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Virtual field strategy for collaborative signal and information processing in wireless heterogeneous sensor networks

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ABSTRACT

A novel collaborative signal and information processing (CSIP) method, which is based on virtual fields excited by sensor nodes, is proposed for wireless heterogeneous sensor networks. These virtual fields influence states and operations in sensor nodes located in their regions of influence (ROIs) and thus collaboration is implemented through interactions between surrounding virtual fields and sensor nodes. Described by a group of radial basis functions (RBFs), virtual fields have different magnitudes and ROIs due to different initial energy, communication ranges, sensing ranges and information processing capabilities in heterogeneous sensor nodes. Dynamic mobile agent itinerary decision and adaptive node active probability updating are studied with virtual field strategies in a heterogeneous sensor network using mobile-agent-based computing paradigm. Simulation results demonstrate that this approach can reduce energy consumption in sensor nodes. Information gain efficiency and network lifetime are also increased.

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1. Introduction

Wireless sensor networks (WSNs) are composed of small sensor nodes integrating the capabilities of sensing, computing, wireless communication, and even mobility. Large amounts of these low-cost sensor nodes are scattered in an area of interest and form a loosely-coupled distributed networking system. WSNs have been intensively investigated [1–4] in recent years for its wide range of applications, such as battlefield intelligence, environmental tracking, home automation, and emergency response. The sensor nodes collect data, locally process the data if necessary, and forward them to a processing center when certain events occur. Situation awareness or decisions are generated in the processing center, which can then be accessed by end users of various applications.

One of the key issues in WSNs is how to collaborate energy-efficiently among sensor nodes in order to compensate for limited sensing, limited processing capabilities and extremely constrained energy resources in these nodes as well as to improve the reliability and the performance of information fusion process. This issue has been considered from two different domains: network organization domain and information processing domain. Several protocols have been proposed to deal with energy-efficient network organization problem in WSNs [5–7]. S-MAC [6] proposes a periodic listening and sleeping mechanism for each sensor node, and this low-duty-cycle operation obtains significant energy savings in WSNs. LEACH [8], a distributed cluster formation technique, tries to rotate cluster head positions to evenly distribute the energy load among all the nodes. It has been shown that this scheme can dramatically improve system lifetime. But both of the above protocols lack necessary consideration from information processing perspective since WSNs should be designed not only as a communication infrastructure but also as an information acquisition system of physical world. Zhao et al. [9] proposed an information-driven approach for target tracking to sensor collaboration in ad hoc sensor networks which considered the information utility of each node. They

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formulate the problem of distributed tracking as a sequential Bayesian estimation problem, and try to select a sensor which is likely to provide the greatest improvement to the estimation of target state at the lowest cost of communication and computation. Problems related to network organization, for example, when and how sensor nodes should be activated, are not their consideration focus.

Recently, Qi and coworker [10,11] suggested a mobile-agent-based distributed computing paradigm to support collaborative signal and information processing (CSIP) in WSNs. In the mobile-agent-based paradigm, a processing center (or a sink node) sends out mobile agent carrying the method needed for signal and information processing. The mobile agents autonomously migrate among sensor nodes and perform local processing using resources available at the nodes. It is shown that the paradigm has many advantages over the traditional client/server computing paradigm in terms of scalability, reliability, task-adaptability and energy-awareness. In their algorithms, sensor nodes periodically exchange parameters in order to dynamically decide mobile agent itinerary in consideration of energy consumption, communication cost and information gain. Sensor nodes are assumed to have identical physical parameters in their studies. In case of wireless heterogeneous sensor networks, large numbers of parameters have to be exchanged before any decision can be made since sensor nodes have different values of initial node energy, communication range, sensing range and information processing capability. This exchange process will cause considerable energy consumption. Thus, direct use of their algorithms in wireless heterogeneous sensor network may lead to energy inefficiency. Unlike previous works, we try to investigate energy-efficient CSIP method applicable in wireless heterogeneous sensor network scenario from both network organization and information processing perspectives. The coexistence of different hardware platforms [12–14], which have different initial energy, sensing ranges, communication ranges and information processing capabilities, makes heterogeneous sensor network a real scenario to face.

Potential field methodologies or their variants, which were originally developed in robotics for autonomous robot exploration [15], have been studied in the problem of dynamic node deployment and data collecting using mobile node in wireless sensor network. In [16,17], a virtual force algorithm (VFA) was proposed as a sensor deployment strategy to enhance the coverage after an initial random placement of sensors. For a given number of sensors, VFA attempts to maximize the sensor field coverage using a combination of attractive and repulsive forces. Li and Rus [18] develop navigation protocols in sensor networks that try to direct a mobile node through a region of space. The areas of sensor network that have triggered special events are considered to be "obstacles" and the artificial potential field that corresponds to the current state in the perception space of the sensor network relative to these obstacles is computed. In [19], Pereira et al. discussed the problem of collecting sensor information from wireless sensor networks using mobile robots. A multi-target, dynamical, potential field strategy where a robot is attracted to the sensors that have less remaining data storage capacity is presented. Though the above studies have demonstrated the applicability of potential field methodology in certain applications, field methodology supporting mobile-agent-based computing paradigm, especially in wireless heterogeneous sensor networks, is yet not shown.

A novel CSIP method, using virtual field strategy, is proposed in this paper for energy-efficient collaboration in wireless heterogeneous sensor network using mobile-agent-based computing paradigm. This idea originally comes from that mobile agent migration in WSNs has a close resemblance to robot exploration problem. In robot exploration, a group of robots migrate intelligently within an unknown environment to get information about the environment. Correspondently, in mobile agent migration, mobile agent hops from one sensor node to another in order to get the maximum amount of information out of local raw data in sensor nodes. In this paper, both adaptive node active probability updating and dynamic mobile agent itinerary decision are studied with virtual field strategy. Sensor nodes are assumed to excite two virtual fields with certain regions of influence (ROIs). One is for node active probability updating; the other is for mobile agent itinerary decision. Virtual fields by one node can change states in other nodes and influence their operations if they are located in the ROIs of these fields. Properties of virtual fields depend on both sensor measurement and physical parameters of the exciting node. Virtual field strategy maps various heterogeneous parameters of sensor nodes into properties of correspondent virtual fields. This mapping reduces communication cost for parameter exchange among neighbor sensors in mobile-agent-based computing paradigm. Collaboration among sensor nodes can then be implemented through interaction between sensor nodes and their surrounding virtual fields.

The rest of the paper is organized as followings: In Section 2, the concept of virtual field is introduced and a general form of RBFs is defined for virtual field representation. In Section 3, virtual field strategies in mobile agent itinerary planning and node active probability updating problem are described respectively, and detailed procedures of the CSIP method using these strategies in wireless heterogeneous sensor network are discussed next. Simulation experiments and their results are given in Section 4. Section 5 presents discussion on the application of the proposed CSIP method and Section 6 concludes the paper.

2. Virtual field and its representation

We consider deployment scenario of a wireless sensor network under discussion as a two dimension configuration space and each sensor node is represented as a point in this space. Each active senor node can excite virtual field that covers certain area around the node. The area is called region of influence (ROI) in which states and operations of sensor nodes can be affected by the virtual field. In this paper, ROI of the virtual field excited by a given node is defined as a circular area centered on the node. The radius of this circular ROI is defined by the maximum communication range of the field-exciting node. States and operations in sensor nodes out of this area will not be changed

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