Chapter 10
An Internet Framework for Pervasive Sensor Computing

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ABSTRACT
The rapid increase of sensor networks has brought a revolution in pervasive computing. However, data from these fragmented and heterogeneous sensor networks are easily shared. Existing sensor computing environments are based on the traditional database approach, in which sensors are tightly coupled with specific applications. Such static configurations are effective only in situations where all the participating sources are precisely known to the application developers, and users are aware of the applications. A pervasive computing environment raises more challenges, due to ad hoc user requests and the vast number of available sources, making static integration less effective. This paper presents an Internet framework called iSEE (Internet Sensor Exploration Environment) which provides a more complete environment for pervasive sensor computing. iSEE enables advertising and sharing of sensors and applications on the Internet with unsolicited users much like how Web pages are publicly shared today.

INTRODUCTION

The emergence of pervasive computing technology has enabled many applications in different environments (see Diegel, Bright, & Potgieter, 2004; Symonds, Parry, & Briggs, 2007). With the advent of modern technology that enables massive production of small, inexpensive, and wireless networked sensors, distributed sensor networks have become pervasive nowadays and revolutionized pervasive computing. Instead of personal computers, hundreds of sensor networks are to
be deployed everywhere, providing a pervasive environment that enables people to move, work, and communicate without knowing the presence of computers processing sensor data. However, such ideal settings are not easy to realize, as data captured from these systems are constantly buried in the Internet, partly due to the dynamic nature of the data and the lack of a common framework for sharing such information in the public. While emerging sensor networks provide us with a vision of a powerful pervasive computing environment, feasible frameworks to share data across fragmented and heterogeneous sensor networks have not yet taken a concrete shape, due to the lack of data sharing techniques and cooperation among different sensor data providers. As ever-growing sensor-based services become part of our daily life, they call for new technologies that enable publishing, searching, browsing, and integrating sensor data on the Internet.

Consider sensor networks, called Sensor Webs (Delin & Jackson, 2001), deployed by NASA in a variety of environments including several greenhouses at Huntington Botanical Gardens in California, wetlands on the Florida coast at the Kennedy Space Center, remote eastern ice sheets of Antarctica, desert areas of central New Mexico and Tucson, and a greenhouse simulation of an Amazonian rainforest. Although real-time streaming outputs from these deployments can be viewed at the “NASA/JPL Sensor Web” Web site, the sharing of these data streams must be through a specific application from NASA, that is, the visualization software, and there is no easy way to leverage new research tools developed by third parties for these data. It is also inconvenient to deploy data fusion tools to combine NASA sensor data with those of other organizations.

The enablement of these absent functionalities requires a new sensor computing environment that facilitates:

- Sensor data sharing,
- Sensor application sharing, and
- On-the-fly data integration from various sensor sources.

Recently there has been a growing interest in sensor data management with research activities focusing mainly on either:

1. dealing with packet routing and power conservation issues as well as secure communication mechanisms in sensor networks (Ganesan, Estrin, & Heidemann, 2003; Intanagonwiwat, Govindan, & Estrin, 2000), or
2. managing the sensor networks as a distributed database (Demers, Gehrke, Rajaraman, & Trigoni, 2003; Gibbons, Karp, Ke, Nath, & Seshan, 2003; Madden & Franklin, 2002; Madden, Franklin, & Hellerstein, 2002; Tan, Korpeoglu, & Stojmenovic, 2007).

The latter line of work is more relevant to our paper. Madden (2002a) proposes a technique, called Fjords, for query processing on continuous, never-ending sensor data streams. In this work, the sensor network is modeled as a streaming data source by providing a sensor proxy as the sensor’s interface into the query processor. Madden et al. (2002) develop the TAG service that distributes declarative queries into the sensor network and coordinates sensors on in-network aggregation. This scheme pushes query operators into the network and aggregates partial results at intermediate nodes, resulting in greatly improved query efficiency with decreased power usage. In the Cougar Sensor Database Project, Demers et al. (2003) present a database approach to sensor networks, that is, the client “programs” the sensors through queries in a high-level declarative language similar to SQL. In this project, sensor streams are modeled as virtual relations. These studies present novel architectures for sensor query processing using database technology, and provide effective techniques for sensor databases and query systems. However, their primary limi-