Available online at www.sciencedirect.com
SCIENCE DIRECT®

Journal of Systems Architecture 52 (2006) 485–504

JOURNAL OF SYSTEMS ARCHITECTURE

www.elsevier.com/locate/sysarc

ANSI: A swarm intelligence-based unicast routing protocol for hybrid ad hoc networks ☆,☆☆

Sundaram Rajagopalan *, Chien-Chung Shen

DEGAS Networking Group, Department of Computer and Information Sciences, University of Delaware, Newark, DE 19716, USA

Available online 19 April 2006

Abstract

We present a hybrid routing protocol for both pure and hybrid ad hoc networks which uses the mechanisms of swarm intelligence to select next hops. Our protocol, Ad hoc Networking with Swarm Intelligence (ANSI), is a congestion-aware routing protocol, which, owing to the self-organizing mechanisms of swarm intelligence, is able to collect more information about the local network and make more effective routing decisions than traditional MANET protocols. Once routes are found, ANSI maintains routes along a path from source to destination effectively by using swarm intelligence techniques, and is able to gauge the slow deterioration of a link and restore a path along newer links as and when necessary. ANSI is thus more responsive to topological fluctuations. ANSI is designed to work over hybrid ad hoc networks: ad hoc networks which consist of both lower-capability, mobile wireless devices and higher-capability, wireless devices which may or may not be mobile. In addition, ANSI works with multiple interfaces and with both wired and wireless interfaces.

Our simulation study compared ANSI with AODV on both hybrid and pure ad hoc network scenarios using both TCP and UDP data flows. The results show that ANSI is able to achieve better results (in terms of packet delivery, number of packets sent, end-to-end delay, and jitter) as compared to AODV in most simulation scenarios. In addition, ANSI achieves this performance with fewer route errors as compared to AODV. Lastly, ANSI is able to perform more consistently, considering the lower variation (measured as the width of the confidence intervals) of the observed values in the results of the experiments. We show that ANSI's performance is aided by both its superior handling of routing information and also its congestion awareness properties, though we see that congestion awareness in ANSI comes at a price.

Keywords: Swarm intelligence; MANET; Hybrid network; Hybrid routing; Congestion aware routing

1. Introduction

Hybrid ad hoc networks consist of a mixture of mobile, ad hoc network (MANET) nodes and nodes which belong to highly capable infrastructure such as mesh networks or cellular networks. The problem of hybrid ad hoc networks is to make these networks work efficiently without relying on pre-configured

☆ A section of this work was presented at ICAI 2005, June 2005, Las Vegas, NV, USA.

☆☆ This work is supported in part by National Science Foundation under grant ANI-0240398.

* Corresponding author. Tel.: +1 302 831 1131; fax: +1 302 831 8458.

E-mail address: rajagopa@cis.udel.edu (S. Rajagopalan).

1383-7621/$ - see front matter
doi:10.1016/j.sysarc.2006.02.006

network topologies or centralized control. Hybrid ad hoc networks are useful in many situations where impromptu communication facilities are required such as battlefield communications, and disaster relief missions.

Since the problem of hybrid ad hoc networking shares a lot of problems with typical MANET problems, typical routing solutions for hybrid networks start with a MANET routing solution and then apply some optimizations to work for specific scenarios. A number of ad hoc routing protocols have been proposed, for example [1–5], of which some of them, like AODV [1] work on hybrid ad hoc networks. In *proactive* protocols such as [5], nodes in the network maintain routing information to all other nodes in the network by periodically exchanging routing information. Nodes using *reactive* protocols, such as [1,2], delay the route acquisition until a demand for a route is made. *Hybrid* protocols, like [4,6], use a combination of both proactive and reactive activities to gather routes to the destinations in a network—nodes using ZRP, for example, proactively collect routes in their zone, and other routes are collected reactively. In [6], on the other hand, the level of proactive activity and reactive activity are chosen autonomously by the nodes in the network, and proactive activity is only seen around favorite destination nodes. In most traditional reactive protocols, like [1,2], only when a route breaks irreparably does the protocol mechanisms repair the damage. In reality, route deterioration in mobile networks is most often not sudden but gradual,[1] and most often available routes get better/deteriorate gradually and not suddenly. So the routing protocol should continuously maintain information about the nodes in the local area to perform effectively and avoid too may link breakages.

In this paper, we present a hybrid routing suite (with both proactive and reactive components) for hybrid ad hoc networks which uses the mechanisms of swarm intelligence [7] to select good routes to destinations. We use Swarm Intelligence (SI) because SI mechanisms allow for self-organizing systems [8] and maintain state information about the neighboring network better than traditional MANET routing mechanisms. Self-organizing systems are robust environments where erroneous system behavior is corrected autonomously by the coordinated working of lower-level components. The combination/interaction of lower-level components in SI such as positive/negative feedback and amplification of fluctuations along with multiple interactions are the mechanisms which allow a node to change routing information quickly and efficiently to adjust to an ever-changing local topology and route deterioration, thus initiating fewer link breakages.

Our protocol, ANSI, uses a highly flexible cost function which allows it to use the information collected from the local ant activity, such as the congestion status of the neighboring nodes, in useful ways. In addition, the ant-like working of our protocol allows for the maintenance of multiple routes to a destination. In nodes which use proactive routing in ANSI, this fact is used to perform stochastic routing, and in nodes that use perform reactive routing (pure MANET nodes), when one route fails, others may be used. Our motivation comes from the fact that different networks face different conditions, and thus a protocol suite should allow for various configurations as the network conditions dictate. Furthermore, supporting multiple routes simultaneously is essential to ensure *survivability* of the network [9]. ANSI facilitates ad hoc unicast routing by exploiting route finding behaviors that are *emergent* from ant packets working collectively, rather than explicitly coding them to cope with the problem. We formulate the routing problem at node i as a set of "food foraging" problems from nest i, where each "food source" is a destination d in the network. In this formulation, next hops are evaluated on the basis of the strength of the *pheromone trail*[2] on the link connecting a node and a next hop.

The remainder of this paper is organized as follows: In the next section, we discuss a number of approaches and protocols which are related to our research. In Section 3, we describe in detail the components of ANSI unicast routing protocol, and follow it with Section 4 where we discuss the results of the comparison of simulated models of ANSI with a popular routing protocol, AODV [1]. We conclude in Section 5 with a brief note on future research effort.

2. Related work

The main ingredients of SI, positive/negative reinforcement, and amplification of fluctuations

[1] Some routes, such as routes to neighbors, break suddenly, when the neighbors go out of range. We are commenting on the general case here.

[2] The computational equivalent of the chemical deposited on the forest floor by ants.