BLOSSOMS: A CAS/HKUST Joint Project to Build Lightweight Optimized Sensor Systems on a Massive Scale*

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Abstract. A joint effort between the Chinese Academy of Sciences and the Hong Kong University of Science and Technology, the BLOSSOMS sensor network project aims to identify research issues at all levels from practical applications down to the design of sensor nodes. In this project, a heterogeneous sensor array including different types of application-dependent sensors as well as monitoring sensors and intruding sensors are being developed. Application-dependent power-aware communication protocols are also being studied for communications among sensor nodes. An ontology-based middleware is built to relieve the burden of application developers from collecting, classifying and processing messy sensing contexts. This project will also develop a set of tools allowing researchers to model, simulate/emulate, analyze, and monitor various functions of sensor networks.

1 Introduction

Recent advances in wireless communication and hardware have enabled the dense deployment of distributed sensor networks and opened a wide range of application domains, such as environmental monitoring for endangered species or ecosystems of changes in light, temperature, pressure, acoustics; security surveillance preventing attacks in the forms of chemical, biological, or radiological weapons; target tracking of moving objects; and battlefield awareness [1]. All these applications may have information collected from sensor nodes to be sent to the gateway (sink) from time to time. By exploiting the sensor network's spatial coverage and multiplicity of sensing modalities, the network can achieve a good global measurement. Research in sensor networks has received a great deal of attention worldwide, where the most notable

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one is Berkeley's MOTE [2], due to its potential impact on so many application domains.

In March 2004, recognizing the importance of sensor networks, the Chinese Academy of Sciences and the Hong Kong University of Science and Technology have jointly launched an effort to investigate both fundamental and practical research issues in sensor networks. The goal of this research is to build lightweight optimized sensor systems on a massive scale, namely the BLOSSOMS project. The objective of this research project is to identify research issues at all levels from practical applications down to the design of sensor nodes. As a multidiscipline research, this project involves researchers from different disciplines including hardware design, embedded systems, wired and wireless communications, software engineering, distributed query processing, machine learning, and performance evaluation. In a short period of time, the project has made a very good progress. This paper will give an overview of the BLOSSOMS project and introduce some research directions being investigated.

2 Project Overview

Figure 1 shows the system architecture of the BLOSSOMS project. There are four layers. The bottom two layers are implemented in individual sensor nodes, while the top two layers are executed at gateway nodes or some application nodes. Typically, a gateway node will broadcast a command to all active sensor nodes and selected active sensor nodes will report the result back to the gateway node. The communication among the sensor nodes and gateway nodes is wireless and usually short ranged to reduce power consumption, such as ZigBee. The communication among gateway nodes and application nodes can be either wired or wireless and typically adopts the standard protocols, such as 802.11x and TCP/UDP/IP. In addition, the MEADOWS module (on the left side of the figure) provides a set of tools for sensor network studies. The following sub-sections describe each BLOSSOMS component in more detail.

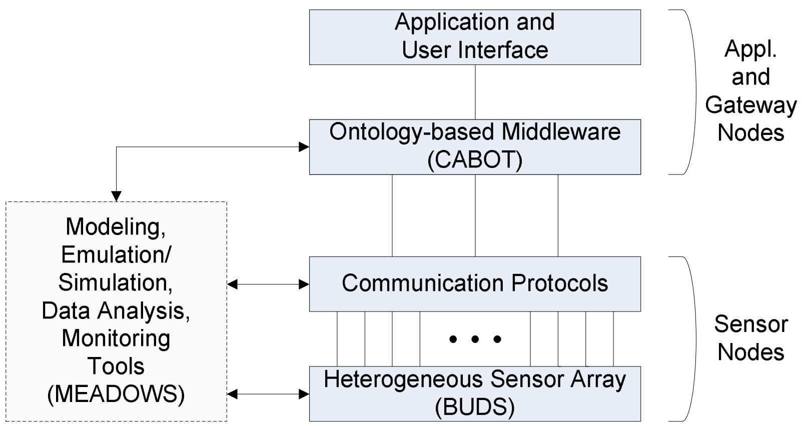

Figure 1: The BLOSSOMS system architecture.

2.1 BUDS: Heterogeneous Sensor Nodes

A sensor node is an embedded system consisting of four basic components, namely a sensing unit, a processing unit, a communication unit, and a power unit. Additionally, there may be application-dependent, optional units such as a mobilizer, a location finding system, and a power generator [1]. Our research on sensor node architecture is currently undertaking at ICT/CAS. The goal is to build multifunctional sensing nodes, called BUDS, targeting on applications such as intelligent transportation systems, precision agriculture, remote medical care, and public safety monitoring system. Efforts are made to tackle the following technical issues:

- the development of an embedded operating system for ultra low power sensor nodes;
- the design of general sensor nodes and system integration method;
- the design of special-purpose sensor nodes, such as video sensors, monitoring sensors, and intruding sensors; and
- the low power management and high reliability design at the system level.

While the general sensors require ultra low power consumption, the special sensors may have different requirements, such as a powerful CPU.

The monitoring sensor is a special sensor needed to help debug and monitor the behavior of other sensors. The monitoring sensor will operate on two frequencies. One is the same as other sensors, which only operates in the listening mode to observe the behavior of other sensors. Another frequency is used to report the collected information to the MEADOWS for further analysis. Power consumption is not a critical issue for such sensors. The intruding sensor is used to simulate malicious sensors trying to attack a working sensor array. We will use the standard low power ZigBee as the wireless communication mechanism.

2.2 Communication Protocols

The communication protocol plays a major role to allow commands to be propagated from gateway nodes to active sensor nodes and to collect replies from some sensor nodes to the gateway nodes. The communication pattern is application dependent and many protocols for different applications have been proposed (e.g., [3]). Furthermore, sensor nodes are unlikely to have a global unique ID, which is too expensive. This creates a new challenge to develop content-based routing among sensor nodes.

If the location of each sensor node can be identified, more useful information can then be collected. Determining the location of sensor nodes is another challenge to be addressed in this research. We are investigating both anchor-free [4] and anchor-based location sensing techniques [5].

2.3 CABOT: Ontology-Based Middleware

Applications of sensor networks often need to be aware of their contexts, which could be related to sensors, time, location, and security. These applications typically have to carry out tedious tasks of gathering, classifying and processing messy context information due to lack of middleware support. The middleware support for these applications is a major topic in pervasive computing. CABOT is a user-centric middleware being developed to provide infrastructural support of sensor network applications. The main responsibilities of CABOT are to provide (a) the resource management of sensor networks, (b) the analysis of dynamic environments, and (c) the development support of context-aware pervasive computing. Current features of Cabot include:

- The support of extensible context gathering (decoupling applications and sensor networks), application-customized context classifying (subscribing interested context information in application-specific ways) and intelligent context processing (reasoning on application requirements).
- The provision of development support for context-aware pervasive applications. This relieves application developers from the tedious programming of gathering, classifying and processing messy context information in sensor networks.
- The provision of naming services to facilitate effective collaboration amongst applications and sensor networks.

CABOT also takes into account the privacy issue. The privacy services in CABOT are able to modify or even hide some certain kinds of sensor contexts based on user identities and relevant privacy policies. For further details about CABOT, please refer to another paper in this workshop [6].

2.4 Application and User Interface

On top of CABOT, many applications may be developed. One application being developed is a location-estimation system. Such systems can be used to support many location based services, such as location based content delivery and object and people tracking. It is still a challenging problem how to predict accurately the location of a wireless device in an indoor environment, especially when one holds a small device with limited computational and power resources. On receiving signals from various access points distributed in an indoor wireless environment, it is natural to ask: where is the user now in the building? And, how may we best help the user [7]?

The above questions present a challenge for computer science in general and artificial intelligence in particular. We have developed an integrated framework called LEAPS (location estimation and action prediction system), which provides solutions for a number of location-related applications, including location queries and location-based user behavior recognition [8]. Such a system can be useful for a variety of applications. In education, the system can provide a student walking in the faculty office area after a class with information about professors, their office hours and class information. The system can offer help by giving directions to the right office. For people suffering from various cognitive limitations in hospitals and care facilities, the technique can discover when a person's behavior is out of the norm and provide help in a timely manner. For students in a university campus, the plan recognizer can enable intelligent pre-fetching of class-content-related information. For shoppers in a busy business environment such as a shopping mall, services and products can be offered not only according to people's current location, but also according to their intended goals and actions. Plan recognition using a relational model also allows prediction of new locations that a user might be visiting even if the location is new to a user.

Some applications require integrated data access, communication, and actions on heterogeneous devices. For instance, a lab monitoring application may need to acquire sensor readings from the environment and to operate network cameras to capture the scene upon the detection of a suspicious event. For these applications, a declarative, SQL (Structured Query Language) interface is useful in order to specify the data interested and actions intended. The interface provides a relational view of the data flowing from sensors as well as an abstraction of device-oriented operations (actions). Systems support and optimization mechanisms are implemented behind the interface for ease of application development and performance [9].

2.5 MEADOWS: A Suite of Evaluation Tools

We are developing a collection of tools for large-scale, in-depth studies on sensor networks. Specifically, these tools are on modeling, emulation, and data analysis for wireless sensor networks (MEADOWS) [11] in addition to monitoring. We have designed a hierarchical power consumption model for sensor databases, a distributed emulator called VMNet (Virtual Mote Network) of sensor networks [10], and a few data analysis functions for sensory data. These tools will interact with all layers of BLOSSOMS closely. On one hand, information about real systems (e.g., sensor node statistics from the BUDS layer) provides system parameters for MEADOWS; on the other hand, MEADOWS enables analysis and validation of real systems.

3 Conclusions

We have presented an overview of the BLOSSOMS project being investigated at CAS and HKUST. Building a working sensor (BUDS) is a major challenge to the project. The MEADOWS tools are also essential because they allow us to simulate the behavior of large-scale sensor applications. The CABOT middleware provides infrastructural support for applications and the LEAPS system allows location-based applications to be easily built. This project involves close collaboration of researchers from different disciplines because of the broad project scope. At the time of writing, the project is still in its beginning stage. As the project moves forward, we expect to identify more research issues and produce more research results.

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