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Distributed Computing in Sensor Systems

Second IEEE International Conference, DCOSS 2006
San Francisco, CA, USA, June 2006
Proceedings

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Message from the General Chair

Welcome to DCOSS 2006 – the second version of the meeting series. DCOSS focuses on distributed computing issues in large-scale networked sensor systems, including systematic design techniques and tools, algorithms, and applications.

I am indebted to the Program Chair, Phil Gibbons, for his efforts in handling the review process and composing the technical program. I appreciate his leadership in putting together a strong and diverse Technical Committee to address various aspects of this interdisciplinary area. I would also like to thank him for his input in resolving a number of meeting-related issues.

I would like to thank all of the authors who submitted papers, our invited speakers, the external referees we consulted, the Vice Chairs and the members of the Program Committee.

I would like to thank Sotiris Nikoletseas for his efforts as the Workshop Chair for DCOSS 2006.

Several volunteers assisted me in putting together the meeting. I would like to thank Jim Reich for handling the poster session, Wendi Heinzelman for publicizing the event, Amol Bakshi for handling Web-based publicity, Loren Schwiebert for handling the student scholarships, Jie Wu for interfacing with IEEE TCDP for student scholarships and Yang Yu for his assistance in putting together these proceedings. Special thanks go to Amol Bakshi for his invaluable input in deciding the meeting focus, format and local arrangements.

I would like to thank Jose Rolim, DCOSS Steering Chair for inviting me to be the General Chair. Indeed, it was a pleasure working with him and with Jie Wu, Vice General Chair. Their invaluable input in putting together the meeting program and in shaping the meeting series is gratefully acknowledged.

I would like to acknowledge support from the IEEE Technical Committee on Distributed Processing and from the Centre Universitaire d'Informatique of the University of Geneva.

Rosine Sarafian, our administrative coordinator, deserves special thanks for her assistance with local arrangements.

The field of networked sensor systems is rapidly evolving. It is my continued hope that this meeting series serve as a forum for researchers from various aspects of this interdisciplinary field to interact and in particular to offer opportunities for those working in algorithmic, theoretical and high-level aspects to interact with those addressing challenging issues in complementary areas such as wireless networks, communications and systems composed of these underlying technologies.

I hope you enjoy the technical sessions as well as San Fransisco.

June 2006 Viktor K. Prasanna

Message from the Program Chair

This volume contains the 33 full papers presented at the Second IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS 2006), which took place in San Francisco, California, during June 18–20, 2006. These papers were selected by the Program Committee from 87 submissions received in response to the call for papers. Submissions were received from 18 countries across 5 continents, and directed to one of three tracks: algorithms, applications, or systems. Each track had its own Program Committee that reviewed the papers and recommended either "accept", "reject", or "accept if room". In a joint meeting between the Vice Chairs and myself we reviewed and discussed this latter category of papers to arrive at the final program.

DCOSS 2006 presentations were arranged into seven sessions, ranging from Data Aggregation and Dissemination to Programming Support and Middleware to Lifetime Maximization. Papers from the three tracks were intermixed within the sessions. Other highlights of the conference included keynote talks by Leo Guibas and Bill Kaiser, two workshops and a poster session.

I would like to add my thanks to Viktor's to all the DCOSS organizers, the authors, the external reviewers, and the Program Committee members. I am especially indebted to the Program Vice Chairs Tarek Abdelzaher, James Aspnes, and Ramesh Rao for their efforts in forming and running the three track Program Committees. The 44 Program Committee members are at universities and research labs from 12 different countries, further evidence that DCOSS is truly an international conference. The quality of the program reflects positively on the expertise and dedication of the Vice Chairs and Program Committee members.

Finally, it was a pleasure working with Viktor Prasanna, General Chair, and José Rolim, Steering Committee Chair, who both worked tirelessly to ensure the success of DCOSS 2006.

June 2006 Phillip B. Gibbons

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Evaluating Local Contributions to Global Performance in Wireless Sensor and Actuator Networks

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Abstract. Wireless sensor networks are often studied with the goal of removing information from the network as efficiently as possible. However, when the application also includes an actuator network, it is advantageous to determine actions in-network. In such settings, optimizing the sensor node behavior with respect to sensor information fidelity does not necessarily translate into optimum behavior in terms of action fidelity. Inspired by neural systems, we present a model of a sensor and actuator network based on the vector space tools of *frame theory* that applies to applications analogous to reflex behaviors in biological systems. Our analysis yields bounds on both absolute and average actuation error that point directly to strategies for limiting sensor communication based not only on local measurements but also on a measure of how important each sensor-actuator link is to the fidelity of the total actuation output.

1 Introduction

Recent interest in wireless sensor networks has fueled a tremendous increase in the study of signal and information processing in distributed settings. Energy conservation is very important for most interesting applications, which generally translates into minimizing the communication among sensors to preserve both individual node power and total network throughput. Consequently, recent sensor network research has primarily focused on adapting well-known signal processing algorithms to distributed settings where individual nodes perform local computations to minimize the information passed to distant nodes (e.g., [1,2,3]).

The goal of many proposed sensor network algorithms has been to get the information *out* of the network (via a special node connected directly to a more traditional data network) with a good trade-off between fidelity and energy expended. However, in many applications the implicit assumption is that the information coming out of the network will be used to monitor the environment and take action when necessary. A significant and natural extension to the sensor network paradigm is a wireless sensor and actuator network (WSAN). A WSAN consists of a network of sensor nodes that can measure stimuli in the environment

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and a network of actuator nodes capable of affecting the environment. While one possible strategy summarizes information for a system outside the network to determine actuator behaviors, greater efficiency should be achieved by determining actions through in-network processing. A more subtle issue is that processing and communication strategies optimizing sensor data fidelity may not yield the best results when actuation performance fidelity is the desired metric.

While WSANs are often discussed, quantitative analysis of their performance has not received much attention. Existing work can be found in areas such as software development models for WSANs [4] and heuristic algorithms for resource competition based on market models [5]. Other recent work [6] has used techniques from causal inference to evaluate specific actuation strategies. Most relevant is the recent work of Lemmon et al. [7] analyzing distributed control systems while considering the underlying communication network. A control system approach is certainly appropriate for some WSAN application models, but may use more communication resources (especially from actuators to sensors) and may require the sensors and actuators to operate in the same signal space.

Merging sensed information directly into actions without centralizing the information and decision making has rarely been considered in man-made systems. Fortunately, we have examples from biology that demonstrate the effectiveness of this strategy. Neural systems perform a chain of tasks very similar to the needs of WSANs: sensing, analysis, and response. Furthermore, evidence indicates that neural systems represent and process information in a distributed way (using groups of neurons) rather than centralizing the information and decision making in one single location. This shrewd strategy avoids creating a single point of vulnerability, so the system can function in the presence of isolated failures.

In neural systems, two types of behaviors exist, depending on whether there is "thinking" involved, which we call *conscious* and *reflex* behaviors. In conscious behavior, biological systems gather sensory information, make inferences from that information about the structure of their environment, and generate actions based on that inferred structure. In reflex behavior, a sensed stimulus directly generates an involuntary and stereotyped action in the peripheral nervous system before the brain is even aware of the stimulus [8]. An obvious example of a reflex behavior is the knee-jerk reaction achieved by a doctor's well-placed tap below the kneecap. A more subtle example is the eye position correction that allows our vision to stay focused on an object even when our head is moving.

WSAN applications have an analogous division, which we call *object-based* and *measurement-based* network tasks. For example, the canonical target tracking scenario is an object-based task because it involves using sensory measurements to infer information about objects in the environment. On the other hand, an application such as agricultural irrigation is a measurement-based task because sensor measurements directly contain all the necessary information — there is no underlying environmental object to try and infer. In this work we consider models of measurement-based WSAN applications. While measurement-based systems are simpler and possibly more limited than object-based systems, they provide an entry point for analyzing and designing WSAN algorithms.