Computer Communications 36 (2013) 121–134

Contents lists available at SciVerse ScienceDirect

Computer Communications

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

Review

Connected dominating sets in wireless ad hoc and sensor networks – A comprehensive survey

Jiguo Yu [a,b,*], Nannan Wang [a], Guanghui Wang [c], Dongxiao Yu [d]

[a] School of Computer Science, Qufu Normal University, Rizhao, Shandong 276826, China
[b] Key Laboratory for Intelligent Control Technique of Shandong Province, Rizhao, Shandong 276826, China
[c] School of Mathematics and System Science, Shandong University, Jinan, Shandong 250100, China
[d] Department of Computer Science, The University of Hong Kong, Pokfulam Road, Hong Kong, China

ARTICLE INFO

Article history:
Received 3 March 2011
Received in revised form 13 October 2012
Accepted 18 October 2012
Available online 27 October 2012

Keywords:
Wireless network
Topology control
Virtual backbone network
Connected dominating set (CDS)

ABSTRACT

Topology control is a fundamental issue in wireless ad hoc and sensor networks. Due to intrinsic characteristic of flatness, hierarchical topology can achieve the scalability and efficiency of a wireless network. To solve this problem, one can construct a virtual backbone network by using a connected dominating (CDS) set of a wireless network. In past few years, efficiently and fast construct a CDS in a wireless network as a virtual backbone has been the main research problem in hierarchical topology control. In this paper, we give a comprehensive survey for CDSs and related problems with various network models and specific applications. To conclude, some open problems and interesting issues in this field are proposed.

1. Introduction

Wireless ad hoc networks are multi-hop, self-organizing autonomous networks, composed of some mobile terminals including radio receivers and transmitters. Cellular mobile communication networks and wireless local networks both need predefined fundamental network facilities such as base stations and access service stations. However, as a decentralized distributed control system, in a wireless ad hoc network, each subscriber possesses the functions of router and host. Thus, it is possible for convenient terminals to implement easy and rapid wireless communication. Wireless ad hoc networks do not rely on any existing or predefined network infrastructure, and terminal nodes randomly dispose. Therefore, how to guarantee high-quality signal communication when terminal nodes are mobile is a key problem in the research field. Wireless sensor networks are decentralized distributed systems. Numerous sensors are densely disposed in the monitor region with a random manner. Sensor networks are used to gather distributed information from a given location or region. These networks consist of tiny devices, each of which is equipped with a power source, a micro-controller, a wireless interface, a small amount of memory, and one or more sensors. The sensors are used for collecting physical parameters such as light intensity, sound, or temperature. Because of the limited radio communication range, sensor nodes communicate by wireless multi-hop routing via intermediate nodes. Wireless networks including wireless ad hoc networks and wireless sensor networks have been attracting more and more attentions in the recent years and they are being used in a variety of military and civil applications such as battle fields, disaster recoveries, conferences, concerts, environmental detections, health applications and so on. It is widely believed that wireless networks would be an ideal and important part of the next generation networks to provide flexible deployment and mobile connectivity.

In a dense and randomly deployed wireless network, in order to ensure a high regional coverage rate or the network redundancy for preventing node failure, many nodes are deployed in a small region. As the network contains many redundant nodes, some specific problems in wireless networks aggravate – mutual interference between the nodes, a variety of possible routing methods, a node directly communicates with distant nodes by using a larger power, the node consumes unnecessary energy, and the reuse of wireless bandwidth is limited. Even if the node moves with a short distance, routing protocols have to be recalculated. These features make the wireless network topology control become a greatly challenging problem. However, if we could control over certain node parameters and could change the mode of operation of the nodes randomly, the topology of the network could be changed and the lifetime of the network could be extended considerably.

* Corresponding author at: School of Computer Science, Qufu Normal University, Rizhao, Shandong 276826, China. Tel.: +86 633 3980462.
E-mail addresses: jiguoyu@sina.com (J. Yu), wangnanyb@163.com (N. Wang), ghwang@sdu.edu.cn (G. Wang), dxyu@cs.hku.hk (D. Yu).

0140-3664/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.comcom.2012.10.005

Once a wireless network is deployed, each node communicates with a subset of the nodes within a certain distance. Communication links are established between those nodes to ensure that the radio signal can be detected. These nodes and links establish the topology of the network. Topology control is the reorganization and management of node parameters and modes of operation from time to time to modify the topology of the network with the goal of extending its lifetime while preserving important characteristics, such as network connectivity and coverage [1]. Fig. 1 from [1] shows the classification of topology control protocols.

Changing the transmission power of the nodes reduces the network topology, saves energy, and increases the lifetime of the network while preserving connectivity and coverage. However, the approach cannot prevent the transmission of redundant information when several nodes are close to each other and may not simplify the network topology enough to make wireless networks scalable for large deployments [1]. In the hierarchical topology construction approach, a subset of nodes is selected as a communication layer, and only the nodes in the communication layer transmit data, greatly reducing the transmission of redundant information, simplifying the topology of the network, saving the energy for information gathering and filtering, routing and forwarding information required.

In a traditional computer network, the key of the scalability and efficiency is that the network infrastructure is a hierarchical structure. Most broadcasting, activity scheduling, and sensor area coverage algorithms rely on the concept of backbone. A backbone is a subset of nodes that is able to perform data communication tasks and to serve nodes that are not in the backbone. However, due to lack of infrastructure, wireless ad hoc and sensor networks are inherently flat. In order to achieve the scalability and efficiency of a wireless network, it is necessary to construct a virtual network base station to organize the network into a hierarchical structure. We call this virtual network base station as a virtual backbone of the network (VBN). A virtual backbone can be used as a spine for routing in a network. The nodes which are responsible for routing are limited to the nodes in the backbone, which greatly reduces routing overhead. VBN also has an important role in broadcasting.

A connected dominating set (CDS) of a graph corresponding to a wireless network is usually used as a virtual backbone of the network [2]. A dominating set (DS) D of a graph G is a subset of V, and each node in $V \setminus D$ is adjacent to at least one node in D. A CDS C of a graph G is a DS of G, and the subgraph $G[C]$ induced by C is connected. CDSs have been used as the basic structure for the MAC, multicast/broadcast, location-based routing, energy conservation, resource discovery protocol and so on. The specific applications are as follows.

- A CDS can create a virtual network backbone for packet routing and control [3]. Messages can be routed from the source to a neighbor in the dominating set, along the CDS to the dominator closest to the destination node, and then finally to the destination. This is called dominating set based routing, backbone based routing, or spine based routing. Restricting the routing to the CDS greatly reduces the message overhead for updating the routing information [4]. Furthermore, the dominating set can be organized into a hierarchy to further reduce control message overhead [5–7].
- The efficiency of multicast/broadcast routing can also be improved through the CDS. A great problem in multicast/broadcast routing is that many intermediate nodes unnecessarily forward a message. Nodes often receive the same message multiple times. This is the broadcast storm problem [8]. If the message is routed along a CDS, most of the redundant broadcasts can be eliminated [9–14].
- CDSs play an important role in power management. Each node in a wireless network is limited by the battery energy. Using a CDS can ensure to add more nodes in an sleep mode, while preserving the ability of the network to forward messages [15–18]. CDSs have also been used to balance the network management requirements to conserve energy among nodes.
- In addition, the virtual backbone formed by a dominating set can also be used to propagate link quality information for route selection for multimedia traffic [7], or to serve as database servers [19] and so on.

In recent years, many new ideas, algorithms and simulators for CDSs have been emerged. For the CDS construction algorithms, the size of CDSs, fault-tolerant, energy-saving, and mobile maintenance have been studied deeply. In this paper, we review a large

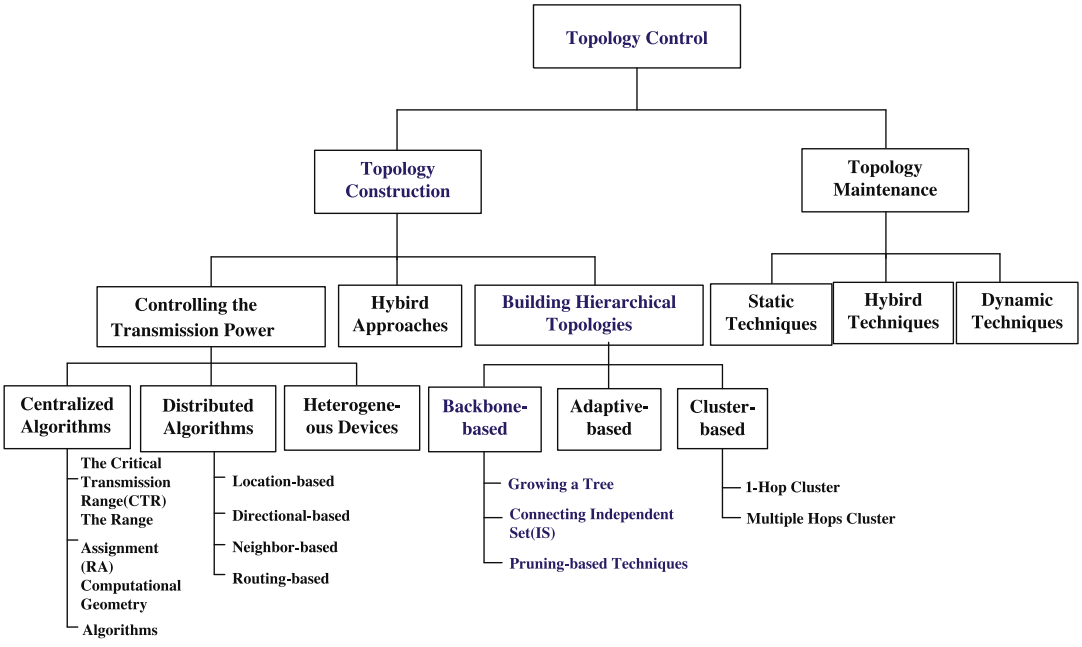

Fig. 1. Classification of topology control protocols.