A New Virtual Backbone forWireless Ad-Hoc Sensor Networks with Connected Dominating Set

Reza Azarderakhsh, Amir H. Jahangir, Manijeh Keshtgary

To cite this version:

Reza Azarderakhsh, Amir H. Jahangir, Manijeh Keshtgary. A New Virtual Backbone forWireless Ad-Hoc Sensor Networks with Connected Dominating Set. WONS 2006 : Third Annual Conference on Wireless On-demand Network Systems and Services, INRIA, INSA Lyon, Alcatel, IFIP, Jan 2006, Les Ménuires (France), pp.191-195. inria-00001024

HAL Id: inria-00001024
https://hal.inria.fr/inria-00001024

Submitted on 30 Jan 2006

A New Virtual Backbone for Wireless Ad-Hoc Sensor Networks with Connected Dominating Set

Reza Azarderakhsh, Amir H. Jahangir and Manijeh Keshtgary*
Department of Computer Engineering
Sharif University of Technology, Tehran,Iran
azarderakhsh@ce.sharif.ac.ir, jahangir@sina.sharif.ac.ir, keshtgar@mehr.sharif.ac.ir

Abstract

A wireless Ad-hoc sensor network consists of a number of sensors spread across a geographical area as a collection of sensors that form an ad-hoc wireless network. Sensors are very tiny devices that their primary function is to sense the target, convert the signal into a suitable data format, and pass on the data to a command node. These sensor nodes are very heavily constrained in processing power, and have a limited energy supply. Since energy is such a scarce resource, several algorithms have been developed at the routing and MAC layers to utilize energy efficiently and extend the lifetime of the network. First layer of the sensor networks is the infrastructure layer and there is no backbone for these networks. In this paper, we propose a virtual backbone for these networks and we measure the network lifetime and survivability as the performance evaluation metrics of the proposed model.

1. Introduction

Sensor networks have attracted recent research attention due to wide range of applications in civil and military settings [9]. The sensors can be deployed in large numbers in wide geographical areas and can be used to monitor, detect and report time-critical events like earthquakes, chemical spills, or the position of moving objects [1]. These sensors are typically disposable and are expected to last until their energy drains. Their small size factor limits their processing and communication abilities. Energy is the scarcest resource for such nodes, and it has to be managed wisely to extend the lifetime of a sensor for the duration of the mission. Sensors are equipped with data processing and communication abilities. The former consists of a sensing circuit that captures data from the target environment and converts them into an electrical signal. The signal is then transmitted via radio transmitter to a command center either directly or through a data concentration center (gateway). The gateway can perform fusion of data received from the sensors and also filtering out the erroneous data, before passing it on to the command center. These data processing and communication activities are the main consumers of a sensor's energy. A battery-operated sensor cannot be kept active all the time since this will deplete its energy resources quickly. The sensor should be notified on when exactly to turn on its circuitry for performing various functions like sensing, transmitting and receiving data. This is done at the MAC layer by a TDMA scheme, in which each sensor is allotted a time slot for performing its duties [9, 7] or other routing like span [3]. The sensor turns off its circuitry when its time slot has passed to conserve energy. A properly designed slot allocation scheme can extend the lifetime of sensors. The energy consumed for transmitting data increases with the distance between the communicating parties. Thus, the sensors that are located at longer distances from the gateway or command center will die out more quickly than those at shorter distances. Instead of having the longer distances sensors transmitting directly to the gateway, certain sensors in between can be used as the forwarding agents. Transmitting data over these much shorter distances leads to substantial power savings at sensors. This approach is at the routing layer, and requires efficient algorithms to dynamically establish routes between sensor nodes. Using connected dominating set in wireless sensor network is a new method for saving energy consumption.

The rest of the paper is structured as follows. We next describe preliminaries on connected dominating set. Section 3 describes the related work. We present our proposed algorithm in section 4. Simulation results are used to evaluate the model in Section 5. Finally Section 6 concludes the paper.

---

* Instuctor at Shiraz University of Technology

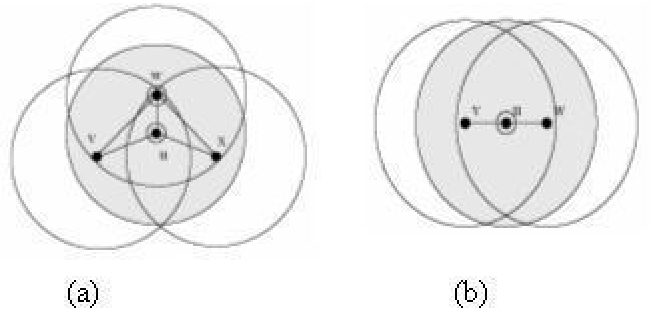

Figure 1: Example of Ad-hoc network

2. Preliminaries

An ad-hoc network can be presented by a unit disk graph where every vertex (host) is associated with a disk connected at this vertex with the same radius (transmitter range) [4]. Two vertices are neighbors if and only if they are covered by each others disk. For example, both vertices v and w in Figure 1(b) are neighbors of vertex u because they are covered by disk u, while vertices v and x in Figure 1(a) are not neighbors. In an Ad-hoc network, some links (edges) may be unidirectional due to the disparity of energy levels of hosts. Therefore a general Ad-hoc wireless sensor network can be considered as a directed graph with a high percentage of bidirectional links.

Routing in wireless Ad-hoc sensor networks is harder than in wired networks, due to the limited resource, network mobility, and lack of physical infrastructure. Virtual infrastructures, such as a Connected Dominating Set (CDS), were proposed to reduce the routing overhead and enhance scalability [5]. In dominating set, every vertex in the graph is either in the set or adjacent to a vertex in the set. Vertices in dominating set are also called gateways while vertices that are outside a dominating set are called non-gateways. Among CDS based routing protocols, only gateways need to keep routing information in a proactive approach and the search space is reduced to the dominating set in a reactive approach [10].

Unfortunately, finding a minimum connected dominating set is NP-complete for most graphs. Wu and Li proposed a simple and efficient approach called marking process which can quickly determine a CDS [10]. This approach was first proposed for undirected graphs using the notion of dominating set only and was later extended over directed graphs by introducing another notion called absorbent [11]. Specifically, each host is marked if it has two unconnected neighbors. It is shown that collectively these hosts achieve a desired global objective - a set of marked hosts forms a small CDS. Based on the marking process, vertices u and w in Figure 1(b) are marked and they form a dominating set in their network. The CDS derived from the marking process is further reduced by applying two dominant pruning rules. According to dominant pruning rule 1, a marked host can unmark itself if its neighbor set is covered by another marked host; that is if all its neighbors are connected with each other via another gateway, it can relinquish its responsibility as a gateway. In Figure 1(b), either u or w can be unmarked (but not both). According to rule 2, a marked host can unmark itself if its neighborhood is covered by two other directly connected marked host. The marking process 1 and 2 are purely localized algorithm where the marker of host depends on topology of small vicinity only [10].

We propose a connected dominating and a clustering algorithm in the MAC layer that can increase the lifetime and survivability of the wireless sensor network.

3. Related Work

Das et al. [6] proposed an algorithm to identify a sub network that forms a minimum CDS (MCDS). This algorithm finds a CDS by growing a tree T starting a vertex with the maximum vertex degree, and adding a new vertex to T according to its effective degree (number of neighbors that are not neighbors of T). The main drawback of this algorithm is its centralized style. The mesh scheme [2] designates a subset of border members as gateways so that there is exactly one virtual link between two neighboring clusters.

Wu and Dai's [10] marking process uses a constant number of rounds to determine a CDS. This approach can be applied to Ad-hoc sensor networks with bidirectional link only. In this paper, we introduce a model to develop a virtual infrastructure for wireless senor networks. Our algorithm consists of 2 phases: First, we cluster sensor nodes using clustering algorithm and then we implement the CDS algorithm to intra clusters.

4. Our Proposed Method

We propose a way to making a virtual infrastructure for wireless sensor network with connected dominating set and its optimization methods in addition to a clustering method for sensor nodes. The wireless sensor nodes are densely deployed in the space. Therefore, if we can cluster them with their gateways (cluster head), the network life time and survivability increases and the routing algorithm will be easy [8, 9]. Lifetime of a sensor network is defined as the time after which certain fraction of sensor nodes run out of their batteries, resulting in a routing hole within the network. The sensor network is divided into separate regions known as clusters. A cluster is nothing but a gateway and a set of sensors that communicate with that gateway. Dividing a network into clusters has the advantage of reducing routing overhead. Since there are fewer sensor nodes in a cluster, the computation of routes is much faster. The number of clusters in the network is equal to the number of gateways, since there is one gateway for each cluster. After clustering the network into a subset of clusters with the proposed algorithm, then we use the CDS finding algorithm. In the simulation, we show that the network lifetime and packet overhead are optimized. We use the packet drop probability as the performance metrics parameter.

4.1. Clustering Algorithm

The main objective of our approach is to cluster sensor network efficiently around few high-energy gateway nodes. The clustering algorithm is responsible for dividing the whole network topology into clusters. The algorithm takes the set of sensor nodes and gateways, and partitions them such that there is one gateway and a subset of the set of nodes in each cluster. Clustering enables network scalability to large number of sensors and extends the life of the network by allowing the sensors to conserve energy through communication with closer nodes and by balancing the load among the gateway nodes. Gateways associate cost to communicate with each sensor in the network. Clusters are formed based on the cost of communication and the load on the gateways. Network setup is performed in two stages; 'Bootstrapping' and 'Clustering'. In the bootstrapping phase, gateways discover the nodes that are located within their communication range. Gateways broadcast a message indicating the start of clustering. We assume that receivers of sensors are open throughout the clustering process. Each gateway starts the clustering at a different instance of time in order to avoid collisions. In reply the sensors also broadcast a message with their maximum transmission power indicating their location and energy reserve in this message. Each node discovered in this phase is included in a range set per gateway. Bootstrapping a sensor network is the processing of establishing inter-node links and forming an overall network topology. Bootstrapping typically consists of two phases:

- Node Discovery: unless the nodes are manually placed, nodes are not aware of their peers and thus should at least discover their neighbors.
- Topology Setup: Based on the established links among neighboring nodes, a network topology should be established to allow for data gathering.

In the clustering phase, gateways calculate the cost of communication with each node in the range set. This information is then exchanged between all the gateways. After receiving the data from all the other gateways each gateway start clustering nodes based on the communication cost and the current load on its cluster. When the clustering is over, all the sensors are informed about the ID of the cluster they belong to. Since gateways share the common information during clustering, each sensor belongs to only one cluster. For inter-cluster communication all the traffic is routed through the gateways. The clustering algorithm may use a number of metrics to determine how to form clusters [12]:

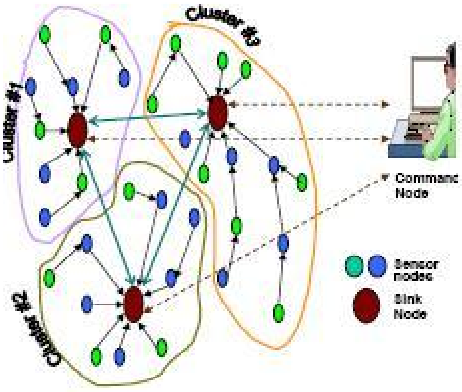

Figure 2: Clustering Nodes in sensor network

- Physical distance of a sensor node from the sensor. In this case, the sensor node determines the nearest gateway and reports to that gateway.
- Equal number of sensors in each cluster. This ensures that each gateway has equal routing overhead.
- Redundancy assurance. A sensor may determine that there exists more than one gateway within transmission range. It chooses one gateway and joins that cluster, and keeps the others as backups. Thus, this algorithm may change the cluster formation due to factors such as gateway failure.

As shown in Figure 2, at first, sensor nodes are clustered into clusters and then the CDS algorithm is applied to the clustered network. The algorithm that has been used in our approach uses the proximity-based metrics. Thus, each sensor node chooses the nearest gateway and joins that cluster. As shown in Figure 2, all sensors find their Euclidian distance from the gateways and join them. After clustering sensor nodes in clusters with cluster head or gateways, the CDS finding algorithm is used in each cluster.

4.2. CDS Algorithm

An Ad-hoc wireless sensor network with unidirectional links can be represented by a simple directed graph $G = (V, E)$, where V is a set of vertices (hosts) and E is a set of directed edges (unidirectional links). A directed edge directed from u to v is denoted by an ordered pair (u,v). A directed graph G is strongly connected if for any two vertices u and v , a (u,v)-path, i.e., a path connecting u to v, exists. If (u, v) is an edge in G, we say that u dominates v, and

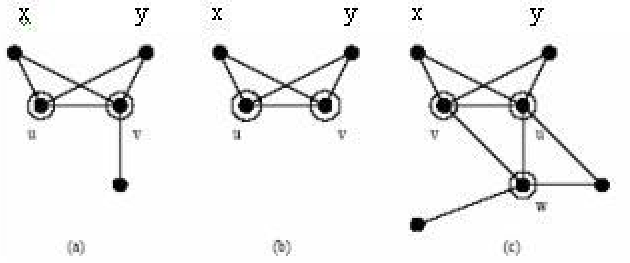

Figure 3: Dominating Set Reduction examples

v is the absorbent of u. The dominating neighbor set Nd (u) of vertex is defined as

$$Nd(u) = \{w : (w, u)\epsilon E\} \tag{1}$$

The absorbent neighbor set Na(u) of vertex u is defined as

$$Na(u) = \{v : (u, v)\epsilon E\} \tag{2}$$

and N(u) represents the neighbor set of vertex u:

$$N(u) = Nd(u)UNa(u) \tag{3}$$

Suppose the marking process is applied to the network that is redrawn in Figure 3(a). Host u will be marked because (x,u) belongs to E and (u,y) belongs to E, but (x,y) doesn't belong to E. Host v will also be marked. All other hosts will remain unmarked because no such pair of neighbor hosts can be found. The marking process is as below:

Algorithm 1: Marking Process[2]

1. Each u periodically exchanges its neighbor set Nd(u) and Na(u) with all its neighbors.
2. u sets its marker to T (marked) if there exist two neighbors v and w of u such that (w,v) belongs to E, and (u,v) belongs to E and (w,v) does not belong to E.

Initially vertices are unmarked. They exchange their open neighborhood information with their one-hop neighbors. Therefore each node knows all of its two-hop neighbors. The marking process uses the following simple rule: any vertex having two unconnected neighbors is marked as a dominator. The set of marked vertices form a connected dominating set, with lots of redundant nodes. Two pruning rules are provided to post-process the dominating set, based on the neighborhood subset coverage. A node u can be taken out from S, the CDS, if there exists a node v with higher ID such that the closed neighbor set of u is a subset of the closed neighbor set of v. For the same reason, a node u will be deleted from S when two of its connected neighbor in S with higher IDs can cover all u's neighbors. This idea is also extended to directed graph. Due to differences in transmission ranges of wireless networks, some links in Ad-hoc wireless network may be unidirectional. In order to apply this to a directed graph like sensor network model, neighboring vertices of a certain node are classified into a dominating neighbor set and an absorbent neighbor sets in terms of the directions of the connected edges.

5. Simulations

The simulation has two different parts. One is the Connected Dominating Set algorithm used by Ji and Dai in [2] to simulate the connected dominating set reduction in Ad-hoc wireless sensor networks and we extend it by adding the clustering algorithm to it. The second part is a general wireless sensor network simulator. To generate a random Ad-hoc network, n hosts are randomly placed in a restricted 100*100 (meter)area. The transmitter range R is adjusted according to the average vertex degree d to produce nd/2 links in the corresponding unit disk graph. Most of these links are treated as bidirectional, but a small portion (p%) of them are randomly selected to be unidirectional links. Networks that cannot form a strongly connected graph are discarded. For each combination of parameters (n, d and p), the simulations repeated 500-2000 times until the confidence interval is sufficiency small (+/-1% for the confidence level of 90%).

For simulating the clustering of sensor nodes in the network, we make a network with below entities: Sensor nodes, Gateways, Clusters, Packets, Packet Queues, Targets, User-interface Events, Event Queues. This calls for an object-oriented design approach to the simulator. Each entity is modeled by a separate object that encapsulates its functionality. These objects represent a high-level decomposition of the sensor network allowing us to establish the interactions between the entities. Our metrics are the energy consumption per node, the average energy consumption within overall network, and network lifetime [6]. The average energy consumption for a uniformly 10-cluster network is less than 50uj, as can be seen in Figure 4. In Figure 5, we can see that fewer than 30 % of the sensors consumed more than 50uj. The density of gateways can be increased to reduce the average energy consumption.

6. Conclusions and Future Work

We have presented a virtual infrastructure backbone for wireless sensor network with the concept of connected dominated graph and we measure the network energy consumption as an important parameter to evaluate network lifetime. To our knowledge this is the first time that a sensor network introduced with clustering and infrastructure

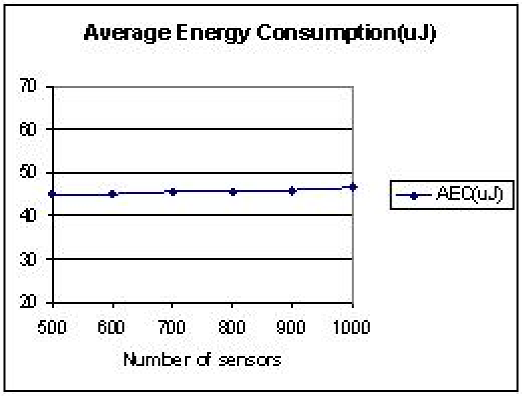

Figure 4: The average energy consumed by sensors in a network with 10 clusters.

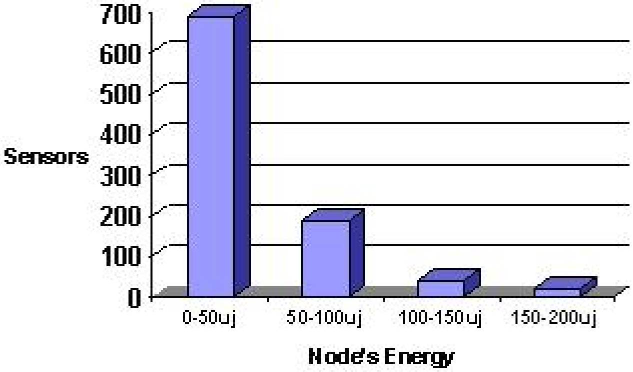

Figure 5: Distribution of sensor energy consumption with our approach

concepts together. In our simulation, we can decompose the wireless sensor network in an object oriented way and we can measure other parameters like Packet Drop Probability (PDP) as a network survivability metrics for our future work. We will also focus on evaluating survivability of the sensor networks considering PDP and network lifetime parameters.

References

[1] Akyldiz, I., Su, W., Sankarasubramaniam, Y. and Cayiroici, E. " A survey on Sensor Network, " IEEE Communications Magazine, vol. 40, Issue:8, pp. 102-114,August 2002.

[2] Arisha, K., Youssef, M. and Younis, M., "Energy-Aware TDMA-Based MAC for Sensor Networks," in the Proceedings of the IEEE Workshop on Integrated Management of Power Aware Communications, Computing and Networking (IMPACCT 2002), New York City, New York, May 2002.

[3] Chen, B., Jamieson, K., Balakrishnan H. and Morris, R. "Span: an Energy-Efficient Coordination Algorithm for Topology Maintenance," in Proc.of the 7th Annual International Conf. on Mobile Computing and Networking, July 2001.

[4] Clerk, B. N. and Colbourn, C. J. " Unit Disk Graph ," Discrete Mathematics, Vol. 86, pp. 165-177, 1990.

[5] Dai, F. and Wu, J. "'An extended localized algorithm for connected dominating set formation in ad hoc wireless networks"', IEEE Transactions on Parallel and Distributed Systems, 15(10):908-920, Oct. 2004.

[6] Das, B. and Sivakumar, R. "Routing in Ad-hoc networks using a spine," Proc. Of ICCN, PP 1-20, Sept 1999.

[7] Heinzelman, W., Kulik, J. and Bakakrishnan, H. " Negotiation -based Protocols for Disseminating in Wireless Sensor Network," in Proc. Of the 5th Annual ACM/IEEE International Conf. on Mobile Computing and Networking, 1999.

[8] Lindesy, S. and Raghavendra, C. " PEGASIS : Power-Efficient Gathering in Sensor Information System," International Conf.'on Communications, 2001.

[9] Servetto, S. and Barrenechea, S. "Constrained Random Walks on Random Graphs: Routing Algorithm for Large Scale Wireless Sensor Netwotks," in Proc. of the 1st ACM International Workshop on Wireless Sensor Networks and Applications, Atlanta, Georgia, USA, 2002.

[10] Wu, J. and Dai, F. "' A distributed formation of a virtual backbone in manets using adjustable transmission ranges"', In Proc. of ICDCS, pages 372-379, Mar. 2004.

[11] Younis, M., Youssef, M. and Arisha, K. "Energy-Aware Routing in Cluster-Based Sensor Networks", in the Proceedings of the 10th IEEE/ACM International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS2002), Fort Worth, Texas, October 2002.

[12] Younis, M., Youssef, M. and Arisha, K. "Energy-Aware management in Cluster-Based Sensor Networks," The International Journal on Computer Networks, Vol. 43, No. 5, pp. 649-668, December 2003.