Receiver-based CDS Algorithm for Wireless Networks*

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Abstract. Energy savings and topology control are inherent tasks of many wireless sensor networks. Sensors are assumed to be randomly deployed and shall organize themselves independently after deployment. Moreover, sensor networks shall operate as long as possible warranting network connectivity. To deal with these tasks we propose the maintenance of a virtual backbone where a fuzzy logic control (FLC) engine is proposed to handle the local backbone access over time. Nodes not participating in the backbone shutdown their radios and go to sleep for a certain time.

1 Introduction

A distributed event detection and tracking framework intrinsically performs application specific tasks such as distributed localization, observer determination, in-network processing, etc. Additionally, such a application needs topology control and routing to supply a communication infrastructure that runs as energy efficient as possible. To support this communication infrastructure we propose the maintenance of a virtual backbone built by a connected dominating set (CDS). The CDS thereby adapts itself to local energy distributions and node conditions in the network. A fuzzy logic control (FLC) engine is proposed to handle the local backbone access over time. Nodes not participating in the backbone shutdown their radios and go to sleep for a predefined long sleep period. In this work we discuss our current approach and outline directions of future research.

The new idea of our approach is to consider multiple properties of the nodes, such as their movement pattern, energy level, and distance to known backbone nodes and make local decisions based on that information.

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2 Related work

There exist a number of approaches that enable the selective disconnection of redundant nodes. ASCENT [1] and SPAN [2] both are distributed and randomized algorithms where nodes make local decisions on whether to sleep, or to join a forwarding backbone. Both schemes demand periodical information exchange among the network nodes to identify the redundant nodes that may go to sleep. Neither SPAN nor ASCENT do consider the movement patterns of the nodes or their locations and are thus not able to make advantage of this information. In GAF [3] nodes form virtual clusters where redundant nodes are timely disconnected from the network. The state of the nodes bases on global virtual positions. The main drawback of GAF is that it does not adapt to the network topology and the nodes individual energy state.

Another set of algorithms determine a connected dominating set (CDS) of a given network graph. The algorithm proposed by [4] first determines a CDS that consists of all nodes which have at least two non-adjacent neighbors. To reduce this CDS two pruning rules are introduced. In [5] the authors enhance their algorithm with the possibility of considering a node's remaining energy level instead of its link degree. In [6] a CDS is built in two phases. In a first step a maximal independent set (MIS) is constructed. In a second step a set of nodes connecting the MIS is determined. The resulting set of nodes builds a CDS. The approach of [7] converges in only one algorithmic step. Each node receiving a dominator message determines a timer based on the number of not yet covered downstream nodes. As soon as a timer expires the node enters the CDS and broadcasts a dominator message. Nodes that do not reach additional nodes cancel their timer and become dominated.

3 Receiver-based CDS algorithm

In this section we introduce our approach, discuss the current state and outline future research directions. In order to set up a virtual backbone nodes have to periodically exchange control messages with each other. The control messages may thereby be enhanced with the node's ID, link degree, position, energy level, and velocity. Based on this information, nodes make decisions like accessing the backbone or determining neighbors to take over their operation in the backbone.

3.1 Preliminaries

A dominating set (DS) of a graph $G = (V, E)$ is a subset $V' \subset V$ where each node in $V - V'$ is adjacent to some node in V'. A connected dominating set (CDS) is a dominating set which builds a connected subgraph of G. To minimize the number of set members it is desirable to find a minimum connected dominating set (MCDS) of G what is however shown to be NP-complete [8]. Moreover, the MCDS does not reflect energy distributions and need of updates within the network. We propose a distributed approximation algorithm that aims on efficiency and network adaptivity.

The decision whether a node enters the CDS is done in a distributed manner based on a fuzzy logic control engine (FLC). The advantage of using a FLC engine is that energy distributions, node movement patterns, etc. are included in the dominator election. Thus, we hope to get a more flexible algorithm that adopts to the current network state and allows the election of the most appropriate nodes in the backbone. Including the movement patterns of the nodes we can prioritize nodes moving at slow speed, thus prematurely excluding nodes with an increased probability of affecting the backbone connectivity in the near future. To derive a node's speed pattern we need the support of location information what we assume to be satisfied by most sensor network applications as they are intrinsically location dependent.

3.2 Setting up the connected dominating set

In this section we describe the CDS algorithm. The FLC engine in not yet implemented and we discuss the CDS construction solely based on the node degree. In the future we will substitute this operations with a FLC engine.

The CDS setup is considered as a graph coloring problem. Initially, all nodes are white. The base station starts the CDS algorithm, coloring itself black and broadcasting a DOMINATOR message. This message contains the node's ID and a list of its neighbors. Thus, each node receiving the DOMINATOR message is able to check if it covers additional nodes. Each node overhearing this DOMINATOR message broadcasts a DOMINATEE message containing a copy of the DOMINATOR message. All nodes that are two hops away from the last elected dominator and overhear a DOMINATEE message compare their

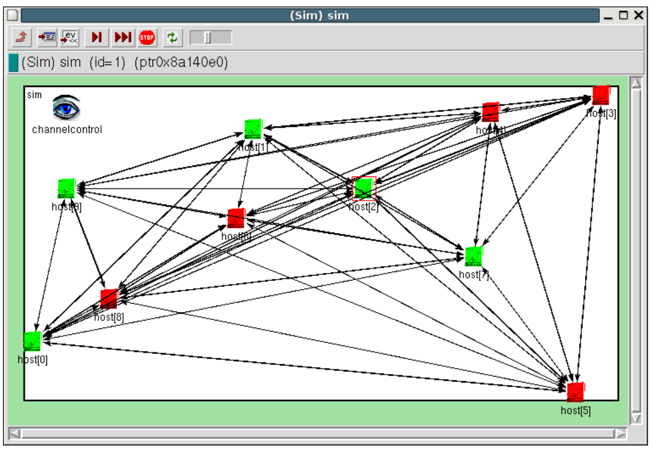

Fig. 1: Receiver-based CDS construction: Colors indicate different node states. Green nodes are dominators, red nodes dominated.

own neighborhood information with the neighborhood information of the last dominator. Based on that information they determine one of their upstream neighbors as dominator, prioritize it, and schedule a DOMINATOR_ELECTED message for it. This message is delayed according to the priority of the elected node. Nodes with only one path to the last dominator are favored and therefore get a higher priority. If multiple paths exist one of them is randomly chosen.

The algorithm terminates as soon as no white nodes remain. Our algorithm is receiver-based and an approximation of the MPR protocol [9] which is used for an efficient broadcast in the OLSR routing protocol [10]. In contrast to MPR our CDS algorithm does not depend on the knowledge of any two-hop neighborhood information. The algorithm described so far is implemented in the OMNeT++ network simulator [11]. An example is depicted in Fig. 1.

Currently we are implementing the replacement of the link based election scheme with the FLC-based election scheme. The link based dominator election seems to have a good MCDS approximation factor. However, the algorithm is inflexible in terms of energy distributions and node movement patterns. To deal with these conditions we expect good results applying a FLC engine.

3.3 Local Path adaptation

In this section we propose a local path adaptation scheme to support local backbone updates. After the CDS setup, all dominated nodes go to sleep for a given amount of time. After this sleep period a dominator may decide to maintain or abandon its work in the backbone. To ensure network connectivity, neighboring dominators that intend to release their backbone job concurrently have to negotiate who remains in the backbone and who goes to sleep. This is achieved using a timer depending on the node's priority. The priority is again derived from the FLC engine that considers the node's speed, location, node degree, etc. The dominator with the shortest delay informs its neighbors and determines the nodes that take over its dominator function in the CDS. Three cases may occur:

1. If there exists a node with a high priority that interconnects all neighboring dominators it is elected and all relevant nodes are informed about the new status.
2. If there is no node with a high priority that connects to all dominators, but there is a set of nodes that interconnect all dominators, chose the most appropriate subset and inform all affected nodes about that election.
3. If there exists at least one dominator that is no longer covered after the disconnection of the node inform the base station to reinitiate the whole CDS algorithm.

A node estimates the connectivity among neighbor nodes by knowing their coordinates. Thus, a node does not need to know its two-hop neighborhood information, which implies high overhead for many applications. A further advantage of applying fuzzy logics is the possibility to 'weaken' nodes that are close to the transmission range. As we base our local update computations on the assumption of circular transmission ranges we may run into problems when having irregular transmission ranges.

4 Conclusions and future work

One of the reasons to propose a topology control mechanism is the need of having an energy efficient backbone structure that supplies routing information for our event detection framework [12]. In the current state it seems that the CDS algorithm is performed efficiently and the MCDS approximation factor of the algorithm looks promising. In our future work we will implement the FLC engine and substitute the current link-based decision making process with it. We will furthermore analyze and evaluate the resulting simulations and refine our protocol based on these insights. To get indications on the performance of our approach we will implement other approaches and compare them to ours. Finally, we will implement the whole event detection and tracking framework, including the virtual backbone, in a real testbed and investigate the impacts and the performance under real world conditions.

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