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Distributed routing algorithms for multi-hop ad hoc networks using *d*-hop connected *d*-dominating sets

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Abstract

This paper describes a distributed algorithm (generalized *d*-CDS) for producing a variety of *d*-dominating sets of nodes that can be used to form the backbone of an ad hoc wireless network. In special cases (ordinary *d*-CDS), these sets are also *d*-hop connected and has a desirable "shortest path property". Routing via the backbone created is also discussed. The algorithm has a "constant time" complexity in the limited sense that it is unaffected by expanding the size of the network as long as the maximal node degree is not allowed to increase too. The performances of this algorithm for various parameters are compared, and also compared with other algorithms.
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1. Introduction

One of the important problems in ad hoc wireless networks is to find efficient and reliable routing algorithms. In such a network, the nodes are often mobile and routing requires a dynamic adaptation strategy. However, it is important to first study static ad hoc networks, such as sensor networks, and to devise good routing schemes for these. This static routing problem will be the focus of this article. There are several approaches to it. A commonly used general method is *cluster-based hierarchical* routing [3,7,8,11]. The network is divided into several clusters and from each cluster, certain nodes

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are elected to be clusterheads. These clusterheads are responsible for maintaining the routing information [1,4]. Each cluster can have one or more gateway nodes to connect to other clusters in the network. These gateway nodes ensure connectivity between all the clusters in the network.

Another approach, called *backbone-based* routing selects certain nodes from the ad hoc network which are similar to gateway nodes. These nodes form a connected dominating set and are responsible for routing within the network [5]. However, this backbone tends to be rather large. Our approach blends features of these two approaches with the intention of gaining the advantages of each. The set produced by our basic algorithm (d-CDS) is not connected and does not produce a traditional backbone. It is a d-hop connected d-dominating set with certain properties.

Each node in the network will obtain an awareness of the other nodes (including at least one backbone node) within d-hops of itself. This facilitates local routing. Once the backbone has been obtained, the backbone nodes are expected to exchange global routing information with each other, using local routing to communicate with each other through intermediary ordinary nodes.

After this, when an ordinary node wishes to send a message to another node that is more than d-hops away, it first polls the backbone nodes that are within d-hops of itself. These will indicate to the sender, the distances from themselves to the target. The sender can then determine which backbone node to use to send the message most expeditiously. The message will then be forwarded through the backbone, using local routing to move the message between consecutive backbone nodes, which will never be separated by a distance in excess of d. Moreover, if the backbone was formed using the d-CDS algorithm, then the path followed will be guaranteed to be a shortest possible path from the source to the target.

2. Definitions

Throughout this article, G will denote a connected graph, representing an ad hoc network. V denotes the set of all vertices in the graph G. The *distance* function in G will be denoted by δ. A vertex u in G is said to have *eccentricity* $e(u)$ if G has a vertex v such that $\delta(u,v) = e(u)$, and for all vertices w in G, $\delta(u,w) \leqslant e(u)$. The *radius* of G, $r(G)$, is the minimum of the eccentricities of its vertices.

G_d will denote the *d-closure* of G, by which we mean the graph whose vertices are the same as those of G, but which has an edge between two vertices u and v if and only if $0 < \delta(u,v) \leqslant d$. We call a subset D of the set of vertices of G a *d-dominating set* of G if it is a dominating set for G_d, that is, if every vertex of G is within a distance d of some vertex in D. A 1-dominating set is simply called a *dominating set*. We say that D is *d-hop connected* if it is connected in G_d.

We say a distributed algorithm is *constant-time* when its execution time does not depend on the number of nodes in the network, although it may depend on the maximum vertex degree. The algorithms to be introduced in this paper have this property.

3. Related work

Minimum connected dominating sets [6] have been used for backbone routing in wireless ad hoc networks. One of the earlier works was done by Das and Bharghavan who used minimum connected dominating sets (MCDS) as a virtual backbone to develop routing schemes for wireless ad hoc networks [5]. This virtual backbone may change with the movement of nodes and is used only for computing and updating routes. Their MCDS routing algorithm computes shortest possible paths for routes and updates routes soon after each node moves. Besides finding routes, their algorithm also supplies backup routes for temporary use while shortest paths are updated. Because their focus is on constructing a minimum connected dominating set, the overhead in setting up such a set is quite time consuming, when contrasted with other methods that merely settle for a reasonably small set. The dominating set induces a virtual backbone of connected vertices in the graph. Since it is connected and dominating, the set is likely to be very big for a network with a large number of nodes. Moreover, if some node

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