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Mobile agent-based energy-aware and user-centric data collection in wireless sensor networks

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ABSTRACT

We design an efficient data-gathering system in wireless sensor networks (WSNs) with mobile agents to achieve energy- and time-efficient collection as well as intelligent monitoring to adapt to the numerous demands of users. We first consider a data-gathering system called MAMS where mobile agents (MAs) and a mobile server (MS) collaboratively collect data. MAs collect data over the WSN and intelligently return this to the MS. We then develop dynamic itinerary planning approach for an MA (DIPMA) to find an optimal itinerary that provides more flexible services using widespread WSNs to users. We focus on two key challenges: (1) developing a new data-searching mechanism for making an MA's itinerary under specified requirements and (2) designing data structures with minimal information stored in sensor nodes, where an MA decides on the next destination based on the information. We validate the proposed solutions by simulation experiments and show DIPMA outperforms the random migration of MAs in terms of execution time by considering the search accuracy of nodes that detect events.

1. Introduction

Wireless sensor technologies have rapidly developed in recent years because of the flexibility, self-organization, and the low cost of conventional sensors. Sensor networks are crucial infrastructures in modern society and for human life because they can observe noise, ultraviolet, or pollution levels and issuing warnings when parameters exceed particular thresholds to avoid damage to humans and the environment [13–15,28,31]. They are also used to find and rescue survivors after natural disasters [16] and on battlefields to detect obstacles, poison gas, bombs, landmines, and enemy positions [17]. Recently hybrid network models have also been discussed [30,31].

Such various application scenarios show that sensor networks monitor relatively large fields. They are especially useful for humans when the monitored field is dangerous and unreachable. For these reasons, a large wireless sensor network (WSN) is preferred and has been studied over the last decade, especially an efficient data-gathering algorithm for both saving time and conserving network energy has been studied. Time-effectiveness is important because services for users must be provided in a timely manner for such mission-critical applications as life-saving. Energy-efficiency is essential because a sensor node's energy resources are limited and easily exhausted.

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Data-gathering approaches using mobile agents (MAs) successfully satisfy this requirement to collect data from all the sensors in networks [1–4]. However, existing research on data gathering using MAs poses a hot spot problem since they employ a fixed server that exclusively dispatches and collects MAs to/from networks. In the hot spot problem, the nodes in the vicinity of the server exhaust their energy quickly because the data traffic on the nodes is heavier than on the others, which shortens the network lifetime [23]. Although MAs consume less energy than server–client based models, the hot spot problem cannot be avoided from the perspective of long-term use. Including a mobile server (MS) in the network can solve this problem and distribute the load balance of nodes because the MS changes its location for data collection. However, if a monitored field is large and many nodes are deployed, it takes much more time to collect data over the network than on an MA-based model.

In this paper, we employ the advantages of both MAs and MSs to prolong the network lifetime while conserving time for data gathering. An MA-based data-gathering system with the help of an MS called the TinyBee system was proposed [25]. However, the itineraries of the MAs are predetermined, and the MS has to send the locations of all the dispatched MAs a message to pick them up from the network. We improve the system such that MAs autonomously migrate to collect data and flexibly find a route to the MS to return after the data collection process.

We address not only the traditional metrics of energy efficiency to prolong the network lifetime and time efficiency to minimize the delay of data delivery from source to destination but also the local computation capability of MAs to intelligently gather specific information from many sensor nodes in a network [5]. For example, while monitoring a forest's wildfire, MAs are dispatched to collect temperature data from sensors deployed in the forest and to find places where the temperature exceeds a particular threshold. Since visiting and checking all of the sensors to obtain their temperature values is too time-consuming during such fire situations, MAs immediately inform a processing center of the detected data and the places as soon as temperatures exceeding the threshold are observed. Such a mechanism is critical in a large-scale network for MAs to reduce visits to sensors. However, the existing results only considered data aggregation in general cases [6,7,26,27] and failed to deal with more complex situations that must be addressed for practical uses.

To improve the data-gathering performance from environments to provide more flexible context-aware services to users, we design dynamic MA itinerary planning by exploiting the following four features of MAs: MAs are application-oriented, task-adaptive, scalable, and flexible. Context-aware services are required to make the system generalized to suit each user's demand. In this paper, as a pilot effort of our research, we consider MA-based data collection and apply it to next-generation agriculture where WSNs are employed to reduce the burdens on farmers [8]. This work is motivated by MA's beneficial features that can be fully utilized in the following application scenarios: (a) since the application demands from farmers vary tremendously, some farmers want MAs to monitor the balance among environmental parameters while the others want MAs to learn a result analyzed from collected data based on different situations; (b) the size of farm lands can change season by season and/or annually, which also depends on the demands of the farmers; and (c) agricultural products are normally influenced by local-weather information and conditions called a microclimate [9], which can be collected and locally processed by MAs. Unlike wide-area information that can be easily obtained from weather forecasts provided by TV and radio, local information is difficult to obtain without expensive infrastructure. Therefore, farmers usually make judgments based on their experience, intuition, and visual observations. Since MAs are expected to provide partial data results that are computed at a processing center, no all sensor nodes deployed on a field require high-capacity sophistication.

As an example of an agricultural application, we consider data gathering to predict killing frosts. Effective local-area information collection and analysis are required to predict such damage to crops. For effective data gathering, an MA only visits sensor nodes that are highly likely to have attractive data. To this end, we develop a new data-searching mechanism with which MAs migrate to a proper node for the next hop that is guaranteed to obtain desired data with high probability. Using the mechanism, an MA constructs its itinerary to collect sensory data for predicting frost damage.

The remainder of the paper is organized as follows. Section 2 reviews related works and compares them with our approach. Section 3 presents an efficient data-gathering scheme called the MAMS system, followed by performance evaluation of our preliminary MAMS system in Section 4. We design a dynamic itinerary plan for MAs in Section 5 and evaluate its performance with simulation experiments in Section 6. Finally, we conclude our paper and outline directions for future work in Section 7.

2. Related work

By data fusion, we collect and process the data sensed by WSN to get useful information about the situations of the fields. Both simple computation and advanced/complex computation/processing exist for data fusion. For example, getting a maximum temperature is a simple computation in an infrastructure type of network. By collecting the data of neighbors (children nodes) and computing, the children nodes finally send the maximum temperature to their parents. However, assessing a disaster's damage or the degree of pollution may require many types of parameters and complex computation of them. Sometimes, the computation algorithms are on-demand and developed based on new findings and ideas while the disaster is happening. Computation programs may need to be dynamically sent to each sensor node, not in advance.

Many data fusion methods exist [18–21] through which a sensor node's data in a network can be collected and