Ad Hoc Networks 42 (2016) 61–73

Contents lists available at ScienceDirect

Ad Hoc Networks

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

Construction of minimum connected dominating set in wireless sensor networks using pseudo dominating set

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ARTICLE INFO

Article history:
Received 11 June 2015
Revised 31 January 2016
Accepted 1 February 2016
Available online 17 February 2016

Keywords:
Connected Dominating Set (CDS)
Maximal independent set (MIS)
Wireless sensor networks
Unit disk graph (UDG)
Steiner Tree

ABSTRACT

In a wireless network, messages need to be sent on in an optimized way to preserve the energy of the network. A minimum connected dominating set (MCDS) offers an optimized way of sending messages. However, MCDS construction is a *NP-Hard* problem. In this paper, we propose a new degree-based greedy approximation algorithm named as Connected Pseudo Dominating Set Using 2 Hop Information (CPDS2HI), which reduces the CDS size as much as possible. Our method first constructs the CDS and then reduces its size further by excluding some of the CDS nodes cleverly without any loss in coverage or connectivity. The simulation results show that our method outperforms existing CDS construction algorithms in terms of both the CDS size and construction cost. CPDS2HI retains the current best performance ratio of $(4.8 + \ln 5)|opt| + 1.2$, $|opt|$ being the size of an optimal CDS of the network, and has the best time complexity of $O(D)$, where D is the network diameter. To the best of our knowledge this is the most time efficient and size-optimal CDS construction algorithm. It has a linear message complexity of $O(n\Delta)$, where n is the network size and Δ is the maximum degree of all the nodes.

1. Introduction

Wireless ad hoc and sensor networks are popularly used in the health-care industry, food industry, agriculture and also in a wide range of military applications such as search and rescue, disaster control [1], etc. They form an important part of the next generation network in providing flexible deployment and mobile connectivity. Unlike wired networks or cellular networks, no physical backbone infrastructure is required in wireless ad hoc and sensor networks, thus offering new paradigms for routing. Wireless networks consist of either static nodes or mobile nodes or a mixture of both. Each node, contains an omnidirectional antenna, which broadcasts messages to all the nodes within its transmission range. Therefore, through broadcasting, a node can reach all of its nearby nodes with one emission. If communicating nodes are not within the single hop radio transmission range of each other, then a communicating session is established through multi-hop links by some intermediate nodes for relaying messages (multi-hop routing). One simple and intuitive method for multi-hop routing between non-adjacent nodes in wireless networks is flooding, in which each node retransmits a packet only once after receiving it. However, owing to the low available bandwidth of the wireless channels and the redundant retransmissions generated through pure flooding, the latter is not used as a communication mechanism in wireless networks. The most popular means of multi-hop routing in wireless networks is through the use of a

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http://dx.doi.org/10.1016/j.adhoc.2016.02.003
1570-8705/

virtual backbone. In this article, we mainly focus on constructing a size optimal Connected Dominating Set (CDS) as a virtual backbone of the network. A CDS is more particularly used as a data aggregation backbone in remote data gathering applications to optimize network communication, which in turn saves communication energy and extends the network lifetime [2].

A Dominating Set of a network is a subset of nodes such that any node not in the subset is a neighbour of some element of that subset. It forms a Connected Dominating Set, if the subgraph induced by this set is connected. In a wireless network, as there is no fixed infrastructure and centralized management, a CDS can be used as a virtual backbone or spine for efficient routing and connectivity management in such networks [3]. The CDS can receive a packet from any node in the network and can retransmit it to any other remote node. A node, which is not in the CDS can send a message to any other node through the CDS nodes. It first sends its message to one of its neighbouring CDS nodes. Now, the search space for any route is reduced to the CDS. If the destination node is within the CDS it can get the message directly, otherwise it gets the message from one of its neighbouring CDS nodes. Thus, during routing, broadcasting responsibility lies only with the CDS nodes, instead of all the nodes in the network. As only the CDS nodes maintain routing information, we can save the storage space by reducing the CDS size. A small sized CDS makes the routing easier, reduces the communication overhead, increases the convergence speed and simplifies connectivity management. So, it is desirable to construct a minimum connected dominating set (MCDS) of the network. However, computing MCDS is an NP-complete problem [4]. So, only polynomial time approximation algorithms are practical for finding out MCDS in wireless networks. For energy constrained wireless networks, an approximation algorithm should not only construct thinner CDSs, but also construct CDSs with low computation and communication costs. Generally, the quality of the CDS is measured by its approximation factor, which is the ratio of its size to that of the MCDS. The construction cost is measured by overall message and time complexities. The computation time of the CDS should also be appreciably small in order to schedule speedy switches between disjoint CDSs to extend battery lifetime and optimize power consumption [5,6].

Although theoretically any centralized algorithm can be implemented in a distributed fashion, with the tradeoff of higher protocol overhead, distributed algorithms are very important for sensor networks and MANETs. CDS must be constructed efficiently to be applicable in a mobile or large scale network. Due to the dynamism of wireless links and nodal mobility, algorithms should rely on limited knowledge of the current network topology. However, for applications where node mobility is rare, centralized CDS construction algorithms are very useful. In those applications, once the topology of the entire network is known to a particular node (may be the sink node), it can construct the CDS without waiting for the information from the other nodes in every step.

In this paper, we propose a new centralized degree-based greedy approximation algorithm which we name as **C**onnected **P**seudo **D**ominating **S**et Using **2**-**H**op **I**nformation (CPDS2HI) to construct smaller CDSs. The preliminary version of our technique is described in [7]. Our scheme CPDS2HI works in three phases. In the first phase, a smaller maximal independent set (MIS), designated as a pseudo-dominating set (PDS) is constructed. The dominating set is pseudo dominating set because some of the elements may be omitted in the final dominating set. The second phase of our algorithm constructs an improved Steiner Tree which interconnects the PDS nodes in an improved way. In the final phase, some of the selected PDS nodes are excluded cleverly to reduce the CDS size further without any connectivity or coverage loss. Through simulation we also show that our proposed algorithm CPDS2HI, outperforms all the existing CDS construction algorithms in terms of CDS size and construction costs. CPDS2HI retains the current best performance ratio of $(4.8+\ln 5)|opt|+1.2$, $|opt|$ being the size of an optimal CDS of the network, and has the best time complexity of $O(D)$, where D is the network diameter. To the best of our knowledge this is the most time efficient and size-optimal CDS construction algorithm. It also has a linear message complexity of $O(n\Delta)$, where n is the network size and Δ is the maximum degree of all the nodes.

One concern of using CDS as virtual backbone is the nodes present in the CDS face the problem of early exhaustion of their battery life. To avoid this situation we need to rotate the CDS periodically. So the proposed CDS construction algorithm can be used in conjunction with CDS rotation algorithms [5]. A customised rotation algorithm might work better than a general one. However, evaluation of rotation schemes and possible development of a customised rotation scheme is beyond the scope of the current work.

The rest of the article is organized as follows. Section 2 provides some preliminary definitions. In Section 3, we discuss related works on CDS construction. Section 4 lists the motivation behind this work and its contributions. Section 5 explains our algorithm in detail. Section 6 provides the analysis of our algorithm. Supporting simulation results are given in Section 7. Our conclusions are finally presented in Section 8.

2. Background

In this section, we discuss the preliminary concepts that are relevant to our work.

Definition 2.1 (DOMINATING SET)**.** A dominating set (DS) for a graph $G(V, E)$ is a subset $V' \subseteq V$ such that each node in $V - V'$ is adjacent to at least one node in V'. The nodes in the dominating set are called **dominators**.

Definition 2.2 (CONNECTED DOMINATING SET)**.** A Connected Dominating Set (CDS) is a dominating set that induces a connected subgraph. The non-CDS nodes in the graph are called **dominatees**.

Definition 2.3 (MAXIMAL INDEPENDENT SET)**.** An independent set of nodes in a graph is a subset of nodes such that no two nodes in the subset are adjacent. A maximal independent set is an independent set which cannot be