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Review

# A1: An energy efficient topology control algorithm for connected area coverage in wireless sensor networks

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ABSTRACT

Energy consumption in Wireless Sensor Networks (WSNs) is of paramount importance, which is demonstrated by the large number of algorithms, techniques, and protocols that have been developed to save energy, and thereby extend the lifetime of the network. However, in the context of WSNs routing and dissemination, Connected Dominating Set (CDS) principle has emerged as the most popular method for energy-efficient topology control (TC) in WSNs. In a CDS-based topology control technique, a virtual backbone is formed, which allows communication between any arbitrary pair of nodes in the network. In this paper, we present a CDS based topology control algorithm, A1, which forms an energy efficient virtual backbone. In our simulations, we compare the performance of A1 with three prominent CDS-based algorithms namely energy-efficient CDS (EECDS), CDS Rule K and A3. The results demonstrate that A1 performs better in terms of message overhead and other selected metrics. Moreover, the A1 not only achieves better connectivity under topology maintenance but also provides better sensing coverage when compared with other algorithms.



**Contents**



## 1. Introduction

Wireless sensor networks continue to be a very popular technology to monitor and act upon events in dangerous or risky places for humans. WSNs are easy to deploy in an application field and the cost is relatively low by the continuing improvements in

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embedded sensor (Very-large-scale integration) VLSI and wireless radio technologies (Dow et al., 2005).

Although WSNs have evolved in many aspects, they continue to be networks with constrained resources in terms of energy, computing power, and memory. In addition, nodes have limited communications capabilities, due to which a source node can cover only within its maximum transmission range. On the other hand, it causes nodes to relay messages through intermediate nodes to reach their destinations. Due to this reason, routing related tasks become much more complicated in WSNs since their is no predefined physical backbone infrastructure for topology control. This drawback motivates a virtual backbone to be employed in a WSN. Conceptually, a virtual backbone is a set of active nodes, which can send message to the destination by forwarding the message to other neighboring active nodes. These set of active nodes provides many advantages to network routing and management. This is due to the reason that routing path get reduced to the set of active nodes only, which provides an efficient fault-tolerant routing. Moreover, the reduced topology reacts quickly to topological changes and is less vulnerable in terms of collision problems caused due to flooding based routing algorithms (Ni et al., 1999).

Ephremides et al. (1987) and Guha and Khuller (1998) introduced the first approximation algorithms to compute a virtual backbone using a Connected Dominating Set (CDS). Since then, CDS based topology control (TC) has emerged as the most popular method for energy-efficient (TC) in WSNs. TC has two phases namely: *topology construction* and *topology maintenance*. In the topology construction phase, a desired topological property is established in the network while ensuring connectivity. Once the topology is constructed, topology maintenance phase starts in which nodes switch their roles to cater for topological changes. In CDS-based TC schemes, some nodes are a part of the virtual backbone, which is responsible for relaying packets in the WSN. These nodes are also called dominator nodes or active nodes. Non-CDS nodes or dominates relay information through the active nodes. Hence, a CDS works as a virtual backbone in the reduced constructed topology.

The CDS size remains the primary concern for measuring the quality of a CDS. Mohammed et al. (2005) and Kim et al. (2009) prove that a smaller virtual backbone suffers less from the interference problem and performs more efficiently in routing and reducing the number of control messages. Moreover, this allows the maintenance of the CDS much easier and provides better reliability for a fixed probability of success. Due to these reasons, most research studies in this area focus on reducing the size of a CDS (Wan et al., 2002; Alzoubi et al., 2002a, 2002b; Wang et al., 2009; Wu et al., 2007, 2006; Feeney and Nilsson, 2001; Yuanyuan et al., 2006; Wightman and Labrador, 2008). However, most studies do not consider the impact of topology maintenance, under which many nodes gets disconnected from sink node. This is due to the reason that for small virtual backbones, fewer nodes handle the bulk of the network traffic and consequently deplete their batteries quickly. This causes the reduction in the virtual backbone size, which effects the coverage region of WSN.

In this paper, we propose a distributed topology control algorithm for wireless sensor networks. The algorithm, referred to as the A1, models the topology as a connected network and finds the set of active nodes to form a CDS. The A1 uses node IDs of different nodes and a node selection criteria for nodes to calculate their timeout. In this way, nodes turn-off themselves and later repeat the process – after the timeout expires – to discover neighbors desiring them to work as an active node. In this way, a reduced topology is formed while keeping the network connected and covered. To achieve energy efficiency, the A1 forms the CDS comprising of high energy nodes in a single phase construction process. In addition, it also forms a proportionate set of active nodes in order to provide better sensing coverage. Moreover, it adapts to the topological changes in the network based on the remaining energy of the nodes. This allows better topology maintenance among different set of nodes, which increases the network lifetime.

We compare the performance of the A1 with Energy Efficient CDS (EECDS) (Yuanyuan et al., 2006), CDS Rule K (Wu et al., 2006) and A3 (Wightman and Labrador, 2008) algorithms. For this purpose, we perform extensive simulations under varying network sizes to analyze the message complexity and energy overhead in terms of spent energy and remaining energy in the CDS. We also analyze the performance of the algorithms under topology maintenance to verify the nodes connectivity in terms of number of unconnected nodes. As the primary task of a WSN network is to provide sensing coverage of the area, we also evaluate the performance of the algorithms on connected sensing area covered at the end of topology maintenance. The results show the proposed A1 has low message complexity. Moreover, it also provides better residual energy resources while having less number of unconnected nodes under topology maintenance. In addition, the A1 has better connected sensing area and it covers 35% more area when compared with the other three algorithms.

The rest of this paper is organized as follows. Section 2 summarizes the related work in this area. We explain the A1 algorithm in Section 3. In Section 4, we explain the empirical evaluation framework utilized for the performance analysis of A1. Section 5 shows the discussion on simulation results with sensing coverage analysis of the algorithms. We summarize the salient findings of this paper in Section 6.

## 2. Related work

The CDS based topology construction in WSNs has been studied extensively. Some of the existing algorithms (Ramanathan and Rosales-Hain, 2000) consider using the transmission power of WSN nodes to achieve energy efficiency while some used geographical location of the nodes (Rodoplu and Meng, 1999). However, power control and location awareness are difficult to realize in practical WSN deployments. Similarly, constructing CDS for heterogeneous networks by using directional antennas is proposed in Yang et al. (2007). In directional antenna models, the transmission/reception range is divided into several sectors and one or more sectors can be switched on for transmission. However, it is difficult to realize these schemes in case of WSNs. We now explain some of the relevant CDS based research efforts in the area.

In an undirected graph, a Maximal Independent Set (MIS) is also a Dominating Set (DS). Most of the distributed algorithms find an MIS and connect this set to form a CDS. Wan et al. (2002) and Alzoubi et al. (2002a, 2002b) first proposed distributed algorithms for constructing CDSs in unit disk graphs (UDGs), which consists of two phases to form the CDS. They form a spanning tree and then utilize nodes in the tree to find an MIS. At start, all the nodes in an MIS are colored black. In the second phase, more nodes are added which have a blue color to connect the black nodes to form a CDS. Later, Yuanyuan et al. (2006) proposed an Energy-Efficient CDS (EECDS) algorithm that computes a sub-optimal CDS in an arbitrary connected graph. They also use two phase strategy to form a CDS. The EECDS also uses a coloring approach to build the MIS. The EECDS algorithm begins with all nodes being white. An initiator node elects itself as part of the MIS coloring itself black and sending a Black message to announce its neighbors that it is part of the MIS. Upon receiving this message, each white neighbor colors itself as gray and sends a Gray message to notify its own White neighbors that it has been converted to gray. Therefore, all white nodes receiving a Gray message are neighbors of a node that does not belong to the MIS. These nodes need to compete to