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A Nash-bargaining-solution Based Cooperation Scheme for Rational Cooperative Communication Networks

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Abstract: By using the wireless broadcast, cooperative communication has this advantage to confront the severe fading effect on wireless communication. Resource allocation is one of the most important challenges in cooperation. In this study, we propose a Nash Bargaining Solution (NBS) based cooperation scheme to optimal allocate resources for cooperation. In this symmetric cooperative network, nodes can act as both a data transmitter and a relay for each other and determine the amount of resources to share with its partner. We formulate this cooperative problem as a 2-person barging problem and analyze the proper channel condition for 2 nodes to share their resource for cooperation. Simulation results show that the proposed scheme could improve the system performance and the questions that when to cooperate and how to cooperate were answered.

Key words: Cooperative communication, nash bargaining solution, resource allocation, game theory, amplify and forward

INTRODUCTION

Cooperative communication has attracted more and more attention now a days for being an efficient technology to combat wireless fading (Sendonaris *et al*., 2003; Hunter and Nosratinia, 2002; Laneman *et al*., 2004). Since the small size of terminal is hard to implement multiple antennas and perform spatial diversity, cooperative communication exploits Wireless Broadcast Advantage (WBA) for conquering this problem. Nodes in the network are being taken advantage to relay the data from their partner for creating virtual multiple antennas to confront the fading effect. Various cooperative protocols have been proposed, such as amplify and forward, decode and forward and estimate and forward (Sendonaris *et al*., 2003; Hunter and Nosratinia, 2002; Laneman *et al*., 2004; Ahlswede *et al*., 2000; Tang and Wang, 2013). Amplify and Forward (AF) scheme is a cooperation scheme that relay node first receives the message of source node (coding or non-coding) without decoding and detection, directly amplifies and transmits it to the destination node. In this scheme, relay node does not acquire the coding or modulation information of the source, which makes it less complex to be applied.

In cooperative communications, besides the relay selection problems and signal combining algorithm problems (Xu and Wang, 2013; Liu *et al*., 2014), resource allocation is one of the most important challenges. Since relaying data from others means that there should be some kinds of resources being shared, power and bandwidth are mostly considered as these kinds of resources. For a rational node in a commercial network, there always is an incentive to occupy all its resources to get maximal benefits. It has been shown that game theory can be a potentially effective tool to solve this kind of problem (Fudenberg and Tirole, 1991). By employing non-cooperative game theory, (Zhang *et al*., 2009; Cong *et al*., 2011) presented how a node should allocate bandwidth to relay information. In (Shastry and Adve, 2006), a pricing game that using reimbursements to relays inspires selfish nodes to cooperate. Use Stackelberg game (Shastry and Adve, 2006), a distributed resource allocation for multiple user cooperative networks is performed in (Wang *et al*., 2009), which multiple relays compete with each other in terms of price to gain the highest profit from offering power to a single user.

In this study, we study a symmetric cooperative network in which nodes can act as both a data transmitter and a relay for each other. To relay the data from the partner, the resources being shared in this system are symbol times as we will define. We formulate this cooperative communication problem as a 2-person barging problem (Shastry and Adve, 2006). In addition, we analyze the proper channel condition for nodes to share

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their resources for cooperation and the amount of symbol times should be shared in this circumstance. With computer simulations, we will show the advantage of our proposed scheme which improves the system performance with cooperation.

SYSTEM MODEL

In this study, we consider a cooperative communication system model as shown in Fig. 1. The system includes two nodes (users) and one destination (AP). Each user has W Hz for transmission and all nodes share the channels by using TDMA. Data transmitted by node 1 can be received by node 2 and vice versa. Node 1 and node 2 choose each other to be the cooperative partner. Each node relays part of its partner's data to destination depending on the willingness of the node itself. The corresponding frame structure is illustrated in Fig. 2.

We employ the AF cooperative protocol in this system and a length of T seconds time slot that one time slot constructs a frame only. Assuming that the time length of a transmission frame is short compared with the channel coherence time. Consider a well-defined signal constellation with T_0 seconds' symbol period. In one frame that the number of symbols can be transmitted is $N = T/T_0$, as illustrated in Fig. 2. To be a relay, node 1 would like to share m ($0 \le m < 1$) percent of symbol times in one frame to relay symbols from node 2 who is source node at the moment. Therefore, node 1 only could transmit its own data by using N (1-m) symbol times. Similarly, node 2 would like to share n ($0 \le n < 1$) percent of symbol times to relay data from node 1 and it could transmit its own data only using N (1-n) symbol times in the meantime. For node 1, only nN symbol times will be transmitted by node 2 in a cooperative manner which could be combined at destination with the part transmitted by its own by using the Maximal Ratio Combining (MRC) to achieve the user cooperation diversity. The remained N (1-m-n) symbol times of node 1's data will be transmitted directly to destination without relay and could not have diversity gain. Symbols originated by node 2 have the similar situation.

We assume that data originated by one node only be relayed by its partner. None of the nodes relay their own symbols. As a relay, a node could only forward the maximal amount of symbols that originated by its partner under this assumption. Thus, we get $mN \le N(1-n)$ for node 1 and $nN \le N(1-m)$ for node 2. For meaningful cooperation, m and n have to be non-negative. Then we get Eq. 1:

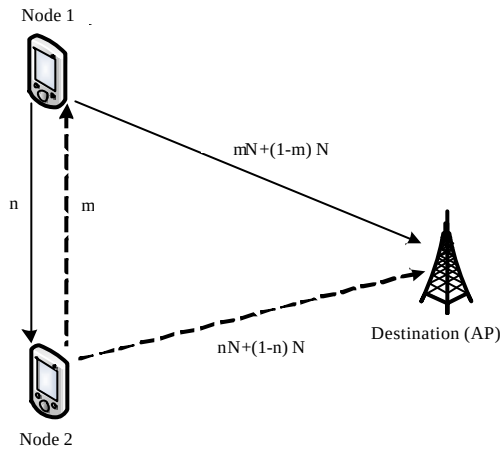

Fig. 1: Cooperative communication system model

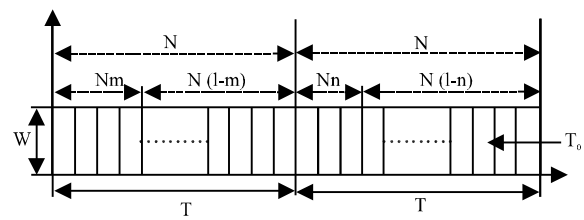

Fig. 2: Cooperative relay frame structure

$$\begin{cases} m \ge 0 \\ n \ge 0 \\ m + n \le 1 \end{cases} \tag{1}$$

where, m and n are the decisions made by these two rational nodes that one will affect another. This lead us to find a solution to get both nodes an optimal tradeoff, we employ nash bargaining solution in game theory to solve this problem.

PROBLEM FORMULATION AND GAME MODEL

Utility function: Assuming that each packet transmitted in wireless data system contains L information bits. The total size of each packet is M (M>L). At terminal i when it becomes a transmitter, where the distance from node i to the corresponding receiver is d, the signal-to-noise ratio could be written as $\gamma_i = hp_i/N_0W$ (Goodman and Mandayam, 2000) where, h be the channel gain, p_i be the transmit power of node i and N_0W be the power of noise. Then the corresponding probability of correct reception is q (γ_i). Thus, with p_i watts be the transmit power and assuming it is constant during the whole duration of a symbol time. The energy expended for one packet is

p_iT_0 joules. The benefit is simply the information content of the signal multiplies q (γ_i), Lq (γ_i) bits. Therefore, during the whole time slot with N symbol times, our utility measure is Eq. 2:

$$U_i(p_i) = \frac{Lq(\gamma_i)}{p_iT_0} \cdot N \quad (\text{bit } J^{-1}) \tag{2}$$

In this study, we consider the utility as the number of information bits received per joule of energy expended. To retain the advantages of Eq. 2 and eliminate the degenerate solution, $p_i = 0$, we modify the utility function by replacing q (γ_i) with another function f (γ_i) with the properties f (∞) = 1 and f (γ_i)/p_i = 0, for $p_i = 0$ (Goodman and Mandayam, 2000). Therefore, could be rewritten as Eq. 3:

$$U_i(p_i) = \frac{Lf(\gamma_i)}{p_iT_0} \cdot N \tag{3}$$

where, $f(\gamma_i) = (1\text{-}2BER_i)^M$. With a non-coherent frequency shift keying detection, we assume $BER_i = 0.5 \exp(-\gamma_i/2)$.

Assuming that the transmit power of node 1 is p_1 watts, the utility function of node 1 could be written as Eq. 4:

$$U_1(p_1) = U_{1,D}(p_1) + U_{1,AF}(p_1) \tag{4}$$

where, $U_{1,D}$ (p_1) denotes the utility function of direct transmission and $U_{1,AF}$ (p_1) denotes the utility function of cooperative transmission. The utility function of direct transmission and cooperative transmission could be described as follows (Eq. 5):

$$\begin{cases} U_{1,D}(p_1) = \dfrac{L}{p_1T_0} f(\gamma_{1,d})(1-m-n)N \\ U_{1,AF}(p_1) = \dfrac{L}{p_1T_0} f(\gamma_{1,AF})nN \end{cases} \tag{5}$$

where, Eq. 6:

$$\gamma_{1,AF} = \gamma_{1,d} + \frac{\gamma_{1,2}\gamma_{2,d}}{1+\gamma_{1,2}+\gamma_{2,d}} \tag{6}$$

is the equivalent SNR of AF cooperative channel from node 1 to destination with node 2 relaying. Meanwhile, $\gamma_{1,d}$, $\gamma_{2,d}$ and $\gamma_{1,2}$ are the SNRs of the channels between these three nodes. Then we have utility function of node 1 as Eq. 7:

$$U_1(p_1) = \frac{LN}{p_1T_0}\left[f(\gamma_{1,d})(1-m-n) + f(\gamma_{1,AF})n\right] \tag{7}$$

By a similar way, we could have utility function of node 2 as Eq. 8:

$$U_2(p_2) = \frac{LN}{p_2T_0}\left[f(\gamma_{2,d})(1-m-n) + f(\gamma_{2,AF})n\right] \tag{8}$$

where, Eq. 9:

$$\gamma_{2,AF} = \gamma_{2,d} + \frac{\gamma_{2,1}\gamma_{1,d}}{1+\gamma_{2,1}+\gamma_{1,d}} \tag{9}$$

Game model of cooperation: The bargaining problem of cooperative game model could be described as follows (Rasmusen, 1995). Let k = {1, 2} be the set of players (here we have 2 players as node 1 and node 2) in a bargaining game. S is a closed and convex subset of $\Re^2$ to reflect the set of potential payoff allocations. Let U_i be the cooperative payoff of node i and $\underline{U}_i$ be the minimal payoff that node i does not participate a cooperative communication. According to the definition of cooperative game theory (Sendonaris *et al*., 2003), node i will not proceed a cooperative action while U_i is less than $\underline{U}_i$, to ensure that it can benefit from cooperative communication. The potential payoff allocations that two players get is Eq. 10:

$$S = \{U = (U_1, U_2) \mid U_1 \in S_1, U_2 \in S_2\} \tag{10}$$

where, $S_i = \{U_i \mid U_i = U_i(p_i m, n), m \geq 0, n \geq 0, m+n \leq 1\}$ is the potential payoff allocation for player i. $(S, \underline{U}_i)$ is a 2-person bargaining problem only if S is a convex set.

For simplicity, we consider the transmit power $p_i = p$ (i = 1, 2) is constant. We then have to prove that U (U_1, U_2) $\in$ S is a convex set. That means for any θ ($0 \leq \theta \leq 1$), if $U^a = (U_1^a, U_2^a) \in S$ and $U^b = (U_1^b, U_2^b) \in S$, $\theta U^a + (1-\theta)U^b \in S$ (Zhang *et al*., 2008).

Proof: By substituting (1) into $\theta U_1^a + (1-\theta)U_1^b$, we get Eq. 11:

$$\theta U_1^a + (1-\theta)U_1^b = \frac{LN}{pT_0}\left[f(\gamma_{1,d})(1-A-B) + f(\gamma_{1,AF})B\right] \tag{11}$$

where, $A = \theta m^a + (1-\theta)\, m^b$ and $B = \theta n^a + (1-\theta)\, n^b$. Accordmg to Eq. 1 we could get m^a, m^b, n^a, $n^b \geq 0$, $m^a+n^a \leq 1$, $m^b+n^b \leq 1$. With condition $0 \leq \theta \leq 1$, we can derive Eq. 12:

$$A \geq 0,\ B \geq 0,\ A+B \leq 1 \tag{12}$$

Therefore, $\theta U_1^a + (1-\theta) U_1^b \in S_1$. By the same method, we can also prove that $\theta U_2^a + (1-\theta) U_2^b \in S_2$. Eventually, we get $\theta U^a + (1-\theta) U^b \in S$ and S is convex. Thus, we have proved that the game between nodes in this model is a 2-person bargaining problem.

Cooperative time allocation strategy: According to Zhang *et al.* (2008) there is a unique NBS for this 2-person bargaining problem which satisfies Eq. 13:

$$U^* = \underset{U_i(p) > \underline{U}_i(p)}{\text{Arg max}} \prod_{i=1}^{2} \left(U_i(p) - \underline{U}_i(p) \right) \tag{13}$$

where, $\underline{U}_1(p) = LNf(\gamma_{1,d})/pT_0$ and $\underline{U}_2(p) = LNf(\gamma_{2,d})/pT_0$ are the utilities of node 1 and node 2 for direct transmission when bargaining breaks down, respectively.

According to theorem 1 in (Zhang *et al.*, 2008), by given transmit power, $p_i = p$ (i = 1, 2) is constant, if:

$$f(\gamma_{1,AF}) f(\gamma_{2,AF}) > f(\gamma_{1,AF}) f(\gamma_{2,d}) + f(\gamma_{2,AF}) f(\gamma_{1,d})$$

we could get Eq. 14:

$$\begin{cases} m = \dfrac{1}{2}\left(1 - \dfrac{f(\gamma_{1,d})}{f(\gamma_{1,AF})} + \dfrac{f(\gamma_{2,d})}{f(\gamma_{2,AF})}\right) \\ n = \dfrac{1}{2}\left(1 - \dfrac{f(\gamma_{2,d})}{f(\gamma_{2,AF})} + \dfrac{f(\gamma_{1,d})}{f(\gamma_{1,AF})}\right) \end{cases} \tag{14}$$

This root of (m, n) in Eq. 14 is the optimal cooperation symbol times allocation of both nodes. Otherwise, the nodes do not cooperate at all. Also, this is the NBS to this game model.

SIMULATION RESULTS

Consider a wireless network which contains one stationary destination (AP) and one settled node (node 1) with the other node (node 2) moving from west to east, as shown in Fig. 3. AP is fixed at the origin point and node 1 is located at the point with 800 m far from destination in the east. Node 2 is moving along the y = 1 with its coordinates is (d_2, 1) while d_2 varies from 0 to 1500 m. Since the channel gain is set $h = (7.75\times10^{-3})/d^{3.6}$ (Rasmusen, 1995) where, d denotes the distance between AP (or node 1) and node 2 (in meters), d should not be zero when $d_2 = 0$ and $d_2 = 800$. We set L = 16 and M = 20. Assuming $N_0W = 5\times10^{-15}$ W and each node has a T = 5 m sec^{-1} transmit time slot and W = 1 MHz bandwidth. For simplicity, we assume the transmit

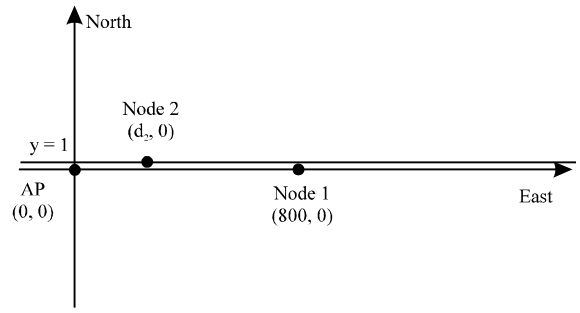

Fig. 3: Locations of the nodes and destination (AP)

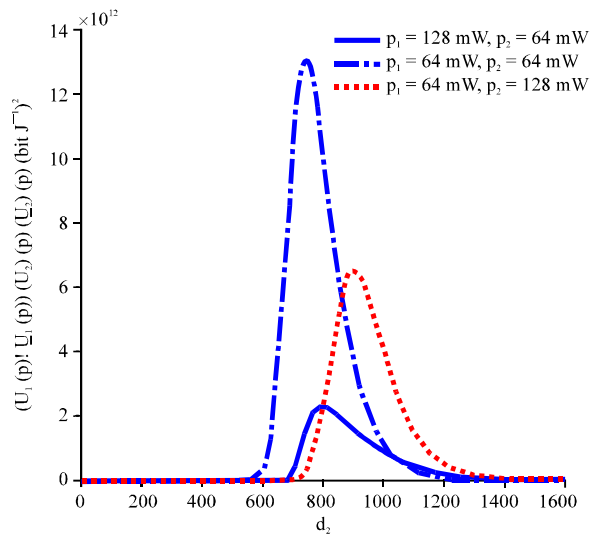

Fig. 4: Value of $(U_1 - \underline{U}_1)(U_2 - \underline{U}_2)$ with node 2 moving from west to east

powers of both nodes have the same value that $p_1 = p_2 = p = 64$ mW and the number of symbols in on time slot is N = 16.

The X-axis in Fig. 4 denotes the distance from transmitter to receiver where $d \approx d_2$ and the Y-axis represents $(U_1 - \underline{U}_1)(U_2 - \underline{U}_2)$ (bit $J^{-1})^2$. The dash-dot line indicates the result of $p_1 = p_2 = p = 64$ mW. We can see form the X-axis that d is increasing as the movement of node 2 from west to east. When node 2 is in the region of d<560, $(U_1 - \underline{U}_1)(U_2 - \underline{U}_2)$ is equal to 0 the whole time, which means that when node 2 is in this region the utility function of cooperation is nearly the same with utility function of direct transmission. The figure also means that it is not necessary for both two nodes to cooperate when node 2 is in this region. Nevertheless, when node 2 is in the region between 600 and 1300, $(U_1 - \underline{U}_1)(U_2 - \underline{U}_2)$ becomes positive, which indicates that the cooperation between them brings a remarkable benefit in utility. And

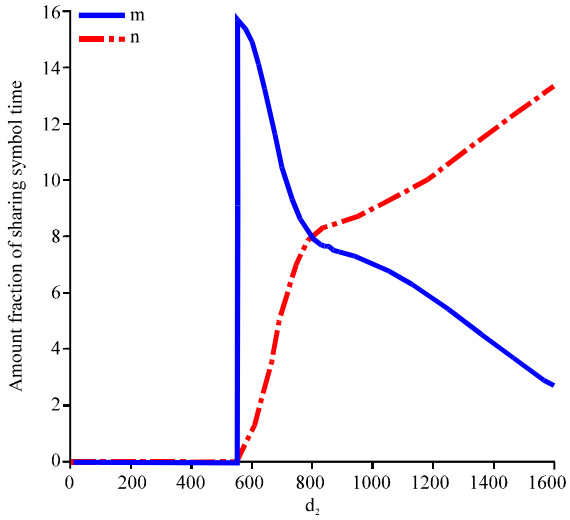

Fig. 5: Amount fraction of sharing symbol time with node 2 moving from west to east

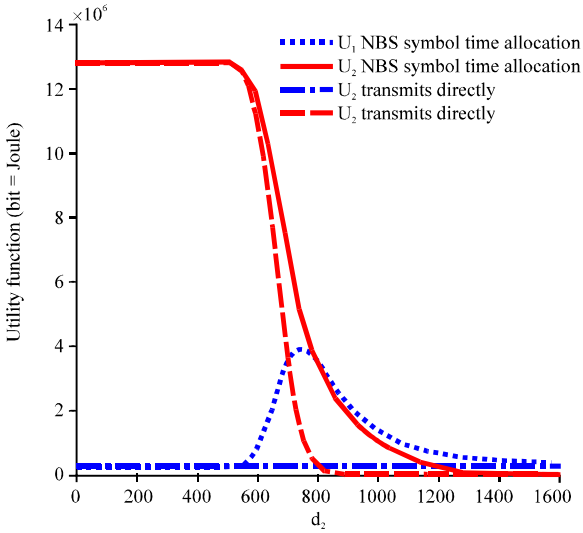

Fig. 6: Utilities of both nodes with node 2 moving from west to east

when d>1300, the value of $(U_1 - \underline{U}_1)(U_2 - \underline{U}_2)$ returns to almost 0. It reflects that when node 2 is in this region the utility improvement of cooperation is too tiny to inspire both nodes to cooperate. The dash line and the solid line indicate the results of non-equal transmit power where, p_1 = 128 mW, p_2 = 64 mW and p_1 = 64 mW, p_2 = 128 mW, respectively.

The dash line shows that when $p_1>p_2$, since the benefit of cooperation with node 2 improves the utility less, when node 2 is in region of d<750, node 1 does not cooperate. The solid line shows the similar results, that node 1 could not provide enough utility benefit to make node 2 to share its symbol time.

Figure 5 shows the amount of sharing symbol times results of both nodes in the proposed scheme. When d_2<560, neither of the nodes is willing to cooperate with each other. Since for node 2, the channel condition is so well that it is no use to cooperate with a node that has poorer channel condition. And for node 1, the channel condition between itself and AP is as poor as the channel condition between itself and node 2, thus, it can't inspire node 1 to cooperate with node 2. With node 2 in this region, the sharing amount is m = n = 0. The cooperation starts at d_2 = 560. As we can see that the values of m and n has a sudden leap at the point of cooperation (Zhang *et al*., 2008), it is because that node 2 has better channel condition than node 1's when the cooperation starts. Hence, node 2 would like to share much less symbol times with node 1, on the contrary, node 1 will share much more symbol times with node 2 to get the benefit of cooperation. Thus, the relation of sharing amount fraction is m>n. When d_2>800, the channel condition of node 2 is poorer than node 1's, therefore, node 2 is willing to share more symbol times to cooperate and node 1 would like share less, then m<n. As we can predict, when node 2 is moving too far away from AP and could contribute too little to the cooperation, the relation of cooperation will end.

Figure 6 shows the utilities of both nodes that each node has two kinds of utilities which are the one of our proposed scheme and the one of direct transmission. As we can see that for node 1 the utility of noncooperation is constant due to its fixed location. When node 2 is moving in the nearby region of AP, because of the good channel circumstance the change of its location affect both utilities slightly. Since node 2 in this region is not necessary for it to cooperate, the utility of the proposed scheme for node 1 remain stably low. However, when node 2 is in the region closer to node 1 than to AP, locations between 560 and 1200, utilities of the proposed scheme for both nodes are improved by cooperating with each other. With the movement of node 2, when distance between node 2 and AP is much larger than 1200, the utilities of both nodes in the proposed scheme are nearly equivalent to the utilities of noncooperation, which is in accordance with the prediction we have made in Fig.4. Cooperation in our scheme brings a good advantage in comparison with direct transmission, which proves that our strategy can improve system performance by proper cooperation.

CONCLUSION

In this article, we analyze the behavior of cooperation for rational nodes in cooperative communication

networks. We formulate the symbol time sharing problem in a symmetric system of cooperative communication as a cooperative game and prove that it can be modeled as a 2-person bargaining problem. By using the nash bargaining solution method, we obtain the solution of the game. The problem of when to cooperate and the problem of how to cooperate can be solved by our proposal. Simulation results show the advantage of the proposed scheme in term of utility and the symbol time sharing protocol with distance. Also, the results show that both nodes could get better performance than they work independently by adopting NBS resource allocation.

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