An Improved Distributed Algorithm for Connected Dominating Sets in Wireless Ad Hoc Networks

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Abstract. The idea of virtual backbone routing has been proposed for efficient routing among a set of mobile nodes in wireless ad hoc networks. Virtual backbone routing can reduce communication overhead and speedup the routing process compared with many existing on-demand routing protocols for routing detection. In many studies, Minimum Connected Dominating Set (MCDS) is used to approximate virtual backbones in a unit-disk graph. However finding a MCDS is a NP-hard problem. We propose a distributed, 3-phase protocol for calculating the CDS in this paper. Our new protocol largely reduces the number of nodes in CDS compared with Wu and Li's method, while message and time complexities of our approach remain almost the same as those of Wu and Li's method. We conduct extensive simulations and show our protocol can consistently outperform Wu and Li's method. The correctness of our protocol is proved through theoretical analysis.[1]

1 Introduction

A wireless ad hoc network is a particular type of wireless networks in which an association of mobile nodes forms a temporary network, without any support of fixed infrastructure or central administration. They are widely deployed for many applications such as automated battlefield operations, wireless conferences, disaster rescues, and connection to the Internet in remote terrain, etc. Mobile nodes can control connections and disconnections by the distances between them and the willingness to collaborate during the formation of short-lived networks. That means a connection is achieved either through a single-hop radio transmission if two nodes are located within wireless transmission range of each other, or through relaying by intermediate nodes that are willing to forward packets for them.

In this paper, we assume that a wireless ad hoc network is deployed in a two-dimensional space, and each mobile node is equipped with an omni-directional antenna which has an equal maximum transmission range. Thus the topology of such a wireless ad hoc network can be modeled as a unit-disk graph (UDG). "A graph is a

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unit graph if and only if its vertices can be put in one to one correspondence with equisized circles in a plane in such a way that two vertices are joined by an edge if and only if the corresponding circles intersect." [16]. A wireless ad hoc can be represented as a simple graph G (V, E), where V represents a set of mobile nodes and E represents a set of edges. An edge (u,v) in E indicates that nodes u and v are neighbors, and that u is within v's range of transmission, while v is within u's range.

Features of wireless ad hoc networks have posed a lot of challenges on routing protocols that are used to find a route to send a packet from a source to a destination. Mobility and lack of infrastructure cause topological changes within the network, therefore the volatility of network information is also increased. The property of limited bandwidth in wireless networks makes information collection very expensive and the power limitation factor leads to mobile nodes disconnecting frequently. Thus, an efficient and scalable routing scheme needs to be devised.

Routing protocols are classified into two main categories: topology-based and position-based. Topology-based routing protocols are based on the information concerning links [7,8,9,10,11]. In position-based routing protocols, mobile nodes know physical position information by geolocation techniques such as GPS [12,13,14]. Although a wireless ad hoc network has no fixed backbone infrastructure, many routing protocols propose the promising idea of virtual backbones such as cluster-based routing, backbone-based routing and spine-based routing [2,3,6,15]. The basic idea behind these types of algorithms is to divide a wireless ad hoc network into several small overlapping sub-networks, where each sub-network is a clique (a complete subgraph). Each sub-network has one or more virtual backbones to connect to other parts in the network. Virtual backbones are usually connected and form a dominating set of the corresponding wireless ad hoc network.

In general, a dominating set (DS) is a subset of vertices of a graph where every vertex that is not in the subset is adjacent to at least one vertex in the subset. A connected dominating set (CDS) is a dominating set that induces a connected subgraph. A virtual backbone plays a key role in routing as it simplifies the routing process to one in a smaller subgraph generated from the connected dominating set. Obviously, it is important to find a minimum connected dominating set (MCDS) of a given graph in order to reduce communication overhead, to increase the convergence speed, and to simplify the connectivity management. However, finding a MCDS is NP-complete for most graphs. Several distributed algorithms have addressed the problem of determining CDS in wireless ad hoc networks. Wu and Li [6] proposed a two-phase distributed algorithm for the construction of an approximation MCDS. The first phase is called marking process, where each node first broadcasts all IDs of its neighboring nodes to its neighbors, and after receiving two-hops information from all its neighbors it declares itself as a dominator if and only if it has two unconnected neighbors. The dominators form the initial CDS. In the second phase, the algorithm removes certain locally redundant nodes from the initial CDS. We notice that this algorithm does not mention any control messages to bridge the two consecutive stages. Further Wu's algorithm is outperformed by Das' algorithm when transmission range is very large. That means the reduction of cardinality of dominating sets is limited in dense network. The time and message complexities of this approach are $O(\Delta^2)$ and $O(\Delta n)$ respectively, where Δ is the maximum node degree and n represents the total number of vertices in graph G.