Expert Systems with Applications 40 (2013) 1381–1392

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Dynamic genetic algorithms for the dynamic load balanced clustering problem in mobile ad hoc networks

Hui Cheng [a,*], Shengxiang Yang [b], Jiannong Cao [c]

[a] Department of Computer Science and Technology, University of Bedfordshire, Luton LU1 3JU, UK
[b] School of Computer Science and Informatics, De Montfort University, Leicester LE1 9BH, UK
[c] Department of Computing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

ARTICLE INFO

Keywords:
Dynamic optimization problem (DOP)
Dynamic load balanced clustering problem (DLBCP)
Dynamic genetic algorithm
Mobile ad hoc network (MANET)

ABSTRACT

Clustering can help aggregate the topology information and reduce the size of routing tables in a mobile ad hoc network (MANET). To achieve fairness and uniform energy consumption, each clusterhead should ideally support the same number of clustermembers. However, a MANET is a dynamic and complex system and its one important characteristic is the topology dynamics, that is, the network topology changes over time due to the factors such as energy conservation and node movement. Therefore, in a MANET, an effective clustering algorithm should efficiently adapt to each topology change and produce the new load balanced clusterhead set quickly. The maintenance of the cluster structure should aim to keep it as stable as possible to reduce overhead. To meet this requirement, the new solution should keep as many good parts in the previous solution as possible. In this paper, we first formulate the dynamic load balanced clustering problem (DLBCP) into a dynamic optimization problem. Then, we propose to use a series of dynamic genetic algorithms (GAs) to solve the DLBCP in MANETs. In these dynamic GAs, each individual represents a feasible clustering structure and its fitness is evaluated based on the load balance metric. Various dynamics handling techniques are introduced to help the population to deal with the topology changes and produce closely related solutions in good quality. The experimental results show that these GAs can work well for the DLBCP and outperform traditional GAs that do not consider dynamic network optimization requirements.

1. Introduction

A mobile ad hoc network (MANET) (Minhas, Zhang, Tran, & Cohen, 2011; Siva Ram Murthy & Manoj, 2004) is a self-organizing and self-configuring multihop wireless networks, which is comprised of a set of mobile hosts that can move around freely and cooperate in relaying packets on behalf of one another. It has the advantages of low cost, plug-and-play convenience, and flexibility. Analogous to the IP subnet concept in the Internet, a MANET can also be divided into a hierarchical architecture by organizing nodes into clusters. Within each cluster, the information regarding the nodes and links is aggregated. Each cluster can thus be seen as a logical node at the cluster level. The network layer only needs to maintain and manage the information of these logical nodes. The control overhead of the network is reduced with the aid of clustering.

Clustering is a key issue in MANETs and their applications (Wang, Liu, Zhou, & Ansari, 2008). The importance of the clustering problem can be summarized in two aspects. First, it plays a critical role in effective network management. A MANET usually has hundreds of mobile nodes. Its flat network infrastructure encounters the scalability problem when the network size keeps rising. Due to node mobility, scalability is more challenging in MANETs than in wired network. Therefore, effective network management is extremely important. So far, clustering is the most efficient way to manage MANETs (Chatterjee, Das, & Turgut, 2002). Second, clustering serves as the foundation for many other key issues in MANETs, e.g., routing (Safa, Artail, & Tabet, 2010; Su, Hwang, & Dow, 2008), intrusion detection (Kim, Kim, & Kim, 2006), topology control (Shen et al., 2004), and backbone construction (Andronache & Rothkugel, 2008). All these problems are solved based on a well clustered network structure.

The goal of a clustering algorithm (Yu & Chong, 2005) is to find a feasible interconnected set of clusters covering the entire set of nodes in a MANET. At any instant, one mobile node can only belong to one cluster. A cluster may have a clusterhead or not. However, since the recruiting of clusterheads brings the advantage of easy management, most of the prior research works focus on clustering where clusterheads are appointed. In this paper, our algorithms also generate the clusters with clusterheads. Furthermore, clustering

* Corresponding author. Tel.: +44 1582743933.
E-mail addresses: hui.cheng@beds.ac.uk (H. Cheng), syang@dmu.ac.uk (S. Yang), csjcao@comp.polyu.edu.hk (J. Cao).

0957-4174/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2012.08.050

must be conducted with at least one metric such as node ID, node degree and energy (battery energy). The metric is determined based on the application requirements. For example, in the highest degree heuristic (Gerla & Tsai, 1995), the node with the maximum number of neighbors (highest degree) is chosen as the clusterhead.

In this paper, we consider the load balance as the clustering metric since it is an important application requirement. The load balance means that every clusterhead should ideally support the same number of clustermembers. It can guarantee the fairness for all the clusterheads in terms of the workload. Moreover, the load balanced clustering can help prolong the lifetime of the cluster structure since each clusterhead will evenly consume its battery energy. It has been proved that finding an optimal set of clusterheads with one or more clustering metrics is NP-hard (Chatterjee et al., 2002). Conventional search techniques, such as hill climbing (Russell & Norvig, 2003), are often incapable of optimizing non-linear multimodal functions. In such a case, a random search method might be required. Genetic algorithm (GA) is a well-known guided random search and optimization technique, which is based on the basic principles of evolution: survival of the fittest and inheritance. Generally speaking, GAs are applied to find a close to optimal solution with respect to a fitness function for NP-hard problems.

However, since we consider the load balanced clustering in a continuously changing network environment, the problem turns out to be one dynamic optimization problem (DOP). In recent years, studying GAs for DOPs has attracted a growing interest due to its importance in GA's real world applications (Yang & Yao, 2008). The simplest way of addressing DOPs is to restart GAs from scratch whenever an environmental change is detected. Although the restart scheme really works for some cases (Yang & Yao, 2005), for many DOPs it is more efficient to develop other approaches that make use of knowledge gathered from old environments. Over the years, several approaches have been developed for GAs to address dynamic environments (Branke, 2002; Morrison, 2004; Yang, Ong, & Jin, 2007), such as maintaining diversity during the run via random immigrants (Grefenstette, 1992; Vavak & Fogarty, 1996), increasing diversity after a change (Cobb & Grefenstette, 1993), using memory schemes to reuse stored useful information (Branke, 1999; Trojanowski & Michalewicz, 1999; Trojanowski & Michalewicz, 2000; Yang, 2005a; Yang, 2005b), and applying multi-population and speciation schemes to search in different regions of the search space (Branke et al., 2000; Oppacher & Wineberg, 1999; Parrott & Li, 2006). For the sake of description convenience, we term these GAs that are properly enhanced to address DOPs as *dynamic GAs*.

In this paper, we adapt and apply several types of dynamic GAs that are developed to deal with general DOPs to solve the dynamic load balanced clustering problem (DLBCP) in MANETs. First, we design the components of the Standard GA (SGA) specifically for the DLBCP. Then, we integrate several immigrants, memory, multi-population schemes and their combinations into the SGA to enhance its capability in handling the environmental dynamics. For example, regarding the immigrants schemes, at each generation, a certain number of immigrants are generated and added into the population to maintain the diversity. Once the topology is changed, the new immigrants can help guide the search of good solutions in the new environment. For comparison purposes, we also implement the SGA and the Restart GA (RGA). By extensive simulation experiments, we evaluate their performance on the DLBCP. The results show that these dynamic GAs significantly outperform both the traditional GA methods and the non-GA technique. They work really well in the dynamic real-world wireless networks.

The rest of this paper is organized as follows. We discuss related work in Section 2. The MANET model and the DLBCP model are described in Section 3. Section 4 presents the design of a specialized GA for the static load balanced clustering problem. The dynamic GAs that are investigated for the DLBCP are described in Section 5. The extensive experimental study and relevant analysis are presented in Section 6. Finally, Section 7 concludes this paper with some discussions on the future work.

2. Related work

A typical cluster structure in a MANET is shown in Fig. 1. Within one cluster, mobile nodes may act as different roles, such as clusterhead, clustergateway, or clustermember. A clusterhead normally serves as a local coordinator for its cluster, performing intra-cluster transmission control, data forwarding, and so on. A clustergateway is a non-clusterhead node with inter-cluster links, so it can access neighboring clusters and forward data between clusters. A clustermember is an ordinary node, which is a non-clusterhead node without any inter-cluster links.

The primary step in clustering is the selection of clusterheads. The clusterhead can be the leader node, for example, the node with the maximum remaining energy. The selection is based on different criterion derived from specific communication requirements. For one-hop clustering, the cluster structure is determined once the clusterheads are determined. In the following, we describe the clusterhead selection problem in a formal way. A MANET is represented as an undirected graph $G(V,E)$, where V represents the set of mobile nodes and E represents the set of links between nodes. Let $N(v)$ be the neighborhood of node v, defined as follows:

$$N(v) = \bigcup_{v' \in V, v' \neq v} \{v' | dist(v, v') < D\}. \tag{1}$$

where $dist(v,v')$ is the distance between node v and node v', and D is the transmission range of node v. The generalized procedure for selecting the clusterhead is as follows.

Step 1 : from G, select one mobile node v as a clusterhead according to a certain rule.
Step 2 : delete node v and all its neighbors (i.e., all nodes in $N(v)$) from G.
Step 3 : repeat Steps 1 to 2 for the remaining nodes in G until G is empty.

The above three steps generate a set of clusterheads. In *Step 1*, the rule determines which node to be selected as the clusterhead. Different clustering algorithms define different rules, such as the lowest node-ID (Baker & Ephremides, 1981; Ephremides, Wieselthier, & Baker, 1987), the highest node-degree (Gerla & Tsai,

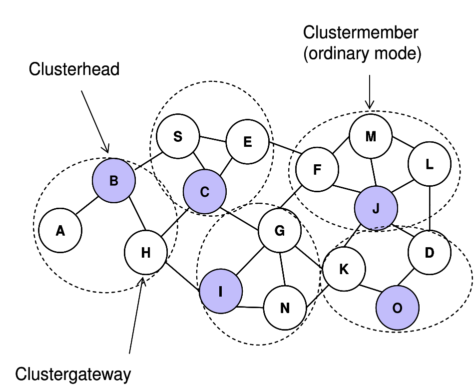

Fig. 1. Illustration of a cluster structure in a MANET.