Sotiris Nikoletseas
José D.P. Rolim (Eds.)

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Algorithmic Aspects of Wireless Sensor Networks

First International Workshop, ALGOSENSORS 2004
Turku, Finland, July 2004
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Preface

This volume contains the contributed papers and invited talks presented at the 1st International Workshop on Algorithmic Aspects of Wireless Sensor Networks (ALGOSENSORS 2004), which was held July 16, 2004, in Turku, Finland, co-located with the 31st International Colloquium on Automata, Languages, and Programming (ICALP 2004).

Wireless ad hoc sensor networks have become a very important research subject due to their potential to provide diverse services in numerous applications. The realization of sensor networks requires intensive technical research and development efforts, especially in power-aware scalable wireless ad hoc communications protocols, due to their unusual application requirements and severe constraints.

On the other hand, a solid theoretical background seems necessary for sensor networks to achieve their full potential. It is an algorithmic challenge to achieve efficient and robust realizations of such large, highly dynamic, complex, non-conventional networking environments. Features, including the huge number of sensor devices involved, the severe power, computational and memory limitations, their dense deployment and frequent failures, pose new design, analysis and implementation challenges.

This event is intended to provide a forum for researchers and practitioners to present their contributions related to all aspects of wireless sensor networks.

Topics of interest for ALGOSENSORS 2004 were:

- Modeling of specific sensor networks.
- Methods for ad hoc deployment.
- Algorithms for sensor localization and tracking of mobile users.
- Dynamic sensor networks.
- Hierarchical clustering architectures.
- Attribute-based named networks.
- Routing: implosion issues and resource management.
- Communication protocols.
- Media access control in sensor networks.
- Simulators for sensor networks.
- Sensor architecture.
- Energy issues.

This volume contains 2 invited papers related to corresponding keynote talks, one by Viktor Prasanna (University of Southern California, USA) and one by Paul Spirakis (University of Patras and Computer Technology Institute, Greece) and 15 contributed papers that were selected by the Program Committee (PC) from 40 submitted papers. Each paper was reviewed by at least 2 PC members, while a total of 99 reviews were solicited.

We would like to thank all the authors who submitted papers to ALGOSENSORS 2004, the members of the Program Committee, as well as the

external referees. Also we thank the members of the Organizing Committee. We especially wish to thank Prof. Dr. Jan van Leeuwen for valuable comments.

We gratefully acknowledge the support from the Research Academic Computer Technology Institute (RACTI, Greece, http://www.cti.gr), and the Athens Information Technology (AIT, Greece, http://www.ait.gr) Center of Excellence for Research and Graduate Education. Also, we thank the European Union (EU) IST/FET ("Future and Emerging Technologies") R&D Projects of the Global Computing (GC) Proactive Initiative FLAGS (IST-2001-33116, "Foundational Aspects of Global Computing Systems") and CRESCCO (IST-2001-33135, "Critical Resource Sharing for Cooperation in Complex Systems") for supporting ALGOSENSORS 2004. Finally, we wish to thank Springer-Verlag, Lecture Notes in Computer Science (LNCS), and in particular Alfred Hofmann, as well as Anna Kramer and Ingrid Beyer, for a very nice and efficient cooperation.

July 16, 2004 Sotiris Nikoletseas and Jose Rolim

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Algorithm Design and Optimization for Sensor Systems*
(Invited Talk)

Viktor K. Prasanna

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Distributed collaborative computation will play a key role in next generation of smart sensor systems. Till now, most research has focused upon development of networking protocols and simple data aggregation algorithms to facilitate robust communication and localized processing in sensor systems. One of the key challenges involved in realizing future sensor systems is design of efficient and scalable algorithms to facilitate large scale collaborative computation in such networks.

In the state-of-the-art, partitioning of computation tasks among nodes, node-level optimization, and data routing is done in an ad-hoc, largely empirical manner. While this does not necessarily result in inferior designs, it does require the application developer to be aware of the details of the underlying node hardware, networking paradigms, and their performance. We believe that next logical step in the evolution of networked wireless sensor systems is to develop computation models and programming abstractions to complement the existing body research. A layer of abstraction from an algorithm design perspective is needed to provide the end user with a modular, layered, composable paradigm to design and optimize networked sensor systems.

In this talk, we discuss various issues in addressing the following questions:

- What are the suitable abstractions for networked sensor systems that can be used by a programmer to develop applications that are efficient with respect to relevant performance metrics?
- Given control over the lower layers of the protocol stack, and also over hardware 'knobs' such as radio range, power states, etc., how to design and optimize algorithms so that optimal or near-optimal time and energy performance can be realized?
- What are the reusable primitives for rapid application synthesis?

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S. Nikoletseas and J. Rolim (Eds.): ALGOSENSORS 2004, LNCS 3121, pp. 1–2, 2004.

Although we approach sensor systems from a parallel and distributed systems' perspective, most of the general models of parallel and distributed computation need to be redefined. Wireless communication and energy constraints are two major factors that are responsible for this.

To illustrate our ideas, we consider a network of sensor nodes uniformly distributed over a terrain, continuously sampling the environment. We define a simple model of computation to evaluate the performance of various techniques for the classic problem of topographic querying. Topographic querying is the process of extracting metadata from a sensor network to understand the graphic delineation of regions of interest. We propose a simple technique that creates a hierarchical distributed storage infrastructure in the sensor system and performs in-network aggregation at each level of the hierarchy to reduce the total energy and latency. We conclude by summarizing issues in automatic synthesis of sensor systems.

Algorithmic and Foundational Aspects of Sensor Systems*
(Invited Talk)

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Abstract. We discuss here some algorithmic and complexity-theoretic problems motivated by the new technology advances in sensor networks and smart dust. We feel that the field of algorithms has a nice and sizeable intersection with the field of design and control of sensor networks. New measures of efficiency and quality of such algorithms are discussed. Some clear directions for future research are highlighted.

1 Introduction

Sensor networks employ a set of a vast number of very small, fully autonomous computing and communication devices. These devices (the network's *nodes*) should co-operate in order to accomplish a *global* task.

When the devices are ultra-small (abstracted to *points*) then the name *smart dust* (or *smart dust cloud*) is used. We use the term *particles* then for nodes.

The set of nodes of such a network is usually assumed to take *ad hoc* positions in e.g. a surface (2 dimensions) or in an area in the 3-dimensional space. The *area* (or space) *of deployment* of the sensors may include *obstacles* (or *lakes*) i.e. subareas where no sensing device can be found.

Sensor nets differ from general ad-hoc nets with wireless communication in the sense that local resources of each node (such as available energy, storage, communication/computation capability, reliability) are seriously constrained. (See [1], [2] for a nice survey.) In most sensor networks there are also one (or more) *base stations* to which data collected by sensor nodes is relayed for uploading to external systems.

Although the technology of construction of individual cheap sensors is quite advanced today, (e.g. there are sensors of less than a cubic *cm* size, that can even sense a perfume's smell [3]), the corresponding system aspects research is still at its infancy. The general question of "what can a sensors net do/not do globally" is quite open and it is a challenge for the algorithmic thought. Abstract models

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of such nets exist but there are many of them, each emphasizing certain aspects and connecting to certain fields of e.g. Mathematics (or Physics). For example, there is a whole field of *Random Geometric Networks* (see e.g. [5]) aiming at studying the combinatorial properties of, usually, geometric graphs created by a randomly deployed set of points in an area of the plane and having edges among two points when they are able to communicate (i.e. they happen to be close in a certain sense).

Thus, it seems that a (small maybe but technologically crucial) algorithmic subfield is trying to demonstrate itself, motivated by such networks/systems. We highlight here some concrete algorithmic problems of this field; the further development of the algorithmic thought here is, for us, a basic prerequisite for most of the pragmatic issues (software, middleware, protocols e.t.c.) aiming at controlling or *successfully* exploiting such systems.

Furthermore, it is obvious from the start that these very restricted systems cannot do everything; the ideas of impossibility results and/or trade-offs (e.g. arising from the foundations of distributed computing) should be welcomed here.

2 Information Propagation and the "Ad-Hoc" Notion

Perhaps the most natural problem in sensor systems is the "efficient" propagation of a sensed *local* event E towards some receiving center (assuming an event-driven data delivery operation). For example, consider the case where a node (sensor) in the field senses a local event (e.g. a local fire in the forest); such an event may arise arbitrarily and at any time, triggered by unusual changes in the local environment. The goal here is to inform the base station quickly, without of course depleting the net from its resources.

The difficulty here stems from (a) the ad-hoc position of nodes in the area "covered" by the sensors net (b) the fact that usually each sensor has its own coordinates system (c) the basic restriction that a sensor node v can communicate info(E) (the necessary information about the event E) only to nodes that happen to be "nearby" (within v's communication *radius* r). Even when each node r knows *a priori* the direction to the base center (*sink*) and even if nodes can broadcast within an angle of radius r, still info(E) will travel via a sequence of *hops* to the sink. In the (unrealistic) case in which a powerful Mind knew all the topology of the system, a *shortest path*, P, to the sink could be established. (Here "shortest" may include energy availability.)

Thus, the *hops efficiency* $h(A)$ of a local propagation protocol A can be defined to be the ratio of the number $l(A)$ of hops done by A to reach the sink, divided by the "length" (minimum number of hops) of P, $l(P)$. This is a *competitive* measure, motivated by the seemingly on-line nature of which node is nearby to which. The question is interesting even if one assumes a known probability distribution of sensors in the area; the existence of obstacles (or lakes) makes it even harder and resembles older research on searching "without a map" (see e.g. [6], [7]).

Assuming that each local execution of the *(forwarding) Propagation Protocol* A spends some considerable energy of the sensor, we conclude that a successful Propagation Protocol should not involve sensors that are "far away" from the shortest path from the source of the local event to the sink. (An obvious, flooding the net, protocol, will succeed in sending info(E) wherever possible but it will employ the whole net.) Thus, each node receiving info(E) has a basic, local, decision to make: to further propagate info(E) or not?

If n_A are the nodes that forward info(E) via protocol A and n are all the nodes in the sensors *field*, then $\frac{n_A}{n}$ may serve as another performance measure of A that abstracts the notion of energy efficiency of A.

Robustness of a propagation protocol to single sensors failures, as well as *scalability* (to any size n of the net) are two other important properties here. For some good proposals to design efficient propagation protocols, see e.g. [6], [4], [8].

The whole issue of efficient propagation of a local event to a source is connected to the issue of *Geometric Routing* [9]. Since, optimally, each node should deliver the packet to the closest (to the sink) neighbor, initially one may think of a simple *greedy* algorithm based on their principle. However, *voids* (nodes with no neighbor closer to the sink) may exist, due to the distribution of nodes or due to obstacles, lakes or failures.

Since GPS antennae are costly (both in price and energy consumption) it is unlikely that future ad-hoc nets can rely on the availability of precise geographic coordinates. [10] recently proposed the idea in which nodes first decide on *fictitious virtual coordinates* and then apply greedy routing based on those. But, even if the construction of such virtual coordinates can be allowed as a preprocessing step in the network, can such coordinates always exist? Which must be the properties of the network's graph in order to guarantee such coordinates?

In fact, if G is a graph with nodes embedded in $\mathcal{R}^k$ and d is the k-dimensional Euclidian distance, define a path of nodes $(v_0, v_1, \ldots, v_m)$ to be *distance decreasing* if $d(v_i, v_m) < d(v_{i-1}, v_m)$ for $i = 1, \ldots, m$.

If G has the property that $\forall s, t$ nodes of G *there exists* a distance decreasing path from s to t, and if also there exists an efficient way for the net G to construct these paths, then the greedy routing problem will be solved nicely. Relevant questions (and answers) here can be found in e.g. [9] but many versions of the problem are open.

3 Some Energy Optimality Considerations

The attenuation of a signal with power P_s at the source s (i.e. its power P_r at a node r) is

$$P_r = \frac{P_s}{d(s,r)^\delta}$$

where $d(s,r)$ is the Euclidian distance of s, r and $\delta \geq 2$ is the so called *distance-power gradient* [11].

Assume now that nodes in the sensor field can decide (based on an algorithm) on *how far* to broadcast (i.e. they can modify the radius of broadcasting). What is then the best distances to broadcast?

The problem is interesting even in the simple case of the net being an 1-dimensional lattice from source s to sink t (Fig. 1).

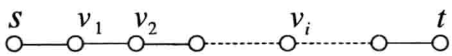

Fig. 1. 1-dimensional lattice from source s to sink t

Let l be the number of edges in the lattice (say, each of distance r). Consider the following decision problem for each node v_i: Should v_i broadcast just by radius r, or use a very big radius (e.g. an $R \geq d(v_i, t)$ would do)?

This problem always reminds the corresponding decision problem of a soccer player: to shoot directly, or to pass the ball to a next, closer to the target, attacker?

If a protocol A here makes initially x small hops and then a final broadcast to t, then the delivery time of A is $T = x + 1$, while the energy spent (assuming a unit of energy for each small hop) is $E = x + c(l - x)^{\delta}$ where c is a constant. But then

$$E = (T - 1) + c(l + 1 - T)^{\delta} \qquad (1)$$

and this is a "universal" energy-time trade-off for all such protocols A. Such trade-offs (and their discovery) are reminiscent of the area-time trade-offs of the older research in VLSI, and their precise statement will be of immense value.

Of course, there are many refinements and complications to the above question. First of all, a message can be decoded only if P_r is no less than source threshold γ. But then, node v_i may not have enough energy left to make the final "long jump".

If we now think of a graph G instead of a line, and of the need of propagating a sequence of events to the sink t, then any successful protocol should face the problem of energy-depleted nodes in the time course of serving the whole sequence of events.

Furthermore, for any position of the sink t, its nearby (within communication distance) nodes are always bounded by some number related to the volume of the sphere of radius r around t. These nodes are bound to suffer severe energy losses even when the origins of local events are fairly distributed in the sensors field.

Such limitations lead to a sequence of problems (*Range assignment problems*) that can be viewed either as off-line optimization questions or even on-line questions. The complexity of such problems has been well-studied in the off-line setting (see e.g. [12]) but even there many questions remain.