is very close to the exact one. This illustrates that the approximation done for optimization problem is accurate. The maximum relative difference between the approximate and exact α that occurs at location (25m,20m) for mobile node, is about 6.5 percent. As shown in the figure 2, when the mobile node is located at (100m,20m), α is 1 and consequently, both nodes provide equal help to each other. The location (100m, 20m) for mobile node is where nodes have the same channel conditions to the destination. Furthermore, it can be seen that in the figure that the farther node helps more. Hence, the proposed method performs fair power allocation.

Figure 3 shows the utility of fixed node. It is seen that when fixed node cooperates with nodes closer to it, it has a bigger utility. Thus, it can be concluded that if we apply the proposed game to a large network with several nodes, nodes closer to each other have a greater tendency to make pairs.

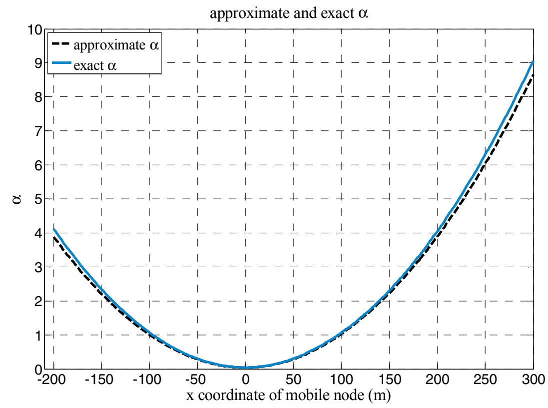

Figure 2. ratio of powers that each node consumes for relaying the other node data

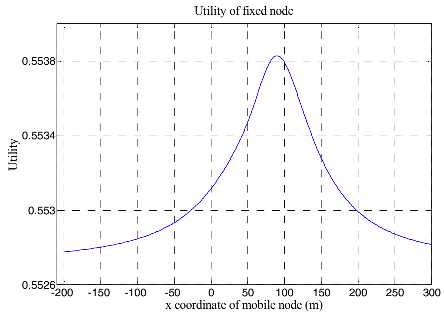

Figure 3. Utility of fixed node

- Leader- Follower Selection

The power allocation for bidirectional cooperative communication is a symmetric problem, i.e. there is no difference between two nodes. The game introduced in this paper for solving this problem has an asymmetry: one node is leader and the other one is follower.

We should utilize a mechanism for choosing a node as the leader and the other one as the follower. In order to do this, a parameter is defined for evaluating whole network utility. This parameter is the sum of nodes utilities.

$$U_n = U_1 + U_2 \tag{43}$$

Two scenarios are considered. In the first scenario, the node farther to the destination is assumed as the leader. In the second scenario the node closer to the destination is assumed as the leader. The value of U_n in two scenarios is $U_{n,FL}$ and $U_{n,NL}$ respectively. Relative difference of U_n in two scenarios is defined as

$$e_{U_n} = \frac{U_{n,FL} - U_{n,NL}}{U_{n,FL}} * 100 \tag{44}$$

This parameter value is sketched in figure 4. As shown in the figure, the parameter value is positive for all positions of mobile node. Therefore, from whole network utility perspective, it is better to select the node farther to the destination as the leader and the closer node as the follower of Stackelberg game.

V. Conclusion

In this paper, we studied power allocation for bidirectional cooperative communication. We proposed a method using

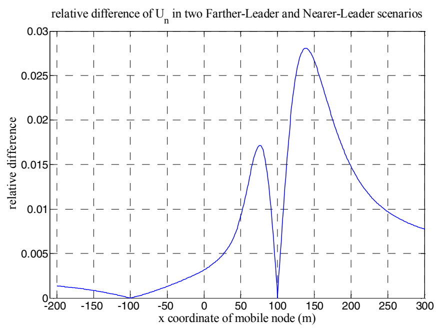

Figure 4. e_{U_n} parameter

Stackelberg game to answer this question: How much power each node contributes for relaying other node's data?

To answering the above question, the power each node consumes for sending its own data was optimized in the non-cooperative mode. Then, in order to find the game solution, some function properties was proved. Finally we reached an approximate solution on the leader side and a precise solution for the follower side. Simulation results for a realistic node configuration showed that the maximum deviation of this approximate solution from the exact solution is about 6.5 percent.

We found the cooperation region between two nodes. In the proposed scheme, when two nodes are closer to each other, they cooperate more and reach greater benefits. Rate of convergence of the proposed method is 1, i.e. the game reaches its equilibrium in only one stage. This property is very important and practical for large networks, where we require least amount of negotiations among nodes. Solution of the game is very close to Nash equilibrium. Simulation verified that the game result is a fair power allocation. The proposed idea can be used as a basis for exploiting bidirectional cooperation in large networks for partner selection problem.

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