Journal of Advanced Research (2011) 2, 253–264

Cairo University

Journal of Advanced Research

Self-organization of nodes in mobile ad hoc networks using evolutionary games and genetic algorithms

Janusz Kusyk [a], Cem S. Sahin [a,*], M. Umit Uyar [a,b], Elkin Urrea [a], Stephen Gundry [b]

[a] *The Graduate Center of the City University of New York, New York, NY 10016, USA*
[b] *The City College of the City University of New York, New York, NY 10031, USA*

Received 23 September 2010; revised 4 March 2011; accepted 10 April 2011
Available online 14 May 2011

KEYWORDS

Evolutionary game;
Genetic algorithms;
Mobile ad hoc network;
Self-organization

Abstract In this paper, we present a distributed and scalable evolutionary game played by autonomous mobile ad hoc network (MANET) nodes to place themselves uniformly over a dynamically changing environment without a centralized controller. A node spreading evolutionary game, called NSEG, runs at each mobile node, autonomously makes movement decisions based on localized data while the movement probabilities of possible next locations are assigned by a forced-based genetic algorithm (FGA). Because FGA takes only into account the current position of the neighboring nodes, our NSEG, combining FGA with game theory, can find better locations. In NSEG, autonomous node movement decisions are based on the outcome of the locally run FGA and the spatial game set up among it and the nodes in its neighborhood. NSEG is a good candidate for the node spreading class of applications used in both military tasks and commercial applications. We present a formal analysis of our NSEG to prove that an evolutionary stable state is its convergence point. Simulation experiments demonstrate that NSEG performs well with respect to network area coverage, uniform distribution of mobile nodes, and convergence speed.

Introduction

The main performance concerns of mobile ad hoc networks (MANETs) are topology control, spectrum sharing and power consumption, all of which are intensified by lack of a centralized authority and a dynamic topology. In addition, in MANETs where devices are moving autonomously, selfish decisions by the nodes may result in network topology changes contradicting overall network goals. However, we can benefit from autonomous node mobility in unsynchronized networks by incentivizing an individual agent behavior in order to attain an optimal node distribution, which in turn can alleviate many problems MANETs are facing. Achieving better spatial

* Corresponding author. Tel.: +1 603 318 5087.
E-mail address: csafaksahin@gmail.com (C.S. Sahin).

Peer review under responsibility of Cairo University.
doi:10.1016/j.jare.2011.04.006

Production and hosting by Elsevier

placement may lead to an area coverage improvement with reduced sensing overshadows, limited blind spots, and a better utilization of the network resources by creating an uniform node distribution. Consequently, the reduction in power consumption, better spectrum utilization, and the simplification of routing procedures can be accomplished.

The network topology is the basic infrastructure on top of which various applications, such as routing protocols, data collection methods, and information exchange approaches are performed. Therefore, the topology (or physical distribution) of MANET nodes profoundly affects the entire system performance for such applications. Achieving a better spatial placement of nodes may provide a convenient platform for efficient utilization of the network resources and lead to a reduction in sensing overshadows, limiting blind spots, and increasing network reliability. Consequently, the reduction in power consumption, the simplification of routing procedures, and better spectrum utilization with stable network throughput can be easily accomplished.

Among the main objectives for achieving the optimum distribution of mobile agents over a specific region of interest, the first is to ensure connectivity among the mobile agents by preventing the isolated node(s) in the network. Another objective is to maximize the total area covered by all nodes while providing each mode with an optimum number of neighbors. These objectives can be accomplished by providing a uniform distribution of nodes over a two-dimensional area.

As it is impractical to sustain complete and accurate information at each node about the locations and states of all the agents, individual node's decisions should be based on local information and require minimal coordination among agents. On the other hand, autonomous decision making process promotes uncooperative and selfish behavior of individual agents. These characteristics, however, make game theory (GT) a promising tool to model, analyze, and design many MANET aspects.

GT is a framework for analyzing behavior of a rational player in strategic situations where the outcome depends not only on her but also on other players' actions. It is a well researched area of applied mathematics with a broad set of analytical tools readily applied to many areas of computer science. When designing a MANET using game theoretical approach, incentives and deterrents can be built into the game structure to guarantee an optimal or near-optimal solution while eliminating a need of broad coordination and without cooperation enforcement mechanisms.

Evolutionary game theory (EGT) originated as an attempt to understand evolutionary processes by means of traditional GT. However, subsequent developments in EGT and broader understanding of its analytical potential provided insights into various non-evolutionary subjects, such as economy, sociology, anthropology, and philosophy. Some of the EGT contributions to the traditional theory of game are: (i) alleviation of the rationality assumption, (ii) refinement of traditional GT solution concepts, (iii) and introduction of a fully dynamic game model. Consequently, EGT evolved as a scheme to predict equilibrium solution(s) and to create more realistic models of real-life strategic interactions among agents. Because EGT eases many difficult to justify assumptions, which are often necessary conditions for deriving a stable solution by the traditional GT approaches, it may also become an important tool for designing and evaluating MANETs.

As in many optimization problems with a prohibitively large domain for an exhaustive search, finding the best new location for a node that satisfies certain requirements (e.g., a uniform distribution over a geographical terrain, the best strategic location for a given set of tasks, or efficient spectrum utilization) is difficult. Traditional search algorithms for such problems look for a result in an entire search space by either sampling randomly (e.g., random walk) or heuristically (e.g., hill climbing, gradient decent, and others). However, they may arrive at a local maximum point or miss the group of optimal solutions altogether. Genetic algorithms (GAs) are promising alternatives for problems where heuristic or random methods cannot provide satisfactory results. GAs are evolutionary algorithms working on a population of possible solutions instead of a single one. As opposed to an exhaustive or random search, GAs look for the best genes (i.e., the best solution or an optimum result) in an entire problem set using a fitness function to evaluate the performance of each chromosome (i.e., a candidate solution). In our approach, a forced-based genetic algorithm (FGA) is used by the nodes to select the best location among exponentially large number of choices.

In this paper, we introduce a new approach to topology control where FGA, GT, and EGT are combined. Our NSEG is a distributed game with each node independently computing its next preferable location without requiring global network information. In NSEG, a movement decision for node i is based on the outcome of the locally run FGA and the spatial game set up among i and the nodes in its neighborhood. Each node pursues its own goal of reducing the total virtual force inflicted on it by effectively positioning itself in one of the neighboring cells. In our approach, each node runs FGA to find the set of the best next locations. Our FGA takes into account only the neighboring nodes' positions to find the next locations to move. However, NSEG, combining FGA with GT, can find even better locations since it uses additional information about the neighbors' payoffs. We prove that the optimal network topology is evolutionary stable and once reached, guarantees network stability. Simulation experiments show that NSEG provides an adequate network area coverage and convergence rate.

One can envision many military and commercial applications for our NSEG topology control approach, such as search and rescue missions after an earthquake to locate humans trapped in rubble, controlling unmanned vehicles and transportation systems, clearing mine-fields, and spreading military assets (e.g., robots, mini-submarines, etc.) under harsh and bandwidth limited conditions. In these types of applications, a large number of autonomous mobile nodes can gather information from multiple viewpoints simultaneously, allowing them to share information and adapt to the environment quickly and comprehensively. A common objective among these applications is the uniform distribution of mobile nodes operating on geographical areas without a priori knowledge of the geographical terrain and resources location.

The rest of this paper is organized as follows. Section 'Related work' provides an overview of the existing research. Basics in GT, EGT, and GA are outlined in Section 'Background to GT, EGT, and GA'. Our distributed node spreading evolutionary game NSEG and its properties are presented in Section 'Our node spreading evolutionary game: NSEG'. Section 'Analysis of NSEG convergence' analyzes the convergence of NSEG. The simulation results are evaluated in Section 'Experimental results'.