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Game balanced multi-factor multicast routing in sensor grid networks

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ABSTRACT

In increasingly important sensor grid networks, multicast routing is widely used in date aggregation and distributed query processing. It requires multicast trees for efficient data transmissions. However, sensor nodes in such networks typically have limited resources and computing power. Efforts have been made to consider the space, energy and data factors separately to optimize the network performance. Considering these factors simultaneously, this paper presents a game balance based multi-factor multicast routing approach for sensor grid networks. It integrates the three factors into a unified model through a linear combination. The model is standardized and then solved theoretically by using the concept of game balance from game theory. The solution gives Nash equilibrium, implying a well balanced result for all the three factors. The theoretic results are implemented in algorithms for cluster formation, cluster core selection, cluster tree construction, and multicast routing. Extensive simulation experiments show that the presented approach gives mostly better overall performance than benchmark methods.

1. Introduction

With the rapid development of wireless communication technologies, sensor grid networks are becoming more and more popular and increasingly important. They gather, distribute, and act on, the information about the behavior of all participants, e.g., suppliers and consumers [27]. They are widely used in various applications. Among those applications are smart power grids, environmental monitoring, smart transportation, and habitat monitoring.

A sensor grid network consists of hundreds of thousands of wireless sensor nodes. In general, these sensor nodes have limited resources and computing power. Thus, the computational tasks that are resource demanding and/or computationally intensive have to be partially or mostly offloaded to somewhere else from the sensor devices for prompt processing. Also, data gathered or generated by the sensor devices need to be transmitted over the sensor grid network [23]. All these re-

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quirements cause severe issues in wireless communications. Particularly, a challenges in sensor grid networks is to support efficient multicast routing for data aggregation and distributed query processing [5].

In sensor grid networks, efficient multicast routing typically use data aggregation. For data aggregation, the technique of data aggregation tree is generally employed. More specifically, a base station or sink node gradually collects data from distributed sensor nodes by using a reverse multicast tree [13]. Thus, multicast becomes a key concept in data aggregation for traffic routing and distributed query optimization.

While research on multicast has been extensive for data aggregation, existing multicast schemes have mainly considered the shortest transmission distance from the geographical factor perspective. When a hierarchical multicast tree is constructed, the geographical center is often chosen as a core node at which the data is aggregated. This reduces the transmission distance of the data [14]. However, in addition to the geographical space factor, energy consumption and data generation volume are also significant factors in sensor grid networks. For a longer lifetime of the network, sensor nodes with a higher energy residual should be assigned more communication tasks. This requires to change the core node dynamically in multicast routing. Also, the volume of data that each sensor node generates or collects is quite different from each other. This has a significant impact on the performance of the data communications through data aggregation. While space, energy and data factors have been considered separately in existing methods, simultaneous considerations of all these three factors have not yet been reported except our preliminary work [6,7]. This motivates our research in this paper on efficient routing in sensor grid networks.

This paper presents a game-balanced multi-factor multicast routing approach for sensor grid networks. It makes three main contributions: 1) a unified model is established with simultaneous considerations of the three factors of space, energy and data through a linear combination with unknown coefficients; 2) after standardization, the unified model is solved theoretically for all unknown coefficients by using the concept of game balance, giving Nash equilibrium with well-balanced result among the three factors; and 3) the theoretical results are implemented in five algorithms. The presented approach is evaluated through simulation experiments against benchmark methods.

The remainder of this paper is organized as follows. Section 2 reviews the related work and motivates our research. Section 3 describes the multi-factor problem. The problem is solved theoretically in Section 4 through game balance theory. The theoretical results are implemented in algorithms in Section 5. Section 6 demonstrates the performance of the presented approach in comparison with benchmark methods. Finally, Section 7 concludes the paper.

2. Background, related work and motivations

Multicast routing in sensor grid networks relies on data aggregation and distributed query processing. This section reviews the related work of data aggregation, distributed query processing, and multicast routing. Then, it discusses the motivations of our research in this paper.

2.1. Data aggregation

In sensor grid networks, data acquisition typically utilizes data aggregation through a structure called "data aggregation tree". More specifically, a base station or sink node collects data from distributed sensor nodes by using a reverse multicast tree. The collected data are aggregated and then sent out [13].

In the network layer, there are two categories of routing strategies through data aggregation: address-centric (AC) and data-centric (DC). For AC routing, each source node sends data along the shortest path in the intermediate nodes to the sink node. In comparison, DC routing considers the content of the data to be transmitted. During the data forwarding process, the intermediate sensor nodes aggregate data from multiple data sources according to the content of the data. They do not necessarily follow the shortest path for traffic routing.

Energy is one of the major issues in wireless and mobile sensor grid networks. It has been considered in data aggregation design. Two popularly used methods for data aggregation and traffic routing with consideration of energy are and TEEN (Threshold sensitive Energy Efficient sensor Network protocol) [1] and TDMA-based LEACH (Low-Energy Adaptive Clustering Hierarchy) [11]. While LEACH is a good approximation of a proactive network protocol, with some minor differences, TEEN is targeted at reactive networks.

Both LEACH and TEEN use periodic clustering. They experience two operational phases in each round: cluster establishment and data communications. In clustering, adjacent nodes form a dynamic cluster and generate its core. To achieve a balanced network energy consumption, each node in the cluster needs to rotate the cluster core. Nodes that have been cluster cores cannot become cluster cores again for a certain number of rounds. In data communications, cluster nodes send data to the cluster core. Then, the cluster core aggregates the data and sends the aggregated data to the sink nodes.

2.2. Distributed query processing

Distributed query processing in sensor grid networks can use data aggregation for efficient data collection from multiple data sources. It also disseminates queries from sink nodes to other sensor nodes over the network. Then, the sensor data converge toward the sink nodes in a reverse multicast manner.