Wireless Cooperative Relaying Using Game Theory

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***Abstract*—Wireless systems have various applications in aerospace technologies including aircraft navigation system, and monitoring and control module. In wireless networks, specially for the range-limited transceivers, relaying systems are widely used to extend the reach of communication networks, increase throughput, and save on power. In most of relay networks, the source and relay nodes share the same radio channel to send data, so there is a competition among nodes to access the channel.**

In this article, a novel stochastic game theoretical model for cooperative packet forwarding is proposed to provide an efficient cooperation solution for nodes to achieve better power and throughput performance. The proposed method is based on the Markovian stationary game theoretical model with two players. Both cooperative and non cooperative solutions are provided.

I. Introduction

Aerospace technologies has always been accompanied with wireless technologies. An aircraft needs to communicate to air traffic control tower (ATC) to take off from and land safely at airport. Wireless sensors are placed in jet engine, airplane outside body, cockpit, gas tank and etc to constantly monitor its operation. Recently some wireless entertainment systems such as telephony service and web access are provided for passengers during flight. [1]

Wireless communications plays a crucial role in aerospace industry by providing remote sensing and data transfer capabilities within and outside the vehicles.

In near future, wireless sensors may be placed in jet engines to monitor structural health and avoid unnecessary time scheduled maintenance or even prompt a problem before scheduled maintenance. Sensors are capable of playing vital roles by providing information from vehicle body, cockpit, gas tank,

One important category of wireless networks is Ad-hoc sensor Networks, where there is no central control over nodes. In most of wireless Ad-hoc systems, relaying methods are widely used to extend the range of the communication link, save transmit power at nodes and reduce interference. In a basic relay enabled Ad-hoc network, each node in addition to transmitting its own packets, is supposed to cooperate with other nodes to transmit their packets to the destination.

Game theory is a proper method to model the packet forwarding in Ad-hoc Networks and analyze the contrast between nodes' interest to avoid forwarding others packet due to limited power and to provide relay service in order to increase throughout of the system on the other side [3].

Repeated game theory is considered to analyze cooperative packet forwarding in [4]. Also, Markov stationary game theory is applied to address this issue and model the competition between nodes in a basic relay network to send their packets on a common channel [5]. This article has considered a case, in which relay node has one buffer to keep all different types of packets.

In this paper, we investigate this problem, proposing a new solution which is more efficient in terms of channel use. In the proposed model, two different buffers are assigned to the relay node to distinguish between different types of packets, and to apply appropriate strategy for each type. First buffer is called *original buffer*, which keeps the generated packets at relay node and also the packets returned to relay node due to channel collision, while the other buffer called *forward buffer*, which keeps received packets from the source node. This new solution provides the relay node with the option of accepting packets even if there is a recently generated or blocked packet in the original buffer, provided that the forward buffer is empty.

II. Stochastic Games

Game theory is an analytical approach to model the interaction between some rational players that compete to obtain a common interest. Stochastic games were first introduced in [6]. In these games, complete history of the game in each round is summarized in a state that follows a Markov process. Hence, the current state and the action profile of players determine the next state.

A discrete time stochastic game with N player is shown by $(Q,\ \{A_i\}_{i=1}^N, \{U_i\}_{i=1}^N, r)$,where

- Q, is the Borel state space.
- A_i, is action set of player i, and $A = A_1 \times \ldots \times A_N$, denotes the action profile of all players.
- $U_i :\ Q \times A \to \mathbb{R}$, where $\mathbb{R}$ is Real set. U_i determines the immediate utility function of player i, which depends on the current state and the action profile of the game.
- $t :\ Q \times A \to [0, 1]$, is the transition probability function.

Solution of the game achieves the Nash equilibrium strategy set of all players when each rational player selects its best possible response to other players' strategies, provided that neither player can increase its utility by unilaterally changing its strategy. A strategy profile, S^* achieves Nash equilibrium iff,

$$\forall i \in N,\ \forall s_i \in S_i,\ U_i(s_i^*,\ s_{-i}^*) \geq U_i(s_i,\ s_{-i}^*) \tag{1}$$

In this paper, both cases of cooperative and non-cooperative games are considered. In non-cooperative game, each player i selfishly maximizes its own stationary utility function, $U_i(\delta)$, to reach the best response Nash equilibrium strategies. In cooperative games, players collaborate with each other to jointly maximize the total utility of the game.

III. System Model

In this paper, a basic relay network consists of a source node, a relay node and a destination node is considered. This system is modeled as a two-player game, including source and relay nodes. Source node has a single transmit buffer to keep the generated packets prior to sending and relay node has two transmit buffers, all of them have length one. The first buffer of relay node is called *original buffer* and contains the generated packets at the relay node or the packets to be retransmitted due to collision in the previous time slots. The second one is called *forward buffer* contains the received packets from the source node in the previous time slot. Packets are generated at the source and relay nodes independently provided that their buffers are empty at the end of previous time slot. The system is modeled as a Markovian stationary process, in which occupancy status of buffers is defined as the states of a Morkovian game.

Mixed stationary strategy profile of the game is determined by $\delta = (p_{sd},\ p_{sr},\ p_{rd},\ p_{ac})$, where

- p_{sd}, is the probability of sending a packet from source node to destination node.
- p_{sr}, is the probability of sending a packet by source node to the relay node.
- p_{rd}, probability of sending packet from relay node to the destination node.
- p_{ac}, probability of accepting the received packet from source node.

Payoff of players is defined as the difference between obtained rewards and paid costs for a specific strategy set. The assigned costs and rewards to different possible actions follows the following rules. Each node receives the delivery reward, denoted by R^d, for successful delivery of a packet to the destination node. When the relay node accepts a packet from source node, it receives a reward called forwarding reward, R^f from source node. Transmission cost is defined as the cost of energy of transmitting a single packet with acceptable reliability over the channel and is denoted by C_{ij}^t, where i and j represent the origin and target nodes, respectively. Keep cost, C^k is defined to encourage the nodes to attempt sending their packets and prevent waiting as much as possible. Waiting is not desirable since it will contribute to the latency in the network and reduce the system throughput. This delay cost, is also applied to the retransmission of the corrupted packets, due to collision, as well as the rejected packets by relay node that should be retransmitted to the destination in the next time slot. According to previously mentioned definitions, we calculated the utility functions of both source and relay nodes and used the obtained functions to study the behavior of the proposed game model.

IV. Simulation Results

In this section, numerical results of system analysis for both cooperative and non-cooperative scenarios are presented. Best response Nash equilibrium strategy profile is evaluated as system behavior in non-cooperative scenario, while in the cooperative case, the summation of utilities is investigated as the system performance. In this case, both nodes try to maximize the sum utility and jointly select the best strategy profile.

Summation of players' utilities can be considered as a criteria to evaluate system performance. In fig. 1, sum of utilities of source and relay nodes versus the packet generation rate of relay node, g_r is depicted. As shown in fig. 1, summation of utilities is directly proportional to packet generation rate of relay node. Summation of players' utilities decreases as the delay cost of system is increased. Players adaptively take an appropriate strategy profile to maximize their utility. A higher value is set for keep cost in systems, where low latency is desirable. Hence, the maximum achievable utility in these systems is less than systems without strict delay requirements. In cooperative scenario both nodes jointly select the strategy profile of the game in order to maximize the total utility. While, in non-cooperative scheme, nodes selfishly try to maximize their own payoffs. Therefore, the summation of nodes utilities in cooperative game is always greater than non-cooperative game. However, non-cooperative approach is more applicable in practical systems, in which nodes are not aware of each others strategy sets. Fig. 1, shows that the achieved performance of proposed non-cooperative scheme asymptotically approaches the cooperative system performance and confirms the appropriate performance of the proposed model.

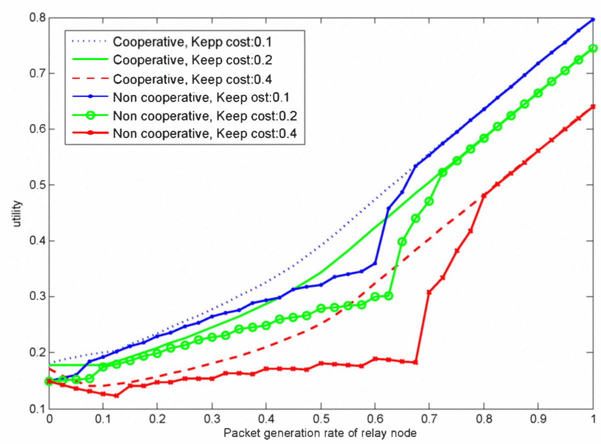

Fig. 1. Summation of utilities of source and relay nodes versus relay node packet generation rate for cooperative and non-cooperative game and different keep cost values, when $C_{sr}^t = 0.4, C_{sr}^t = C_{rd}^t = 0.1, g_s = 0.3$, $R^f = 0.4$, $C^a = 0.1$.

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