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A new energy efficient and fault-tolerant protocol for data propagation in smart dust networks using varying transmission range ☆

Azzedine Boukerche[a,*], Ioannis Chatzigiannakis[b], Sotiris Nikoletseas[b]

[a]*School of Information Technology and Engineering (SITE), University of Ottawa, 800 King Edward Av., Ottawa, ON, Canada K1N 6N5*
[b]*University of Patras and Computer Technology Institute, Patras, Greece*

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Abstract

Smart Dust is a special case of wireless sensor networks, comprised of a vast number of ultra-small fully autonomous computing, communication and sensing devices, with very restricted energy and computing capabilities, that co-operate to accomplish a large sensing task. Smart Dust can be very useful in practice, i.e. in the local detection of remote crucial events and the propagation of data reporting their realization to a control center.

In this paper, we propose a new energy efficient and fault tolerant protocol for data propagation in smart dust networks, the Variable Transmission Range Protocol (VTRP). The basic idea of data propagation in VTRP is the varying range of data transmissions, i.e. we allow the transmission range to increase in various ways. Thus, data propagation in our protocol exhibits high fault-tolerance (by bypassing obstacles or faulty sensors) and increases network lifetime (since critical sensors, i.e. close to the control center are not overused). As far as we know, it is the first time varying transmission range is used.

We *implement* the protocol and perform an *extensive experimental evaluation and comparison to a representative protocol* (LTP) of several important performance measures with a focus on energy consumption. Our findings indeed demonstrate that our protocol achieves significant improvements in energy efficiency and network lifetime.

Keywords: Wireless sensor networks; Data propagation; Algorithms

1. Introduction

Recent dramatic developments in micro-electro-mechanical (MEMS) systems, wireless communications and digital electronics have already led to the development of small in size, low-power, low-cost sensor devices. Such extremely small devices integrate sensing, data processing and communication capabilities [24,25]. Examining each such device individually might appear to have small utility; however, the effective *distributed co-ordination* of large numbers of such devices may lead to the efficient accomplishment of large sensing tasks. Large numbers of sensor nodes can be deployed in areas of interest (such as inaccessible terrains or disaster places) and use *self-organization and collaborative methods* to form a sensor network.

Their wide range of applications is based on the possible use of various sensor types (i.e. thermal, visual, seismic, acoustic, radar, magnetic, etc.) in order to monitor a wide variety of conditions (e.g. temperature, object presence and movement, humidity, pressure, noise levels, etc.). Thus, sensor networks can be used for continuous sensing, event detection, location sensing as well as micro-sensing. Hence, sensor networks have important applications, including (a) military (like forces and equipment monitoring, battlefield surveillance, targeting, nuclear, biological and chemical attack detection), (b) environmental applications (such as fire detection, flood detection, precision

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* Corresponding author. Tel.: +1 6135625800x6712; fax: +1 613 562 5664.

E-mail addresses: boukerch@site.uottawa.ca (A. Boukerche), ichatz@cti.gr (I. Chatzigiannakis), nikole@cti.gr (S. Nikoletseas).

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agriculture), (c) health applications (like telemonitoring of human physiological data) and (d) home applications (e.g. smart environments and home automation). For an excellent survey of wireless sensor networks see [1] and also [10,16].

Note, however, that the efficient and robust realization of such large, highly-dynamic, complex, non-conventional networking environments is *a challenging algorithmic and technological task*. 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 and implementation aspects* which are essentially different not only with respect to distributed computing and systems approaches but also to ad hoc networking technique [20].

Contribution. In this paper, we focus on an important problem under a particular model of sensor networks. More specifically, we study the problem of *multiple event detection and propagation*, i.e. the local sensing of a series of crucial events and the energy efficient and fault tolerant propagation of data reporting the realization of these events to a (fixed or mobile) control center. The control center could in fact be some human authorities responsible of taking action upon the realization of the crucial event. We use the term 'sink' for this control center. We note that this problem *generalizes* the single event propagation problem (w.r.t. [6,7,9]) and poses new challenges for designing efficient and fault tolerant data propagation protocols. The new protocol we present here can also be used for the more general problem of data propagation in sensor networks [16].

The basic innovation in our protocol is to vary the range of data transmissions. The idea of variable transmission range has already been used in wireless networks (and ad hoc networks, in particular) and we here use and adopt it in the context of wireless sensor networks. This feature aims at better performance, compared to typical fixed transmission range data propagation, in some rather frequently occurring situations like:

(a) The case of low densities of sensor particles. In such networks, fixed range protocols may trap in back-tracking actions when no particles towards the sink are found. Our protocol, by increasing the transmission range, may find such particles and avoid extensive backtracking.
(b) Because of the possibility to increase transmission range, VTRP performs better in cases of obstacles or faulty/sleeping sensors. Also, it bypasses certain critical sensors (like those close to the sink) that tend to be overused, and thus prolongs the network lifetime.

To demonstrate the above properties of VTRP, we compare it to a typical fixed range protocol: the Local Target Protocol (LTP).

The ability of LTP to propagate information regarding the realization of a crucial event to the control center depends on the particle density of the network. The experiments conducted in [7] indicate that for low particle densities, LTP fails to propagate the messages to the control center (while for high particle densities the failure rate drops very fast to zero, i.e. the messages are almost always reported correctly). The new protocol that we propose in this paper successfully overcomes this problem by increasing the transmission range of the particles that fail to locate an active neighboring particle towards the sink. In fact, the experiments conducted in this paper (see Section 8) demonstrate the superiority of VTRP over LTP even for sensor networks with very low particle densities.

Further note that this is the first time that the LTP protocol is evaluated under the setting of multiple events. Our findings indicate that LTP has a fundamental design flaw in this case, as the success of the propagation process heavily depends on the lifetime of the particles that are located around the control center. As soon as these particles exhaust their power supplies, the whole network becomes inoperable. Note that this design flaw that protocols for sensor networks are prone too was first reported in [14]. The new protocol that we present here successfully overcomes this problem by adjusting the transmission range of the particles as soon as the particles closer to the control center 'die'. Our experiments indicate that VTRP increases the ability of the network to report multiple events up to 100%, compared to LTP.

We propose four different mechanisms for varying the transmission range of the particles that aim at different types of smart dust networks regarding particles densities and energy saving criteria. In particular, the variations studied differ with respect to the speed of adapting the transmission range, i.e. the adaptation speed is linear, multiplicative, exponential or random. We exemplify these adaptation variations by studying some particular functions for changing the transmission range in each case. Our experimental results show that VTRP can be easily modified to further improve its performance. Actually, VTRP_p (where range is increased aggressively) and VTRP_r (that randomizes between the various range change functions towards a better average case performance) successfully propagate about 50% more events that the 'basic' VTRP and almost 200% more events that the original LTP protocol.

Discussion of selected related work. In the last few years, Sensor Networks have attracted a lot of attention from researchers at all levels of the system hierarchy, from the physical layer and communication protocols up to the application layer.

A family of negotiation-based information dissemination protocols suitable for wireless sensor networks is presented in [15]. Sensor Protocols for Information via Negotiation (SPIN) focus on the efficient dissemination of individual sensor observations to all the sensors in a network. However, in contrast to classic flooding, in SPIN sensors