Computer Communications 52 (2014) 1–20

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Mobility in wireless sensor networks – Survey and proposal

Ricardo Silva *, Jorge Sa Silva, Fernando Boavida

Department of Informatics Engineering, University of Coimbra, Polo II – Pinhal de Marrocos, 3030-290 Coimbra, Portugal

A R T I C L E   I N F O

Article history:
Available online 28 May 2014

Keywords:
Wireless sensor networks
Mobility
6LoWPAN
Proxies

A B S T R A C T

Targeting an increasing number of potential application domains, wireless sensor networks (WSN) have been the subject of intense research, in an attempt to optimize their performance while guaranteeing reliability in highly demanding scenarios. However, hardware constraints have limited their application, and real deployments have demonstrated that WSNs have difficulties in coping with complex communication tasks – such as mobility – in addition to application-related tasks. Mobility support in WSNs is crucial for a very high percentage of application scenarios and, most notably, for the Internet of Things. It is, thus, important to know the existing solutions for mobility in WSNs, identifying their main characteristics and limitations. With this in mind, we firstly present a survey of models for mobility support in WSNs. We then present the Network of Proxies (NoP) assisted mobility proposal, which relieves resource-constrained WSN nodes from the heavy procedures inherent to mobility management. The presented proposal was implemented and evaluated in a real platform, demonstrating not only its advantages over conventional solutions, but also its very good performance in the simultaneous handling of several mobile nodes, leading to high handoff success rate and low handoff time.

1. Introduction

Wireless Sensor Networks research has intensely addressed performance, reliability and capacity optimization, in an attempt to shorten the gap that separates them from conventional networks. However, WSNs are largely constituted by resource-constrained devices, whose characteristics are still far from those required by most applications. Advanced routing algorithms, neighbor and service discovery mechanisms, security, mobility and debugging, among others, are just examples of features that researchers are trying to implement in WSNs. Even though it is possible to install and evaluate them individually, the integration of all of these features with the aim of developing a reliable, complete system will, on one hand, limit the algorithms' complexity due to ROM and RAM restrictions and, on the other hand, contribute to a decrease in the lifetime of each mote due to added energy requirements.

While working on the GINSENG project [1], an European project whose main objective was the deployment of performance-controlled WSNs in critical scenarios, we faced this problem when we tried to include all features we considered fundamental in a real, deployed WSN, whose target was Petrogal's oil refinery in Sines, Portugal. In this case, the adopted solution was to remove some features and simplify the software installed in each mote, in order to still achieve the necessary performance without negatively affecting the network lifetime.

In [2] the authors also arrived at a similar conclusion, namely that motes must be relieved from the routing process and must become as simple as possible, acting just as end nodes and delegating routing procedures on more powerful entities. Basically, the authors advocate the separation of the sensing activity from the network operation activity. A similar line was taken in [3], in which the authors study the enhancement of mobile networks by adding infrastructure support, concluding that, in general, this kind of support is highly beneficial when mobility is concerned.

Since WSN nodes are frequently small, portable devices, which can be easily coupled to mobile entities such as vehicles or people, many applications require mobility support. Therefore, it is crucial to support efficient mobility mechanisms in WSNs, without compromising the main application operation and network lifetime.

Mobility in WSNs has been approached from several perspectives and targeting different goals, leading to a variety of solutions. In the first part of this paper we propose a WSN mobility classification and survey the main existing mobility approaches. This not only provides a broad view of the field, but also allows the reader to identify the potential and implications of the various options where mobility is concerned, constituting one of two main contributions of the paper.

* Corresponding author. Tel.: +351 962476436; fax: +351 239 701266.
E-mail addresses: rnsilva@dei.uc.pt (R. Silva), sasilva@dei.uc.pt (J. Sa Silva), boavida@dei.uc.pt (F. Boavida).

http://dx.doi.org/10.1016/j.comcom.2014.05.008
0140-3664/

Given the problems and limitations of the various mobility solutions, identified in the first part of the paper, in its second part we present and evaluate a WSN mobility support proposal, called Network of Proxies (NoP), designed to perform complex, time-consuming, processor-intensive and energy-demanding operations, such as mobility management operations, on behalf of WSN nodes. The Network of Proxies concept was originally proposed in [4,5], where we concluded that conventional node-based mobility solutions, such as MIPv6, could not meet the requirements of many WSN applications in terms of reliability and overall performance. NoP was then designed to overcome the problem, guaranteeing controlled end-to-end performance in the presence of high mobility while contributing to an extension of the WSN's lifetime. The entire NoP development process, assessment and final comparison with MIPv6 collectively constitute the second main contribution of this paper.

NoP's objective is to simplify the sensor network, moving the complexity from the motes to local proxies. These proposed proxies are machines without the stringent energy restrictions of sensor nodes, and with the ability to operate alone or to be part of a mesh network. They should be capable of monitoring each mote's link quality and determining when handoff should be done, taking care of it on behalf of mobile nodes. In this way, it is possible to keep mobile nodes as simple as possible, focusing their activity on sensing, and saving energy.

NoP was specifically designed for critical scenarios, such as GINSENG, in which the extra cost of a wireless mesh network infrastructure is largely compensated by the added reliability and performance control of the resulting system.

Although we are dealing with mobility support in this paper, the NoP concept can be used to support any other activity whose complexity level requires more powerful mechanisms, such as security.

This paper is organized as follows. The next section presents the general characterization of mobility in WSNs. Section 3 surveys WSN mobility support at the MAC layer, while Section 4 surveys it at the Network layer. Section 5 details the concept of Network of Proxies and its application to mobility support in WSNs, presenting an overview of implementation and operation aspects and concluding with a presentation and discussion of the NoP's evaluation results. Section 6 surveys important, related projects in this research field. The conclusions and guidelines for further work are provided in Section 7.

2. General characterization of mobility in WSNs

Mobility in wireless sensor networks can be classified considering the following aspects: the element that is mobile; the type of movement; the protocol level at which mobility is supported; and the entity who handles the mobility process. While the former two concern the physical aspects of mobility, the latter two regard the architectural aspects. The following sub-sections detail each of them.

2.1. Mobile element

Table 1 summarizes the mobility characterization in what concerns the WSN element that is mobile. As it can be seen in the table, two cases can occur: mobility of the sink node, and mobility of the sensor node.

Sink node mobility was introduced in [6,7], among others, with the objective of making sink nodes closer to each sensor node or sensor node cluster, in order to save the nodes' energy. A second objective was to avoid the high cost of maintaining long multi-hop paths.

Table 1
Mobile element.

Sink node	Mobile Base Stations (MSB) Mobile Data Collectors (MDC) Rendezvous (Hybrid)
Sensor node	Weak Strong robotic Strong parasitic

Three classes of sink node mobility exist: Mobile Base Stations (MBS), Mobile Data Collectors (MDC), and Rendezvous-Based solutions (which is a hybrid of the former two classes).

With Mobile Base Stations the sink node is capable of moving across the network, increasing the coverage and decreasing the number of hops to reach each node. Ref. [8] evaluates sink node mobility performance for various network topologies and types of movement.

Mobile Data Collectors (MDC), in turn, takes advantage of the capability of more powerful nodes (either sink nodes or other dedicated nodes) to perform on-demand collection, avoiding the need for data to travel through several hops. Ref. [9] introduced the concept of data mules, where mobile sink nodes move randomly, collecting data across the network. Ref. [10] proposed a solution where the trajectory of the Mobile Data Collector is not controlled but is known a priori, while [11] proposed a controlled MDC in real-time.

Rendezvous-Based solutions are a hybrid of the two previous classes of solutions: MBS and MDC [12]. Instead of uncontrolled mobility or on demand data gathering, [13] proposed a careful mobility/positioning of the sink node in order to better cover the network. The same author also introduced the concept of dynamically changing position, readapting to network changes.

Sensor node mobility can be classified into two basic modes [14]: weak mobility and strong mobility.

Weak mobility is the mobility forced by the death of some network nodes. Due to their intrinsic characteristics, namely hardware restrictions and battery operation, nodes have limited, often short lifetime. Consequently, new nodes must be added to replace dead nodes, thus leading to network topology changes.

Strong mobility, in turn, is the type of mobility associated with the movement caused by either an external agent (wind or water) or by an intrinsic characteristic of the sensor node. Strong mobility can be further subdivided into robotic and parasitic. In the former case, the sensor node has the capacity to move on its own. In the latter case, it is attached to a moving entity.

An example of robotic node mobility is Robomote [15], a wheel-equipped sensor node designed for easy deployment and low cost. Robomote was also equipped with two engines, one infrared sensor to detect obstacles and a sun-rechargeable battery. Despite the interest in and potential of Robomote, most existing applications are based on nodes attached to mobile bodies, i.e., on parasitic sensor node mobility. In [16] this issue is analyzed in depth, using various types of parasitism to classify the possible forms of association between motes and mobile bodies.

2.2. Types of movement

Mobility in WSNs can also be classified according to the type of movement of the moving entity. The following types are commonly referred to in the literature: random, pre-defined, and controlled. Random movement means that the moving entity (be it a sink node or a sensor node) moves randomly within the area under consideration. Predefined movement means that the entity moves along a specific path, with known speed, reaching each point of