

Application Of Game Theory in Cooperative Communication in Wireless Sensor Networks

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Abstract: In Wireless Sensor Networks Cooperative communication network, cooperative diversity, a wireless sensor network communication research hot spot, can bring diversity gain. Collaboration forwarding power is a kind of shared resources between the sensor nodes, researchers proposed a program which based on cooperative communication power of game theory applications in wireless sensor networks. The program aims to encourage autonomy sensor nodes to participate in relay collaboration communication, and to ensure collaborative partnerships node gain equitable benefit from the collaboration communication. Firstly, Setting up a cooperation game model, then solving it; Finally proving the obtained solution is Nash bargaining solution, and analyzing the complexity and feasibility of the algorithm. According to the simulation results, algorithm based on cooperative game model and the Nash bargaining solution can ensure fairness in the sharing of resources between sensor nodes and also optimize system performance.

Introduction

Cooperative diversity which forming a multi-node transmission to achieve spatial diversity by virtual multi-antenna array is a new form of spatial diversity, aims to effectively resist the impact of inherent fading characteristics of radio channels. Cooperative relaying can expand coverage of the wireless communication system well, and optimize the quality of wireless link communication in the wireless sensor network. The adjacent nodes form collaborative partnerships, relay data between each other sensor nodes and constitute a virtual multiple-input multiple-output (MIMO) system, which can acquire cooperative diversity gain. Based on the node information symbol transmit power as a collaborative communications resources, power sharing scheme is a cooperative game theory-based collaboration, which can encourage autonomy relay node to participate in cooperation, so as to obtain collaboration gain.

System Model

System model shown in Fig 1:

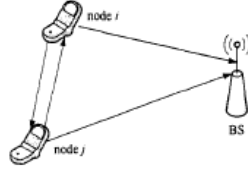


Fig 1 System Model

Any source communication node $n_i(n_j)$ and its destination node $d_i(d_j)$ composite a channel $_i$ (channel $_j$).In the model,Comparing to the data source sensor node $n_i(n_j)$,the data source sensor node $n_j(n_i)$ is closer to the destination node $d_i(d_j)$,therefore the data source node n_i and n_j can cooperate with each other.The system uses the AF(AF:amplify-and-forward) protocol,a cooperative system model shows in the Fig 1,the implementation of AF protocol requires two discrete stages,as follows:Firstly,we assume that during any stage channel belongs to non-frequency selective Rayleigh slow fading mode,namely just multipath propagation leads to the envelope of the received signal Rayleigh distribution.For a smooth,independent and identically distributed white Gaussian noise channel,the noise variance is σ^2 .As to the analysis of channel $_i$,the procedure is divided into the following two stages,as follows:

1) In the first stage,the source node n_i broadcasts its data symbols,the destination node d_i and the relay node n_j receives the relevant symbol information,node n_j and node d_i receive information,they can be expressed as:

$$Y_i^j = \sqrt{p_i[1]}g_i^j X_i + Z_i^j \quad (1-1)$$

$$\text{And} \quad Y_i^d = \sqrt{p_i[1]}g_i^d[1]X_i + Z_i^d \quad (1-2)$$

In the formula, n_i is a transmitting data symbols node, Z_i^j and Z_i^d are additive white gaussian

noise in channel $_i$ (AWGN).At any stage $t(t=1,2)$,the maximum power of node $n_j(n_i)$ is p . $p_i[1]$

represents transmit power that node n_i transmit to n_j in the first slot, g_i^j represents the channel gain from node n_i to node n_j , $g_i^d[1]$ represents the channel gain from node n_i to node d_i .

2) In the second phase,according to the AF protocol the relay node n_j amplify information symbols which n_j received from n_i in the first phase and forwards them to the destination node d_i . In collaboration ,collaboration SNR generated by the relay node n_j can be expressed as:

$$\Gamma_{i,j}^{d_i} = \frac{p_i[1]g_i^j[1]p_j[2]g_j^{d_i}[2]}{\sigma^2(p_i[1]g_i^j + p_j[2]g_j^{d_i}[2] + \sigma^2)} \quad (1-3)$$

By the cooperative relaying node n_j , d_i can gain efficiently SNR,which can be expressed as:

$$\Gamma_i^{d_i(AF)} = \Gamma_i^{d_i} + \Gamma_{i,j}^{d_i} \quad (1-4)$$

In the formula, $\Gamma_i^{d_i} = \frac{p_i[1]g_j^{d_i}[1]}{s^2}$ is noise ratio that n_i directly transfer data to the destination node d_i in the first stage gain.

Game Modeling

Setting up $K=\{i,j\}$ represent a set of nodes participating in cooperative communication game, given any node's total power p_i in a collaborative period, $p_i[1] + p_i^{d_j}[2] \leq p_i$. Any node wants to obtain additional SNR gained by receiving cooperative relaying by the way of reducing node to destination node d outage probability. For each node the power of collaborate in the second stage is equal to the power of cooperative transmission in the first stage.

We define node $n_i(n_j)$'s cooperative strategy is $T_i(T_j)$: In the second phase, relay power ratio which the cooperating node n_i provide to the cooperating n_j , namely:

$$T_i = \frac{p_i[2]}{p_j[1]} \quad (2-1)$$

In the formula, $0 \leq T_i \leq 1$. Feasible payment of the first node is defined as:

$$Q_i = \{R_i | R_i = U_i - U_i^{\min}\} \quad (2-2)$$

In the formula, $U_i = \Gamma_i^{d_i(AF)}$, represents n_i 's payment in cooperative communication, which is a valid SNR user communication through collaboration obtained. $U_i^{\min} = \Gamma_{i,d_i}^{NC}$

$$U_i^{\min} = \Gamma_{i,j}^{NC} = \frac{p_i[1]g_i^{d_i}[1] + p_i[2]g_i^{d_i}[2]}{2s^2} = \frac{p_i[1]g_i^{d_i}[1] + T_i p_j[1]g_j^{bs}[2]}{2s^2}, \text{ Which indicates effective SNR that}$$

the user is not involved in the collaborative communications obtained. As for U_i^{\min} , it's

explanation as follow: When a node is not involved in cooperative communications, it can use the same amount of resources, which is power p in the second phase of the transmission, to get a diversity of other ways, so as to compensate for the opportunity cost of their participation in the cooperative relay. Generally speaking, we assume that the non-cooperative node of system uses repetition coding Joint Maximum Likelihood Ratio Combining (MRC maximal ratio combining) detect temporal diversity (time diversity) of algorithm, therefore it defined as

$$\text{follows: } U_i^{\min} = U_i^{\min} = \Gamma_{i,j}^{NC} = \frac{p_i[1]g_i^{d_i}[1] + p_i[2]g_i^{d_i}[2]}{2s^2} = \frac{p_i[1]g_i^{d_i}[1] + T_i p_j[1]g_j^{bs}[2]}{2s^2} \quad (2-3)$$

For the definitions of the formula (2-3), When the payment of non-cooperative collaboration $U_i^{\min} = \Gamma_{i,d_i}^{(NC)}$ is greater than the payment of cooperative collaboration $U_i = \Gamma_i^{d_i(AF)}$, node n_i will exit cooperation to obtain non-cooperative payments. The definition of feasible payment of Q ensures that it will participate in collaborative communications only when the available SNR of cooperation is higher than its non-cooperation after the coordinated

transmission, reflecting the fairness of resource sharing between user nodes autonomy.

In collaboration game $C = \{K, Q\}$, pay space for node n_i and pay space for node n_j are

defined as follows: $Q = \{R = (R_{n_i}, R_{n_j}) | R_{n_i} \in Q_{s_i}, R_{n_j} \in Q_{s_j}\}$ (2-4)

From the literature^[8], the necessary and sufficient conditions that the Game $C = \{K, Q\}$ exist the only Nash bargaining solution NBS is: Q is a closed, convex subset. From the formula (2-2) and the formula (2-4) know that Q is a closed set. Reference^[6] can prove that Q is also a convex set, then there exists a unique Nash bargaining solution.

Seeking Game Solution

Section 2 has proved that the proposed cooperative relaying Game $C = \{K, Q\}$ exists a unique Nash bargaining solution. Based on the literature^[6,7], The Nash bargaining solution of Game $C = \{K, Q\}$ can be equated to solve the optimization problem as follows:

$$\max_{i,j} U = (U_i - U_i^{\min})(U_j - U_j^{\min}) = (\Gamma_i^{d,(AF)} - \Gamma_i^{d,(NC)})(\Gamma_j^{d,(AF)} - \Gamma_j^{d,(NC)}) \quad (3-1)$$

The problem (3-1) has two optimization parameters T_i and T_j , So this problem belongs to a convex combinatorial optimization problems, In real network, each node has a number of adjustable dispersed power value, namely each node has a limited, discrete relay policy space $T_i(T_j)$. Assumed that the number of discrete power value of each variable node is n , then the calculation (3-1) computational complexity is $O(n^2)$. In the commercial network, the most of user nodes are notebook computers with strong computing ability and mobile terminal with large power, so they ensure that the way of distributed solving problem (3-1) is the optimal solution for each user. But in wireless sensor networks, although the sensor node which distributed around aggregation node (sink node) have only limited power and poor computing ability, but the aggregation sink as a centralized coordination points has plenty of power and well computing ability can perform relevant policy search algorithm (ie, solving the optimal solution of problem (3-1), and then feedback the NBS policy to each user node, they can be saving energy as most as possible, therefore the purpose of achieving prolong the lifetime of sensor networks can be achieved.

Simulation Analysis

In simulation, the node n_i and the node n_j have the same destination. In the experiment of set-cooperative relay network resource allocation algorithm, paper only consider decline that the large-scale communication distance caused, literature^[2-4,8] mainly to clearly express collaborative law that the user node at different relative channel conditions act on. Each data

source node has same predetermined initial transmission power($p_i^{\max} = p_j^{\max} = 0.1W$),

continuous policy space $T_i(T_j) \in [0,1]$. Fading channel model is $0.097/d^4$ this d is the distance between the data source and destination nodes in meters(m), channel noise power is defined as $s^2 = 5 \times 10^{-15}W$. Data source node and the destination node are set at the point (0,0) and point (400, 0). Node n_j is set in the abscissa $x=210$, the ordinate Y ranges from -400 to 0. Letting c_j^y represents node n_j 's ordinate value. Fig2 describes Nash bargaining solutions of two nodes

when node s2 moves in a straight line $x=210$, namely cooperation strategy of each node, such as $T_i(T_j)$. And its $\max_{i,j} U$ namely maximum optimization solutions, shown in Fig 3.

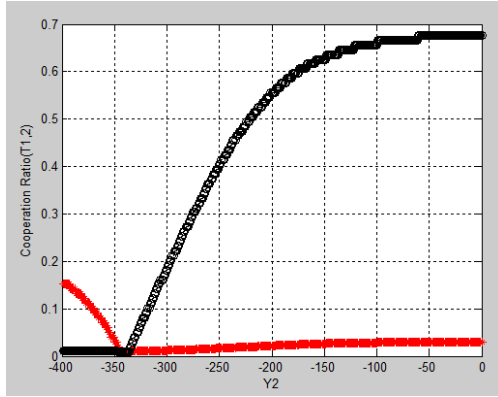


Fig 2 Nash bargaining solutions of nodes

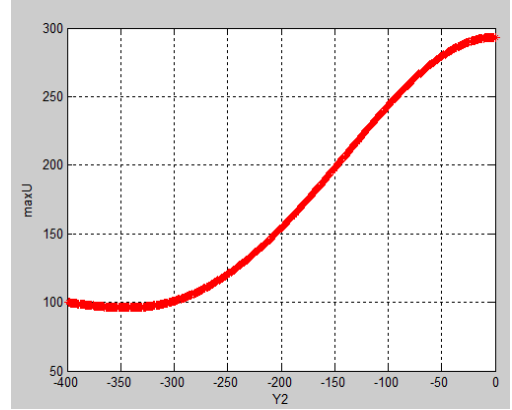


Fig 3 maximum optimization solutions

As can be seen from the simulation results: when $-400 < c_j^Y < -340.5$, Node n_i is willing to contribute more collaborative power compare to Node n_j , because n_i in this range node is closer to the node d than the n_j , the channel gain from node n_i to the node d is better than channel gain from node n_j to node d. When n_j moves to the coordinate point (210, -340.5), two nodes realized the same cooperative allocation power, since the distance d that two nodes far away from the node d are same, namely two nodes have the same channel condition. When $-340.5 < c_j^Y < 0$, Node n_j is willing to contribute more collaborative power compare to Node n_i , because in this range node n_j is closer to the node d than the node n_i , the channel gain from node n_j to the node d is better than channel gain from node n_i to node d. As can be seen from Figure 3, as node n_j continuously moving, both nodes continue to adjust the value of each other's policies in order to ensure the total maximum SNR increasing continuously, reflecting the game theory and Nash bargaining solution can guarantee the fairness of resource sharing between the nodes and also optimize system performance.

Conclusions

Based on modeling collaboration power of game theory, solving, and analysing fairness and selfishness of the node, this paper uses game theory model to analysis the cooperative relay network power allocation problems, provide an effective relay network collaboration strategy to stimulate nodes to participate relay collaboration communication, and propose the use of game theory to solve the problem of theory and cooperative relaying method, so that the performance of the entire network is optimized.

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