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Improving hybrid ad hoc networks: The election of gateways

A.J. Yuste-Delgado, J.C. Cuevas-Martinez*, J. Canada-Bago, J.A. Fernández-Prieto, M.A. Gadeo-Martos

Universidad de Jaén, E.P.S. de Linares, Telecommunication Engineering Department, Alfonso X El Sabio, 28, 23700 Linares, Jaén, Spain

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ABSTRACT

The selection of an appropriate and stable route that enables suitable load balancing of Internet gateways is an important issue in hybrid mobile ad hoc networks. The variables employed to perform routing must ensure that no harm is caused that might degrade other network performance metrics such as delay and packet loss. Moreover, the effect of such routing must remain affordable, such as low losses or extra signaling messages. This paper proposes a new method, Steady Load Balancing Gateway Election, based on a fuzzy logic system to achieve this objective. The fuzzy system infers a new routing metric named *cost* that considers several networks performance variables to select the best gateway. To solve the problem of defining the fuzzy sets, they are optimized by a genetic algorithm whose fitness function also employs fuzzy logic and is designed with four network performance metrics. The promising results confirm that ad hoc networks are characterized by great uncertainty, so that the use of Computational Intelligence methods such as fuzzy logic or genetic algorithms is highly recommended.

1. Introduction

Mobile Ad hoc Networks (MANET) is a main interest area in ad hoc technologies that tries to deal with new trends in wireless communications. MANETs can reduce the impact of problems like deployment and maintenance costs of conventional wireless networks whereas they need more complex link management and routing. MANETs are composed of heterogeneous nodes that move in a confined space without a central infrastructure. Those nodes are interconnected through a multi-hop scheme that usually relies on routing protocols such as AODV or OLSR. Nevertheless, in current personal communications, the main interest of the users in a MANET is to find a reliable means of accessing the Internet through the available gateways in the network. Thus, those MANETs that have active connections to a public network are part of a type of ad hoc network called a hybrid MANET (H-MANET). In addition, the minimal infrastructure needed by MANET networks and their accessibility and adaptability [1] make them suitable to address the new scenarios for mobile communications.

In H-MANETs, the number of active gateways can vary, and they can be placed everywhere. Therefore, due to the heterogeneity and movement of the nodes, some of those gateways might need to manage higher traffic rates than others; that would cause a faster depletion of their batteries [2]. Moreover, the overload in the radio interface would increase packet losses due to signal interference, and the selection of one path to a gateway from another could seriously affect packet delay. Both problems, losses and delay, could have a direct effect on the user experience. Therefore, it becomes necessary to use traffic-engineering techniques to handle the load balancing between different gateways and to achieve better performance and resource optimization of H-MANETs [3]. Moreover, the resulting paths must be as stable as possible to avoid unnecessary control traffic required to reconfigure the entire MANET.

Unfortunately, most ad hoc routing protocols do not implement any load-balancing techniques [4]. A review of the load-balancing techniques employed in MANET shows that minimum-hop routing protocols tend to designate most centralized nodes with a high number of paths. Thus, only a few nodes must bear most of the network throughput, which translates into an increase in congestion and other undesirable effects such as battery depletion, high delays and routing overload.

Furthermore, load balancing can be associated with two separate ideas: pure load balancing and multipath routing techniques. Multipath routing does not show a significant improvement in mobile wireless networks because the majority of paths between any origin and destination share a significant number of nodes [4]. Therefore, if one of those path nodes failed, there would be

* Corresponding author. Tel.: +34 953 648 617; fax: +34 953 648 508.
E-mail addresses: ajyuste@ujaen.es (A.J. Yuste-Delgado), jccuevas@ujaen.es (J.C. Cuevas-Martinez), jcbago@ujaen.es (J. Canada-Bago), jan@ujaen.es (J.A. Fernández-Prieto), gadeo@ujaen.es (M.A. Gadeo-Martos).

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a high probability that most possible routes to the Internet would be affected.

The protocols used in ad hoc multipath networks that address the interconnection between them and the Internet usually employ different adaptations of the Neighbor Discovery Protocol (NDP) [5]. The interconnection is achieved by sending Modified Router Advertisement (MRA) messages [6], which are an adaptation of the Router Advertisement messages sent by NDP. There are three different techniques to send these messages: proactive, reactive and hybrid methods. The proactive method consists of sending MRA messages periodically to the entire network whereas in the reactive technique, a route is only established on demand. The hybrid method creates two zones within the network. One of those areas is the proactive zone, delimited by the TTL of the IP packets, whereas outside that zone, a hybrid method is employed.

Note that the optimization of only one metric, such as load balancing, to improve network performance is likely to cause degradation in other metrics that affect the efficiency of the network [7]. Therefore, it is important to employ a multi-objective technique that considers different parameters or metrics of the system under study to achieve an optimum global solution [8]. However, multi-objective optimization in ad hoc networks is complex to achieve because the information needed for it is not always available in one node, or the signaling cost required to inform every device is not affordable. Thus, ad hoc networks and, more specifically, MANETs, must address a high degree of uncertainty [9], which makes them suitable to employ Computational Intelligence (CI) techniques. Some of the main causes of the uncertainty in MANETs include the following:

- Mobility of the nodes that makes their position unpredictable. Furthermore, links between nodes change continuously, which implies route actualization and side effects of fluctuating latency or delays within communications.
- Device heterogeneity: ad hoc networks can be formed by a wide variety of devices with, for example, different transmission power, signal sensitivity and available energy.
- Topology control is difficult to achieve due to the intrinsic mobility of MANET and to the limited number of control packets that can be sent in ad hoc networks to avoid battery depletion of nodes [10].
- Obstacles, diffraction and fading of signals in indoor environments and weather conditions in outdoor communications [11].

Therefore, to cope with the problem of uncertainty in MANETs and achieve steady load balancing that does not degrade other network performance metrics, this paper presents a new distributed method for gateway election by mobile nodes based on CI techniques such as fuzzy logic and genetic algorithms. Thus, the proposed method, Steady Load Balancing Gateway Election (SLBGE), which represents our main contribution, selects the best path to the right gateway in a MANET, considering only network status and performance variables that can be obtained autonomously by each node. The cost of each route is inferred by Fuzzy Inference System (FIS) based on multiple optimization objectives and stored in the routing table of the node. The cost for each path is actualized periodically with MRA arrivals.

Due to the mathematical complexity of precisely defining the right fuzzy sets of the input variables of the fuzzy system, they have been processed through the Genetic Algorithm (GA) whose novel fitness function is also based on a FIS.

The remainder of the paper is structured as follows. Section 2 presents a review of the most important related work that addresses the gateway selection problem. The method presented in this paper is described in detail in Section 3, whereas Section 4 shows the results obtained through a comparison with other, similar algorithms. To conclude this paper, the conclusions and future work are presented in Section 5.

2. Related work

As was mentioned above, routing and path election in MANETs incorporate a high degree of uncertainty: wireless communications, movement, heterogeneity and power constraints. Thus, different CI techniques are applied to routing, clustering, energy management, security and load balancing. Of the many CI techniques applied to MANET management, fuzzy logic and genetic or swarm intelligence algorithms [12] such as Ant Colony Organization (ACO) are among those commonly used [13].

Some representative examples of routing algorithms based on fuzzy logic for MANETs appear in [14], in which the authors present a solution to increase the time to live of a route, and in Sun et al. [15], which proposes entropy-based stability QoS routing with a fuzzy priority scheduler for MANETs.

For optimization with GA, a study [7] presents a multi-objective routing algorithm whose inputs refer to node status (residual energy, signal strength of the incoming messages and queue status), whereas in [16], to guarantee the stability of the clusters, the optimization process aims to achieve appropriate load balancing.

The contribution of Di Caro et al. [17] deserves special attention due to its relevance in bio-inspired techniques applied to routing in MANETs. In this case, the authors employ an Ant Colony Optimization algorithm to calculate the best route between nodes, keeping obtained paths active as long as possible. Moreover, this routing algorithm implicitly performs load balancing. This approach utilizes a proactive technique for path discovery based on the propagation and special control packets or *ants*. Then, previously established routes are actualized in a proactive approach over fixed intervals, sending new ants.

Focusing now on load balancing, a significant number of articles on H-MANETs have recently been published that use information gathered from control messages such as MRA as presented in [18], in which the author introduced a load-balancing technique for ad hoc and mesh networks based on the Round Trip Time (RTT), queue length or the number of active traffic sources. For example, in [19], the authors present a mixed integer linear problem as a solution for load balancing that minimizes the load of every link to the Internet. Unfortunately, this method needs an enormous amount of information that makes it extremely difficult to implement and compare with other approaches. In Ahn et al. [20], the authors analyze the information carried by the MRA messages and the delay in message reception to obtain metrics to be employed in load balancing such as number of hops, load of the gateway, variance of the arrival interval of the proactive messages and any combination of these.

A variant of the previous Internet draft can be found in [18], in which a load index is calculated for each mobile node and is later broadcast to build all the routing tables.

Among other techniques, fuzzy logic is also used in load-balancing calculations for H-MANETs. In [21], the authors present a related hybrid technique that adjusts the TTL of the MRA messages by the distance between the mobile nodes and the number of the nodes that are simultaneously connected to the Internet. Thereafter, mobile nodes choose their Internet gateway by the number of hops between them. An improved version of the previous contribution can be found in [22], in which a new method is presented to obtain the maximum distance to send control messages to the gateway.

Genetic algorithms have widely employed in optimization problems in the field of MANETs because most of those problems lack exact solutions, or their complexity makes them unaffordable. Therefore, GAs have been used in multiple ways as seen in [23]. On the other hand, the main difficulty of employing genetic algorithms