Ad Hoc Networks 11 (2013) 2512–2525

Contents lists available at ScienceDirect

Ad Hoc Networks

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

Energy constraint clustering algorithms for wireless sensor networks

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ARTICLE INFO

Article history:
Received 10 February 2012
Received in revised form 26 February 2013
Accepted 15 May 2013
Available online 25 July 2013

Keywords:
Sensor networks
Dominating set
Routing protocols
Clustering

ABSTRACT

Using partitioning in sensor networks to create clusters for routing, data management, and for controlling communication has been proven as a way to ensure long range deployment and to deal with sensor network shortcomings such as limited energy and short communication ranges. Choosing a cluster head within each cluster is important because cluster heads use additional energy for their responsibilities and that burden needs to be carefully passed around among nodes in a cluster. Many existing protocols either choose cluster heads randomly or use nodes with the highest remaining energy. We present an Energy Constrained minimum Dominating Set based efficient clustering called ECDS to model the problem of optimally choosing cluster heads with energy constraints. Our proposed randomized distributed algorithm for the constrained dominating set runs in $O(\log n \log \Delta)$ rounds with high probability where Δ is the maximum degree of a node in the graph. We provide an approximation ratio for the ECDS algorithm of expected size $8H_{\Delta}|OPT|$ and with high probability a size of $O(|OPT| \log n)$ where n is the number of nodes, H is the harmonic function and OPT means the optimal size. We propose multiple extensions to the distributed algorithm for the energy constrained dominating set. We experimentally show that these extensions perform well in terms of energy usage, node lifetime, and clustering time in comparison and, thus, are very suitable for wireless sensor networks.

1. Introduction

As sensor networks mature and are used in many applications, the necessity arises for new and improved energy efficient protocols and algorithms. Each sensor has a limited amount of energy available for sensing, processing and communicating. Combined with other limited resources such as processing power, radio bandwidth and memory, new energy efficient clustering protocols and distributed processing algorithms need to be developed for wireless sensor networks. These protocols need to work within this limited environment while achieving their goals.

In most applications of wireless sensor networks, it is impossible to replace batteries in order to extend the lifetime of the network. Adding additional sensors may be a possibility in some situations, but not in cases such as battlefield deployment. This illustrates the need for protocols which extend the lifetime of the network by reducing the communication via the on-board radio which is the most expensive operation of the sensor nodes. In radio communications, the signal strength decreases proportionally to the square of the propagation distance. In other words, to have the same signal strength reach twice the distance, four times the amount of energy is required.

Routing protocols which organize the network into clusters have been shown to greatly improve the network

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http://dx.doi.org/10.1016/j.adhoc.2013.05.016

lifetime [1] due to reduced power consumption. Clustering can be easily made scalable, and is robust in face of node failures [2–4]. A good clustering scheme takes into account one or more of the following: communication range, number and type of sensors, geographical location, and remaining energy [5]. Clustering protocols need to make two important decisions, one is the cluster head selection and the other is which nodes to assign to which cluster head.

A robust cluster head selection is important because cluster heads spend more energy on aggregating and forwarding messages, doing general route maintenance and some other similar actions. A smaller set of cluster heads may not be optimal in terms of network lifetime. As in such a case, a cluster head uses additional energy and could be depleted much sooner than other nodes. On the otherhand, more cluster heads may mean that each cluster head has less work to do and each cluster head may survive a longer amount of time. Choosing too many cluster heads will negate the positive effects of clustering. The dominating set problem models the optimization problem of finding a small number of cluster heads. Consider the graph shown in Fig. 1. Each node starts with the same amount of energy (7 units) (Fig. 1(a)) and one unit is used for each receive or send. The cluster head aggregates the received messages into one outgoing message. The optimal dominating set is one node (Fig. 1(b)), but the network becomes disconnected after only one time step. On the other hand a slightly non-optimal dominating set using the heuristic "Don't give a cluster head more than three nodes" results in a network that survives two time steps as shown in Fig. 1(c) and (d) (the shaded nodes represent the cluster heads).

Thus, cluster head selection in wireless sensor networks benefits from using a dominating set approach. Dominating set clustering can be executed in a constant number of rounds which leads to better clustering [6]. In a dominating set approach each node is either a cluster head or one hop from a cluster head [7]. This can be extended to allow nodes to be at most k-hops from its cluster head. Allowing for k-hops within a cluster improves scalability in very large networks. Very large networks, even when clustered will exhibit problems similar to unclustered smaller networks [8]. Energy Constrained minimum Dominating Set (ECDS) models the problem of optimally choosing cluster heads with energy constraints. The distributed ECDS algorithm run in $O(\log n \log \Delta)$ rounds with high probability (whp) where n is the number of nodes. Experimental evaluations also showed that the distributed algorithm is very well suited for wireless sensor networks. Motivated by the above example shown in Fig. 1, we improve the Energy Constrained Dominating Set Algorithm as follows:

- We introduce a simplified ECDS (sECDS) algorithm. sECDS improves the performance of ECDS by modifying the candidate selection. In sECDS candidate selection is based on the constrained span unlike ECDS which uses the rounded constrained span. This decreases the number of candidates selected at each round and leads to fewer but larger clusters. The sECDS algorithm is described in Section 4.2.
- We introduce a k-hop cluster ECDS (kECDS) algorithm. In kECDS a node can be up to k hops from its cluster head. kECDS just like sECDS and ECDS uses multi-hop from the cluster heads to the base station. Allowing for k-hops within a cluster leads to larger clusters and fewer small clusters. Section 4.3 provides the details of the kECDS algorithm.
- We introduce an extension to the ECDS algorithm which allows each node to have multiple cluster heads. Our mECDS algorithm works with multipath routing to improve reliablity and efficiency. Section 4.4 provides the details of the mECDS algorithm.
- We provide extensive simulations using TOSSIM [9] in Section 5. We compared the performance of the sECDS and kECDS algorithms to ECDS and HEED [10]. HEED selects cluster heads according to residual energy and node proximity to neighbors or node degree. ECDS uses local information about the connectivity of each node and the connectivity of its neighbors in addition to the residual energy to decide which node should become a cluster head. The ECDS algorithms take less time and fewer rounds to cluster, allowing more messages to reach the base station. For our scenarios in this study, sECDS clusters in 2.5 rounds, kECDS clusters in 1 round and ECDS in 2, compared to 4 rounds for HEED. The number of cluster heads, the size of the clusters and

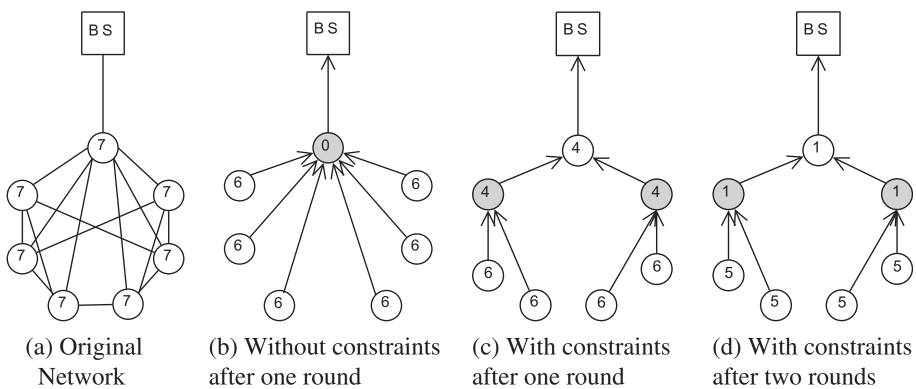

Fig. 1. Energy constraint clustering example.