Distributed Asynchronous Clustering for Self-Organisation of Wireless Sensor Networks

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This paper presents a fully distributed asynchronous clustering protocol for the self-organisation of a wireless sensor network into an infrastructure of well separated cluster heads that supports in-network processing, routing, and deployment. In this protocol, nodes volunteer asynchronously for cluster head duty and use a radio beacon to pre-emptively recruit members. Limited beacon range is used as the primary parameter for self-organisation. The resulting topology substantially reduces total transmission distance and the expected energy consumed by radio communication. To further extend network lifetime and capability, well separated cluster heads may be easily located and replaced by more powerful devices.

1. INTRODUCTION

In this paper we present a hierarchical clustering protocol designed for a large scale Wireless Sensor Network (WSN) of thousands of power constrained data sources, one base station (“sink”), and a data gathering application that continuously monitors the network for an aggregate value such as the mean temperature recorded by all sensors. Sensor network design may be influenced by many factors [1], and each device may differ in terms of its capabilities [2]. However, the fundamental challenge is to reduce the energy consumed by radio communication such that network lifetime is maximised given the application’s quality of service (QoS) guarantees.

The Distributed Asynchronous Clustering (DAC) protocol provides an effective, low cost solution to an essential problem: how to generate a near optimal number of well separated cluster heads in a wireless deployment. DAC solves this problem by using local knowledge of the network and its environment to distribute cluster heads and terminate their generation. As a result, this protocol has many desirable properties.

Fully distributed: Autonomous cluster heads use a limited range radio beacon to recruit members.

By utilising local information, such as the relative strength of radio signals from nearby cluster heads, sensor nodes are able to make decisions that move network topology toward a global optimum. Such decentralised systems are more scalable and more robust against individual node or link failures [3]. Adaptive: The probability of a node volunteering for cluster head duty depends on its power level, its beacon range may depend of factors such as network density, and the shape of each cluster depends on the radio propagation environment. Self-terminating: It stops after all nodes have decided to be either a cluster head or a cluster member. Low overhead: Clustering requires minimal communication of infrastructure data.

We implemented a simulator to model the impact of clustering on communication costs. In particular, we modeled the impact of clustering on transmission distance for the benchmark task. We assumed that a protocol that reduced distance more effectively in our simulator would also reduce the energy used by radio communication more effectively in a real deployment.

We compared the performance of DAC with another low overhead protocol, LEACH [4,5], and a hypothetical k-means [6,7] protocol. We found that DAC required fewer cluster heads to clus-
formation based on periodic data from all nodes.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [15] was designed to be near optimal in terms of energy cost for data gathering applications. In their protocol, chain(s) of communication are built from neighboring nodes. When the authors compared protocols, they let PEGASIS use CSMA and forced LEACH to use TDMA. We note that to make a valid comparison, both protocols should be tested using the same MAC layer protocol. In summary, PEGASIS assumes that all nodes have global knowledge of the network, and energy savings come with a penalty of increased delay.

Bandyopadhyay and Coyle [16] proposed a fast, randomised, distributed algorithm for organising mobile sensors into a hierarchy of clusters. Their algorithm was designed to generate one or more levels of stable clusters with an optimal number of cluster heads on each level.

Distributed Energy-efficient Clustering Hierarchy Protocol (DECHP) [17] outperformed LEACH [5] in simulations partly because LEACH cluster heads communicate directly with the base station, while DECHP used multi-hop routing. Energy consumption was assumed to be proportional to distance $d^4$, so their simulation did not make a fair comparison. LEACH and multi-hop are not mutually exclusive, so a better comparison would require that both protocols use the same form of routing. While DECHP is an interesting protocol that addresses some of the problems associated with LEACH and other clustering protocols, its setup phase requires a large amount of communication overhead.

The Hybrid Energy-Efficient Distributed clustering protocol (HEED) presents fully distributed approach to promoting network lifetime [20] where each node uses local information to generate well separated cluster heads and elects cluster heads based on their residual energy.

5. CONCLUSION

We have presented DAC, a low overhead, energy efficient approach to distributed asynchronous clustering. In order to make straightforward and fair comparisons with other protocols, we assumed direct communication between nodes, and one level hierarchical clusters. Multi-hop routing and $n$ level hierarchical clusters may provide additional energy savings and, depending on the application, many other optimisations are possible and compatible with DAC.

Based on our simulations, we observed that the number of cluster heads that minimises transmission cost depends on a number of parameters including the radio model and base station location, but cluster head beacon range had by far the greatest impact. We noted that because limited wireless channel bandwidth must be shared by all clusters, a protocol should self-organise the network such that clustered network distance is minimised with as few cluster heads as possible. In light of these observations, similar protocols may need about twice as many cluster heads as DAC where our standard network parameters, the $d^2$ radio model and a limited beacon range are assumed.

DAC uses a range limited cluster head beacon and pre-emptive recruitment to generate well separated cluster heads; it automatically stops generating cluster heads after all sensors have been recruited. This not only reduces communication costs, but also promotes connectivity via cluster heads, i.e., sensors should not be “orphans” when high capacity nodes are within range. Well positioned cluster heads may be replaced by more powerful devices to facilitate small-world properties.

The benefits of DAC increased with the scale of the network, and with the cost of radio communication. DAC builds an infrastructure for in-network processing and routing via cluster heads [18] that extends the lifetime of large scale networks.

REFERENCES


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