Enhancing Clustering in Wireless Sensor Networks with Energy Heterogeneity

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ABSTRACT

While wireless sensor networks (WSN) are increasingly equipped to handle more complex functions, in-network processing still requires the battery-powered sensors to judiciously use their constrained energy so as to prolong the elective network life time. There are a few protocols using sensor clusters to coordinate the energy consumption in a WSN, but how to deal with energy heterogeneity remains a research question. The authors propose a modified clustering algorithm with a three-tier energy setting, where energy consumption among sensor nodes is adaptive to their energy levels. A theoretical analysis shows that the proposed modifications result in an extended network stability period. Simulation has been conducted to evaluate the new clustering algorithm against some existing algorithms under different energy heterogeneity settings, and favourable results are obtained especially when the energy levels are significantly imbalanced.

Keywords: Clustering, Energy Heterogeneity, Life-Time, Three-Tier Energy Setting, Wireless Sensor Networks

1. INTRODUCTION

Wireless communication technologies continue to grow in diverse areas to provide new opportunities for business data networking and services. One fast-moving area is wireless sensor networks (WSN). With the advances in micro-electro mechanical systems, sensor devices can be built as small as lightweight wireless nodes. Wireless sensor networks (WSN) are highly distributed networks of such kind of sensor nodes, and have been deployed in large numbers to monitor production systems, and natural or social environments. There is a growing need for the nodes to handle more complex functions in data acquisition and processing, and energy saving solutions remains a major requirement for these battery-powered sensor nodes.

A sensor node consists of three sensor subsystems (Qing et al., 2006): the environment sensor; the data processor that performs local computations on the data sensed, and the communicator that performs information exchange between neighbouring nodes. Each

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sensor is usually limited in their energy capacity, processing power, memory capacity and sensing capabilities. However, a network of these sensors gives rise to a robust, reliable and accurate network.

Many studies on WSNs have been carried out (Akyildiz et al., 2002a, 2002b; Baronti et al., 2007; Younis & Fahmy, 2004). WSN technologies are continuously finding new applications in various areas, such as in battle field surveillance, patient monitoring in hospital wards, and environmental monitoring in disaster prone areas. Although these sensors are not as reliable or as accurate as the expensive macro-sensors, their small size and low cost have enabled applications to network hundreds and thousands of these micro-sensors to achieve greater performance (Heinzelman et al., 2002). It is noted that, to maintain a reliable information delivery, data aggregation and information fusion are necessary for efficient and effective communication between these sensor nodes. Only processed and concise information should be delivered to the sinks or ‘actuators’ to reduce communications energy and to prolong the effective network lifetime. More in-depth discussions on the design issues of in-network processing and data aggregation can be found in Karl and Wilig (2007).

However, one of the key issues that merit attention is the energy heterogeneity in sensor networks (Mhatre & Rosenberg, 2004). To some extent energy heterogeneity among WSN nodes is inevitable. It occurs when there is significant energy difference between an individual sensor and its neighbours, either caused by the introduction of new sensors or re-energization of sensor nodes, or by network settings which may be necessary for some applications, e.g., different nodes having different sensor functions and hence different batteries. An inefficient use of the available albeit heterogeneous energy among the nodes will lead to poor performance and short lifecycle of the network. Despite some progress made in solving this problem, energy heterogeneity remains a challenge to WSNs. We present a modified algorithm for properly distributing sensor energy and ensuring prolonged network life time. Our algorithmic approach operates in a WSN under a modelling of three-level energy heterogeneity that controls the probability of conducting data transmission. Simulation results show an improvement in the effective network life time, and increased robustness of performance in the presence of energy heterogeneity.

The remainder of this paper is organized as follows. We briefly review related work in Section 2. The network model and the cluster formation mechanism are presented in details in Section 3 and the pattern of energy consumption within the clusters is examined. We then present our proposed clustering protocol in Section 4. The simulation results are presented in Section 5. Finally, we conclude the paper and highlight some future directions for further research.

2. RELATED WORK

Clustering techniques have been employed to deal with energy management in WSNs. Low Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman et al., 2002) is a pioneering work in this respect. LEACH is a clustering-based protocol, using randomized election and rotation of local cluster base station (so-called ‘cluster-heads’ for transferring data to the sink node) to evenly preserve the energy among the sensors in the network. The rotation of cluster heads can also be a means of fault tolerance (Abbasi & Younis, 2007). However, the LEACH protocol is not heterogeneity-aware, in the sense that when there is an energy difference to some extent between sensor nodes in the network, the sensors die out faster than a more uniform energy setting (Smaragdakis & Bestavros, 2004). In real life situation it is difficult for the sensors to maintain their energy uniformly, which makes energy imbalance between nodes to occur easily. LEACH assumes that the energy usage of each node with respect to the overall energy of the system or network
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