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A simulation-based performance evaluation of a randomized MIS-based clustering algorithm for ad hoc networks

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ABSTRACT

Ad-hoc networks represent distributed systems that comprise wireless nodes which can dynamically self-organize into arbitrary and temporary network topologies, without relying on pre-existing infrastructure, and thus network hierarchy formation via clustering is vital for them. The present article conducts a comprehensive simulation-based evaluation of the performance achieved by a recently proposed, biology-inspired, clustering algorithm used in wireless ad hoc networks, namely the Randomized Beep Based Maximum Independent Set (*RanMIS*) (Afek et al., 2011). This is the first evaluation done for this high-performance algorithm. The evaluation is done for a set of metrics (measures for protocol cost, backbone description and robustness) some of which has not been used in earlier simulation studies and are developed here. Our study confirms the virtues (message complexity) and reveals the shortcomings of *RanMIS* (latency issues), and quantifies the impact of some of its administratively-tuned parameters. *RanMIS* is compared with two representative graph-theoretic node clustering methods and a new one developed here; the results confirm the message optimality of *RanMIS*, but reveal some shortcomings of it, basically related to the excessive number of rounds that needs to run in order to complete the network clustering.

1. Introduction

A wireless ad hoc network is a type of wireless network which eliminates the complexities of infrastructure setup and administration, by enabling existing nodes to create and join networks *"on the fly"*, anywhere, anytime, for virtually any application. Each node participates in routing by forwarding data for other nodes, but the determination of which nodes will finally forward data is made dynamically.

The decentralized nature of wireless ad hoc networks makes them suitable for a variety of applications where central nodes cannot be relied on, and may improve the scalability of wireless ad hoc networks, compared to wireless managed networks. The minimal required configuration, the quick deployment, and the presence of dynamic and adaptive routing protocols, which allows them to be formed quickly, make ad hoc networks suitable for situations like habitat monitoring, disaster relief, law enforcement operations, battle field communications, target tracking and so on.

The dynamic nature of wireless ad hoc networks though, requires that solutions for multi hop network protocols at all levels must be distributed. Of the solutions proposed for scaling down networks with large numbers of nodes, *network*

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clustering is among the most investigated for mobile ad hoc networks [2–12], for sensor ad hoc networks [13,14], for wireless mesh networks [15] and for vehicular ad hoc networks [16–18]. Other solutions of network management such as topology control [19] are remotely related to this work.

The basic idea in clustering is that of grouping network nodes that are in physical proximity, thereby providing the *flat* network a *hierarchical* organization, which is smaller in size, and simpler to manage.

The subsequent *backbone* construction uses the induced hierarchy to form a communication infrastructure that is functional in providing desirable properties such as minimizing communication overhead, choosing data aggregation points, increasing the probability of aggregating redundant data, and consequently minimizing the overall power consumption.

In a clumpy approach, clustering algorithms can be divided in two major families. The first with its roots in *graph theory*, exploits the localized network structure for estimating dynamically the clusterheads (CHs), while the second provides mechanisms to ameliorate the fact that nodes belonging to the backbone are solely responsible for carrying out all communication, thus running out of energy very soon. Namely, the latter family addresses the energy consumption problem, that is essentially proposes ways to rotate the role of CH among nodes of clusters e.g., the SPAN [20], the LEACH [21] and the HEED [22] protocols. The proposed methods use the residual energy of each node in order to direct its decision about whether it will elect itself as a CH or not. However, this family's methods ignore topological features of the nodes.

The former family of protocols encompasses the most representative and successful solutions in the area of network management. This is because while it exploits the wealth of information extracted from the network topology particularities, it can also take into account application specific requirements, such as QoS. Moreover, algorithms of this family can easily be combined with a round robin CH rotation method as was described in [13], and thus exploit all the advantages the energy-efficient algorithms provide.

Recently, *RanMIS* [1,23] – which belongs to the first family – was proposed as a message-optimal algorithm; it employees a probabilistic technique for node clustering and enables every node to independently decide on its role in the clustered network. It ensures rapid convergence, while keeping the message overhead low. Its message complexity on CH selection was studied analytically in [23], but its performance is still in question with respect to the delay it incurs for the clustering protocol termination, for the 'stability' of the created clusters in case of node failures, and so on. The focus of this paper is exactly to fill this gap by conducting a detailed experimental evaluation of *RanMIS* by simulation.

RanMIS competitors were selected from two distinct protocol categories.[1] The first category is oriented on providing the network with a two-layer hierarchical organization comprised by groups of nodes, i.e., clusters. One 'special' node of each cluster (the CH) participates in the so-called backbone; the backbone nodes form a *dominating set (DS)* over the flat network topology. This means that, each node that is not in the backbone, has at least one backbone node as its neighbor. Backbone nodes are joined via *gateway* nodes. Apparently, if the flat network is connected, it is deterministically guaranteed, that the backbone is connected as well. Distributed Clustering Algorithm (*DCA*) is a high-performance representative of this category.

The second category retains the layered structure of the first category, and it is oriented on facilitating routing without the need of gateway nodes. The concept behind this category is that of building a *Connected Dominating Set (CDS)* directly, without firstly selecting CHs and then joining them. It was initially introduced by Das et al. in [24] when they proposed the concept of creating a *communication spine* inside a flat network topology in order to support unicast, multicast, and fault-tolerant routing within an ad hoc network. *WuLi* is a practical and robust representative of this category.

Contrary to *RanMIS*'s randomized nature, its competitors use iterative clustering techniques, meaning that a node waits for a specific event to occur or certain nodes to decide about their role before making a decision themselves.

1.1. Motivation and contributions

The problem of providing a hierarchical organization for ad hoc networks is of crucial importance due to the widespread deployment of such networks (e.g., mobile ad hoc networks, sensor networks, vehicular ad hoc networks) and their scalability problems. Despite the fact that a really large number of algorithms have been proposed during the last decade for performing clustering, the proposal and study of protocols which exhibit low message complexity, fast convergence, incremental backbone maintenance, resilience to hub node failures, connectivity preservation, and backbone stability is still in quest. The considered clustering algorithms seem to encompass all the aforementioned features and therefore their detailed, joint investigation is a significant task for the area of ad hoc network management.

In this context, the present article makes the following contributions:

- We investigate for the first time by detailed simulation the performance of *RanMIS*. In particular:
  - We confirm its message optimality for backbone construction across all examined network topologies.
  - We reveal the impact of parameter D on the number of rounds before *RanMIS* terminates; moreover, we prove its independence on each node's neighborhood size, contrary to *RanMIS*' original article suggestion.
  - We question the value of parameter M as suggested by the authors of *RanMIS*.

[1] More detailed arguments about the selection of competitors can be found at subSection 3.4.