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MLDS: A flexible location directory service for tiered sensor networks

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Abstract

Many location based services, such as a those used in healthcare facilities to track medical personnel and equipment, need to keep track of mobile entities across wide areas. These services can be realized in a cost-effective and efficient manner using tiered sensor networks comprised of multiple wireless sensor networks connected by an IP network. To simplify the realization of such services, we present MLDS, a Multi-resolution location directory service for tiered sensor networks. MLDS provides a rich set of spatial query services ranging from simple queries about entity location, to complex nearest-neighbor queries. Furthermore, MLDS supports multiple query granularities which allow an application to achieve the desired tradeoff between query accuracy and communication cost. We implemented MLDS on Agimone, a unified middleware for sensor and IP networks. We then deployed and evaluated the service on a tiered sensor network testbed consisting of tmotes and PCs. Our experimental results show that, when compared to a centralized approach, MLDS achieves significant savings in communication cost while still providing a high degree of accuracy, both within a single sensor network and across multiple sensor networks.

Keywords: Sensor network; Location directory; Spatial query; Mobile agent

1. Introduction

Many location based services require the capability of keeping track of a large number of mobile entities over a wide area. These services can be realized in a cost-effective and efficient manner using distributed wireless sensor networks connected via IP networks. Let's consider the specific example of coordinating doctors over multiple make-shift clinics, set up after a natural calamity. Such clinics are often short of doctors, requiring them to move between the various clinics. In such a scenario, there is often a need to keep track of the doctors, as they move within and between clinics, so that it is possible to find a particular doctor or the nearest available doctor when the need arises. In addition to tracking doctors, tracking staff members and medical equipment would also highly improve the efficiency of such clinics. Wireless sensor networks connected via IP networks help automate people and asset tracking in such scenarios by providing the capability to sense and identify mobile entities over wide areas. Moreover, in scenarios like the one mentioned above, existing infrastructure (e.g. phone lines and cell phone towers) is often destroyed or overloaded, requiring the deployment of wireless sensor networks connected via ad hoc IP networks to realize such wide-area location based services. However, to fully realize such services, it is essential to develop a location directory service that can (a) efficiently maintain the location of mobile entities as they move *across multiple sensor networks* and (b) support a broad range of *spatial queries* concerning the mobile entities. Our goal is to realize exactly such a service.

The primary contribution of our work is the design, implementation, and empirical evaluation of MLDS, the first multi-resolution location directory service for *tiered sensor networks*. The key contributions of our work include

- Design of MLDS, which efficiently maintains location information of mobile entities across multiple sensor and IP networks *and* supports a rich set of multi-granular spatial queries.

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– Implementation of MLDS on tiered sensor networks composed of resource-constrained sensor networks and IP networks.
– Empirical evaluation of MLDS on a tiered testbed of 45 nodes. Our empirical results show that MLDS can maintain a high degree of accuracy at low communication cost, both within a single sensor network and across multiple sensor networks.

MLDS adopts a hierarchical architecture with multi-resolution information storage in order to support multi-granular queries at considerably low communication cost. While MLDS' hierarchical directory structure bears some resemblance to the cellular network architecture and to the Internet's Domain Name System (DNS), its novelty lies in the fact that it is specifically designed and implemented for tiered sensor networks consisting of resource-constrained sensor platforms. In particular, our goal is to minimize communication cost without considerable loss in accuracy. By minimizing communication cost we not only minimize the network energy consumption and therefore extend the network lifetime but we also improve the system performance (i.e. achieve low query latency and high query success rate). Further comparisons between our work and location management services used in cellular and IP networks is given in the related work section (Section 7).

The rest of this paper is organized as follows. We describe the system model in Section 2, the services offered by MLDS in Section 3 and MLDS' design in Section 4. We then present implementation details in Section 5, followed by experimental results in Section 6 and related work in Section 7. Finally, we conclude in Section 8.

2. System model

MLDS can support multiple wireless sensor networks connected by IP networks. Each sensor network, consisting of stationary *location-aware* sensor nodes and a base station, is assumed to have a unique name that maps to the base station's IP address. We assume that the sensor networks track mobile entities in the physical environment using existing tracking algorithms [14,12,1,24,17] coupled with or without RFID technology. These algorithms may use existing sensor network localization schemes [16,10] to compute the exact location of the mobile entities. Furthermore, in our implementation of MLDS, we assume that mobile entities are represented by light-weight mobile agents[1] in the sensor network. A mobile agent is a software process that can migrate across nodes while maintaining its state. Mobile agents present a convenient way of representing mobile entities (e.g. cars, people) in the sensor network [5]. For instance, in the make-shift clinic example described above, mobile agents may be created to shadow the doctors. Users can then query the locations of doctors by querying the locations of the corresponding mobile agents, through MLDS. Note that even though MLDS is implemented to work with mobile agents, it can be easily extended to work with other programming models for mobile entity tracking such as EnviroSuite [14] and others based on message passing [12,1,24,17]. For example, in EnviroSuite, a mobile entity is mapped to a dynamically instantiated object with a unique ID in the sensor network. MLDS can be easily adapted to keep track of these mobile objects instead of mobile agents.

3. Services

MLDS supports four types of flexible spatial queries that include (i) finding the location of a particular agent, (ii) finding the location of all agents, (iii) finding the number of agents and (iv) finding the agent that is closest to a particular location. To meet the needs of diverse applications, all of these queries support different scopes and granularities that can be specified by the application. MLDS supports two query scopes, (i) *local scope* i.e. within a single sensor network and (ii) *global scope* i.e. across multiple sensor networks. It supports three query granularities, *fine*, *coarse* and *network*. The query result of a fine query is based on the exact locations of the mobile agents while the query result of a coarse query is based on the approximate locations of the mobile agents. The query result of a network query, on the other hand, is based only on the knowledge of the sensor networks that the agents are in. MLDS supports queries issued from both within a sensor network and from outside a sensor network (e.g. by an agent or user on the IP network).

Most of the queries supported by MLDS take in the parameters S and G which specify the scope and granularity of the query, respectively. Mobile agents may be divided into classes and hence some of the queries also take in the parameter C that specifies the "class" of a mobile agent, thereby limiting the query to that agent class. The API of the four spatial queries are as below:

(i) **GetLocation**(id, S, G) returns the location of agent with ID *id*.
(ii) **GetNum**(C, S) returns the number of class C agents.
(iii) **GetAll**(C, S, G) returns the location of all class C agents.
(iv) **GetNearest**(C, L, S, G) returns the location of the class C agent that is closest to location L.

4. Design

MLDS is designed for location based services that involve tracking of mobile entities (e.g. people, equipment). Due to the high mobility of entities in these systems, the location information update rate is expected to be much higher than the query rate in these systems. Hence, MLDS

[1] The light-weight mobile agents do not add significant overhead to the system as shown in previous empirical results [5].