A greedy-based simulated annealing algorithm for the clustering problem in ad hoc networks

(Extended Abstract)

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Abstract. Clustering has been introduced in ad hoc networking to provide hierarchy and stability and to support information circulation reduction, energy management and scalability. It consists of a process of self-aggregation of nodes into a set of sub-networks called clusters where each cluster would be managed by a master node called cluster centre responsible for gathering, maintaining and updating the cluster topology information as well as ensuring the data routing over the network. The set of cluster centres institutes a temporarily network core that enhances the topology maintenance. From a graph perspective, this set represents a dominating set, that is a set of nodes such that each node of the network is either an element or adjacent to at least one element of this set. This work develops a constrained bi-objective optimization model for finding a dominating set that provides a trade-off between maximizing the energy amount and minimizing the cardinality. A greedy-based bi-objective simulated annealing meta-heuristic for constructing near-optimal Pareto solutions is then presented.

Keywords: Ad hoc Networks, Clustering, Dominating Set, Simulated Annealing, Pareto optimisation

Background and Problem Statement

Ad hoc networks are infrastructure-less collections of heterogeneous mobile devices connected by wireless links. The devices have several limitations in terms of embedded energy, processing power, bandwidth, and internal memory. Ad hoc networks are self-organising networks where nodes are able to establish reactively a temporary network topology tolerant of any increase or decrease in the number of devices, and able to find multi-hop routes to relay any message, when required. Typical applications of ad hoc networks include military intervention, emergency operations, and remote areas coverage.

Clustering is the process of partitioning a network into a number of sub-networks called clusters where each cluster would be managed by a master node called cluster centre responsible for gathering, maintaining and updating the cluster topology information as well as ensuring the data routing over the network. Selection of cluster centres is the main stage in this process and requires a specific selection criterion. Yet, few studies [3, 5] have considered a selection criterion directly related to the residual energy in the nodes. From a graph perspective, the set of cluster centres represents a dominating set, that is a set of nodes such that each node of the network is either an element or adjacent to at least one element of this set. This work aims at dealing with energy issue in ad hoc networks by finding a dominating set that provides a trade-off between maximizing the energy amount and minimizing the cardinality. A bi-objective optimization model and a greedy-based bi-objective simulated annealing meta-heuristic for constructing near-optimal Pareto solutions are presented.

Mathematical model

Let $G = (V, E)$ be an undirected graph where V is the set of vertices representing the network nodes and E the set of edges (pairs of nodes) representing the available direct communication links, and let us consider the following notations

$\mathcal{D}$	:	a dominating set in G
$C(v)$	:	a cluster with centre v
d_v	:	connectivity degree of a node v
e_v	:	residual energy in a node v
ε_v	:	minimal energy required for a node v to manage the communication between each related node
δ_v	:	maximal number of members of a cluster v called the energetic degree budget; it is defined herein as the ratio of the residual energy e_v to the minimal energy ε_v
κ	:	maximal number of clusters

Let us consider the variables x and y such that

$$x_{uv} = \begin{cases} 1 & \text{if } u \in C(v) \\ 0 & \text{otherwise} \end{cases}$$

and,

$$y_v = \begin{cases} 1 & \text{if } v \text{ is a cluster centre} \\ 0 & \text{otherwise} \end{cases}$$

The proposed mathematical formulation consists of the following model

$$\begin{cases} \max\limits_{v} \sum\limits_{v \in V} e_v y_v \\ \min\limits_{v} \sum\limits_{v \in V} y_v \\ \text{subject to} \\ \quad \sum\limits_{v \in V} x_{uv} = 1 \quad ; \quad \forall u \in V \qquad (1) \\ \quad e_v y_v \geq \varepsilon_v \sum\limits_{u \in V} x_{uv} \quad ; \quad \forall v \in V \qquad (2) \\ \quad \sum\limits_{v \in V} y_v \leq \kappa \qquad (3) \\ \quad x_{uv}, y_v \in \{0, 1\} \quad ; \quad \forall u, v \in V \end{cases}$$

Model constraints explanation is given as follows:

- constraint (1) stipulates that each node is assigned to exactly one cluster centre;
- constraint (2) requires that each cluster centre should have enough energy to manage communications with all its cluster members;
- constraint (3) imposes a largest number κ of constructed clusters.

Proposed meta-heuristic

We propose herein a bi-objective simulated annealing approach taking into consideration the energy amount and the cardinality of the cluster centres set. Given the impact of the choice of the initial solution in meta-heuristics, we propose a greedy heuristic to construct a 'qualified' initial solution based on maximizing the *energy-degree evaluation metric* introduced in [2]:

$$m_u = \begin{cases} \dfrac{\delta_u \times d_u}{\delta_u + d_u} & \text{if } \delta_u \geq d_u > 0 \\ \dfrac{\delta}{d} & \text{otherwise} \end{cases}$$

We define a neighbouring solution of a current one any solution having a subset in common, and a fragment $\mathcal{F}$ any starting part inherited from a current solution with random size. Neighbouring solutions are generated from a fragment as illustrated in Fig. 1.

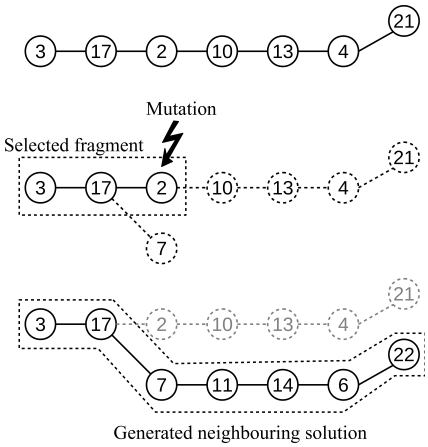

Figure 1: Generating neighbouring solutions on the basis of a randomly selected fragment

The regular acceptance occurs when a neighbouring solution is improving at least one objective, while the probabilistic transition is made according to the following probability

$$\exp\left(\frac{\Delta E \Delta C}{T}\right)$$

where ΔE and ΔC are the variation of the energy amount of the dominating set and of its cardinality respectively and T is the current temperature. Any solution accepted regularly is considered temporarily as near-optimal and stored in a Pareto archive. Overall the above considerations, the proposed simulated annealing approach is presented in the following flowchart (Fig. 2)

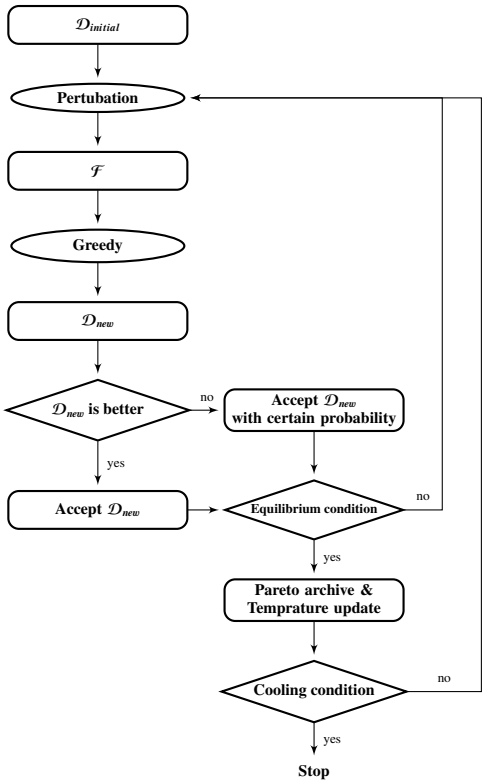

Figure 2: Bi-objective simulated annealing algorithm flowchart

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