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Analysis of coalition formation and cooperation strategies in mobile ad hoc networks ☆

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Abstract

This paper focuses on the formal assessment of the properties of cooperation enforcement mechanisms used to detect and prevent selfish behavior of nodes forming a mobile ad hoc network. In the first part, we demonstrate the requirement for a cooperation enforcement mechanism using cooperative game theory that allows us to determine a lower bound on the size of coalitions of cooperating nodes. In the second part, using non-cooperative game theory, we compare our cooperation enforcement mechanism CORE to other popular mechanisms. Under the hypothesis of perfect monitoring of node behavior, CORE appears to be equivalent to a wide range of history-based strategies like tit-for-tat. Further, adopting a more realistic assumption taking into account imperfect monitoring due to probable communication errors, the non-cooperative model puts in evidence the superiority of CORE over other history-based schemes.

Keywords: Game theory; Cooperation; Coalition formation; Ad hoc networks

1. Introduction

Cooperation enforcement mechanisms have been developed recently in the attempt to cope with the selfish behavior of nodes in mobile ad hoc networks (MANET). As defined in [5,6], a node is considered selfish when it does not participate in the basic network operation in order to save energy. As opposed to maliciousness, selfishness is a passive threat that does not involve any intention to damage the operation of networking functions by active attacks like route subversion, tampering with data, etc.

In this paper we present two different approaches to assess the features of our cooperation enforcement mechanism CORE [6,7]. Using

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CORE, every node locally rates its neighbors through a monitoring mechanism. The observations collected by the monitoring mechanism are processed to evaluate a reputation value associated to each neighbor. The reputation value is used by CORE in a step-like cooperation policy: only nodes with a reputation that satisfy the requirement of being greater than a defined threshold are served (i.e. data and routing packets are forwarded), while nodes with low reputation values are gradually isolated from the network.

Since a large fraction of existing cooperation enforcement schemes are based on principles akin to decision making and economic modeling, a natural tool that emerged to be suitable for the validation of such mechanisms is game theory.

In the first part of this paper we present a model that takes into account both a node-centric and a network-centric perception of the interactions between nodes that participate in a MANET by using *cooperative game theory*. We first demonstrate the requirement for a cooperation enforcement mechanism in order to promote cooperation between self-interested nodes by showing that in the absence of such a mechanism the best strategy for a node would be to free ride. Moreover, we analyze which would be the size of a coalition of cooperating nodes based on the importance given by a node to the node-centric and network-centric perspective of the game. We finally suggest how the CORE mechanism could be used to stimulate a node to join the coalition of cooperators. The benefit from using cooperative GT derives from the ability of this method to seize the dynamics of large group of players: the strategy chosen by a player does not only depend on a self-interested perception of the game but also takes into account a group-wide policy of the coalition the player belongs to.

Although the "cooperative games" approach appears to be appropriate to model the dynamics of large coalitions of nodes forming a MANET, the main limitation of this method is that it is based on a high-level representation of the reputation mechanism that does not take into account the features of CORE. To overcome this weakness, we present in the second part of this paper an alternative approach based on *non-cooperative game theory* [8,9]. In this second method we use a model that describes the strategy of a self-interested node that has to take the decision whether to cooperate or not with a randomly chosen neighbor. Under this model, the CORE mechanism can be translated into a strategy profile that can be compared to other popular strategies. Under the commonly used hypothesis of *perfect monitoring*, we demonstrate the equivalence between CORE and a wide range of history-based strategies like *tit-for-tat*. Further, by adopting a more realistic assumption that takes into account unreliable observations of nodes' behavior due to communication errors, the non-cooperative model puts in evidence the superiority (in terms of stability and robustness) of CORE over other history-based schemes.

Although the two methods described in this paper focus on CORE as a specific mechanism, some general conclusions can be drawn from this analysis towards the design of cooperation enforcement mechanisms in general.

2. Related work

Recently, much attention has been dedicated to game theoretical models for MANET in general and for cooperation enforcement mechanisms in particular and an increasing number of models have been presented to the community. It is however out of the scope of this paper to propose an extensive state of the art of game theoretical models of cooperation in MANET, thus we will focus on some approaches that we deem related to our setting.

In an interesting approach presented in [2] the authors propose a game theoretical model in which energetic information is taken into account to describe the conflicting interaction between heterogeneous nodes involved in a forwarding game, i.e. a game in which nodes that belong to a path from a source to a destination have to collaboratively relay data packets. The authors study the properties of a well known strategy (generous-tit-for-tat, G-TFT) and demonstrate that under the energy constraints imposed to the nodes, G-TFT promotes cooperation if every node of the network