Power-Aware Sensor Selection in Wireless Sensor Networks

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1. Introduction

Wireless sensor networks (WSNs) have become active research topics recently both in academia and industry. Sensors of various types are deployed ubiquitously and pervasively in varied environments such as office buildings, wildlife reserves, battle fields, mobile networks, etc., to accomplish some high-level tasks [1][2]. One of the most significant benefits of sensor networks is that they extend the computation capability to physical environments where human beings can not reach. However, energy possessed by sensor nodes is limited, which becomes the most challenging issue in designing sensor networks. The main power consumptions in sensor networks are computation and communication between sensor nodes. In particular, the ratio of energy consumption for communication and computation is typically in the scale of 1000. Therefore it is critical to enable collaborative information processing and data aggregation to prolong the lifetime of sensor networks. In other words, we should carefully select sensor nodes to participate in the task.

Several methods have been proposed recently to enable collaboration of sensor nodes in data collection and information processing in order to minimize power consumption [3]-[6]. Local greedy algorithms have been developed in [4] and [6] to select the next most informative sensor node based on information utility and entropy respectively. The problem, however, is that if the optimal path is always chosen, the nodes along the path will deplete energy more quickly than others, which greatly affects the network lifetime [7]. Instead, Shah and Rabaey [5] proposed that sometimes sub-optimal paths should be chosen depending on the probabilities to elongate the whole network lifetime. On the other hand, the accuracy of target status can not be guaranteed and it adds latency and computation load by tracing back the path to store the average cost. Another algorithm called “max-min zPmin” has been developed in [3]. Their strategy involves partitioning the networks into zones and computing the power level, which may increase the overhead and lead to the degradation of the performance of the network.

This paper proposes a novel power-aware method for sensor selection, integrating the idea of information utility measurement with power-awareness and synergistically considering three key factors: sensing quality, communication cost and power level. Further, towards a full-fledged autonomic sensor network by applying *Autonomic Computing* technologies, the proposed method enables an important feature of autonomic sensor networks [8], i.e. self-optimization, optimizing the parameters of the objective function adaptively to improve the performance and maintain the energy level of local clusters in a systematic manner.

2. Methodology

In a typical wireless sensor network, sensors are networked to achieve some specific task, e.g. tracking objects. These nodes are severely constrained in energy and in most case can not be recharged. Thus minimizing the communication costs between sensor nodes is critical to prolong the lifetime of sensor networks. Another important metric of sensor networks is the accuracy of the sensing result of the target in that several sensors in the same cluster can provide redundant data. Because of physical characteristics such as distance, modality, or noise model of individual sensors, data from different sensors can have various qualities. Therefore the accuracy depends on which sensor the leader node selects. As shown in **Figure 1**, the leader node, *ln*, sends querying requests to the sensors within its range to localize the target, *T*. Suppose that after comparing the information and communication cost among *A*, *B* and *C*, *ln* decides to invoke *A* at time t_1. Successively it is highly possible that the same node would be selected repeatedly. As a result, *A* would die earlier than other nodes in the local cluster, which reduces the network lifetime and may cause the network partition.

Therefore an alternative approach is that we can tradeoff between the quality of sensed data and power stored in candidate nodes to decide the next sensor. It is desirable that leader nodes can obtain informative sensing data form the neighboring nodes. Meanwhile by balancing energy of all the sensor nodes the system could be maintained in the same order of power as long as possible so as to maximize the lifetime of the entire system.

2.1. Power-aware sensor selection measurement

The main idea of power-aware sensor selection is based on three factors: (i) information that can be transferred from candidate sensors; (ii) communication cost; (iii) power stored in candidate nodes. The problem is how to formulate the criteria for a leader node to select the best sensor that provides satisfied data of the target and balances the energy level among all sensors in a local cluster as shown in **Figure 1**.

We define a combinative measurement for node *i*, denoted as λ_i, which is given by

$$\lambda_i = \alpha\phi(Zi) - \beta\vartheta(j,i) + \chi\varepsilon(i) \tag{1}$$

where $\phi(Zi)$ is the information utility of node *i*; $\vartheta(j,i)$ represents the communication cost between the leader node *j* and *i*; $\varepsilon(i)$ reflects the current energy level in node *i*. Essentially, it is intended to improve the sensor selection and routing efficiency.

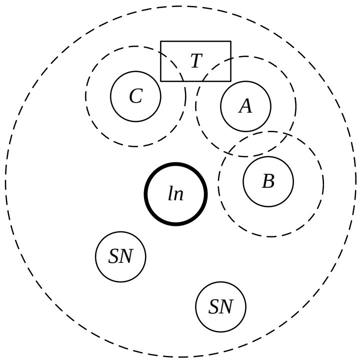

Figure 1. Sensor selection in a cluster. *T* is the target and *ln* is the leader node of the cluster. Sensors A, B and C can sense *T*. *SN* represents a sensor node in the cluster.

As we can see from the above equation, the value of $\varepsilon(i)$ will decrease, when node *i* is selected frequently. Although in the successive time sequence, *i* can still provide better sensing data than other nodes in the cluster, to prolong the system lifetime as a whole, other nodes should be chosen in a power-aware fashion. In the case when *i* is the gateway of two neighboring clusters, the energy depletion of node *i* can lead to the degradation of the performance of the whole sensor network.

Intuitively the coefficients in equation (1) balance the significance of three items. Now the problem becomes whether these coefficients should be fixed or adaptive. We prefer to the latter because of the flexibility of sensor networks with respect to topology, noise model, movement of sensors or targets, etc. This will be discussed later. In order to select the best sensor based on equation (1), the objective is to choose the node *i* so that

$$i = arg_{\, i \in N} \; max \, \lambda \qquad (2)$$

where N is the set of remaining sensor nodes to which the leader node sends querying requests.

2.2. Self-optimization

The previous subsection presents the power-aware sensor selection scheme. To implement such a system, an important issue is that the proposed method should have the capability of self-optimization to adapt three coefficients in equation (1). Traditionally the three coefficient should satisfy $\alpha + \beta + \chi = 1$ and $\alpha, \beta, \chi \le 1$. Moreover, it is critical to choose appropriate values for them at runtime. A promising solution is to make sensor networks self-optimizable, which is one of the key characteristics of *Autonomic Computing*. We first define system utility, u_s, for a local cluster at time *t* as the sum of all the combinative measurements of sensor nodes,

$$u_{s,t} = \sum_{i=1}^{N} \lambda_i \qquad (3)$$

The system utility reflects the system state at time *t*. For a specific task, a set of thresholds and corresponding values of α , β and χ are predefined. For example, if the value of $u_{s,t}$ is small or below a certain threshold, which indicates that the energy of the local cluster decreases, χ should be assigned a larger value compared to α and β. In this case, the leader node will tend to select the nodes with more energy.

As introduced in [9], the main function of self-optimization is to adaptively tune system parameters to keep systems performing correctly and efficiently. With such capability the leader node is able to seek ways to improve the balance of three parameters. Since the main function of leader nodes is to collect and relay information, instead of sensing, the benefit of the adaptive scheme greatly outweighs the consumption of computation and energy. Moreover, since the leader node can select the appropriate sensor node according to the adaptive coefficients, our method also eliminates the communication costs of these parameters between candidate nodes and the leader node. The whole bandwidth can then be dedicated to transform sensing data.

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