Ad Hoc Networks 16 (2014) 70–87

Contents lists available at ScienceDirect

Ad Hoc Networks

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

Wireless sensor networks mobility management using fuzzy logic

Zinon Zinonos [a], Chrysostomos Chrysostomou [b], Vasos Vassiliou [a,*]

[a] Computer Science Department, University of Cyprus, 1 University Ave., 2019 Nicosia, Cyprus
[b] Department of Computer Science and Engineering, Frederick University, 7 Y. Frederickou Str. Pallouriotissa, 1036 Nicosia, Cyprus

ARTICLE INFO

Article history:
Received 4 January 2013
Received in revised form 2 July 2013
Accepted 5 December 2013
Available online 26 December 2013

Keywords:
Wireless sensor networks
Mobility
Handoff control
Performance control
Fuzzy logic
Industrial evaluation

ABSTRACT

This paper presents a novel, intelligent controller to support mobility in wireless sensor networks. In particular, the focus is on the deployment of such mobility solution to critical applications, like personnel safety in an industrial environment. A Fuzzy Logic-based mobility controller is proposed to aid sensor Mobile Nodes (MN) to decide whether they have to trigger the handoff procedure and perform the handoff to a new connection position or not. To do so, we use a combination of two locally available metrics, the RSSI and the Link Loss, in order to "predict" the End-to-End losses and support the handoff triggering procedure. As a performance evaluation environment, a real industrial setting (oil refinery) is used. Based on on-site experiments run in the oil refinery testbed area, the proposed mobility controller has shown significant benefits compared to other conventional solutions, in terms of packet loss, packet delivery delay, energy consumption, and ratio of successful handoff triggers.

1. Introduction

In recent years, applications of sensor networks have evolved in many areas due to their large applicability and development possibilities, especially in the Wireless Sensor Networks (WSN) area. Research on WSN has mainly been focused on protocols and algorithms for applications, in which large, random, and static deployment is the norm and in which node mobility and network performance assurances are not considered critical. In addition to the diverse applications, sensor networks pose a number of unique technical challenges because of their ad hoc deployment, unattended operation, and dynamic changes. Most sensor applications need the deployment to be infrastructure-less, without any human intervention. It is the responsibility of the sensor network to be adaptable to any physical changes like the addition of extra nodes or the failure of a number of them. In addition, there is only a finite source of energy, which must be optimally used for processing and communication. Nowadays, several application sectors like healthcare, industrial automation, urban sensing/computing, and vehicular sensor networks assume and incorporate the use of MN, usually in direct connection (one hop) from the data collection point (sink). However, it is expected that, in the near future, node and network mobility will become common for wireless sensor networks as well. In addition, in spite of the potential of WSNs, real deployments are rare and virtually all have considerable limitations when user mobility is concerned. These limitations include, among others, the need of extra hardware like directional antennas or GPS, and/or the existence of positioning methods. These solutions are difficult to provide the expected results in the case of harsh environments due to the propagation model characteristics arising from the physical environment [1]. Furthermore, the majority of the existing solutions are based on simulation results, something that usually denotes a mismatch between research and reality.

* Corresponding author. Tel.: +357 22892750; fax: +357 22892701.
E-mail addresses: zinonos@cs.ucy.ac.cy (Z. Zinonos), ch.chrysostomou@frederick.ac.cy (C. Chrysostomou), vasosv@cs.ucy.ac.cy (V. Vassiliou).

1570-8705/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.adhoc.2013.12.003

Mobility support in this work has been mainly motivated by the need to monitor the health and status of mobile workers in industrial settings. There are many hazardous activities in an industrial plant that need to be monitored for safety. One such activity is the cleaning and condition assessment of storage tanks in an oil refinery. Tanks are very hazardous environments and typically contain a toxic atmosphere and residues of their previous contents. When employees enter such hazardous areas there is a possibility to loose consciousness. Using orientation and heart or pressure monitoring sensors attached to employees, their condition can be monitored and alarms can be signaled when an emergency occurs. Surrounding the tank that is being cleaned are usual sensors deployed for other scenarios, e.g. production monitoring. As the mobile worker moves around the tank, orientation messages are sent from the sensor to the sink forwarded by intermediate nodes. Data may be sent via different intermediate nodes based on the location of the mobile worker. In order to continuously receive information from the mobile workers a mobility management technique must be implemented so as to enable the handoff between different access points, while at the same time maintaining strict performance guarantees for the critical application.

Supporting mobile nodes in an industrial environment is something that the existing industrial standards like WirelessHart [2,3] and ISA100 [4] do not give special attention to. WirelessHART and ISA100.11a use a centralized network management approach for communication scheduling and managing routes. Despite the advantages of such approach when the network topology and application requirements are static and heavily pre-configured, it is not certain how these standards perform in dynamic situations involving node mobility. The inability to properly handle mobility may result in problems, including increased packet loss, delayed data delivery, and increased downtime, all of which increase the overall energy consumption.

The uniqueness of this work is threefold. Firstly, an intelligent controller, based on fuzzy logic is proposed. This controller enables sensor MN to decide intelligently whether they have to trigger the handoff procedure and perform the handoff to a new position or not. Secondly, a real industrial setting (oil refinery) is used as the evaluation environment, something that poses new challenges regarding the design of mobility support. Thirdly, the approach taken has greater applicability to any WSN industrial environment or testbed setting with mobility requirements, due to the fact that it was designed based on network state parameters that are available to all sensor MN. The selection of fuzzy logic system was based on its simplicity and the fact that, since it processes experts-defined rules governing the target control system, it can be modified to improve system performance.

The overall system was implemented and evaluated in the context of the EU-funded GINSENG project [5,6]. The end user of the project was the company operating the Petrogal oil refinery at Sines, Portugal. The Petrogal refinery is a complex industrial facility, which includes a wide range of processing units that need careful monitoring and control of critical operations. Currently, the refinery is completely automated, but totally wired-based. Upgrades to the current wired system are impossible to perform in order to support mobile users. Therefore, a real WSN has been deployed in the refinery, targeting several specific scenarios including the monitoring of mobile workers (personnel safety scenario). Finally, to the best of our knowledge, GINSENG is the only work that considers the use of MN inside an industrial area.

The paper is organized as follows. In Section 2 background information and related work are presented and in Section 3 the basic methods for handoff control in industrial WSNs are discussed. Section 4 examines the proposed fuzzy logic-based mobility approach. In Section 5 the experimental evaluation and performance analysis are presented and, finally, in Section 6 the conclusions of this work are offered.

2. Background and related work

In critical applications, like personnel safety in an industrial environment, a real-time monitoring system must always be available. In order to efficiently monitor or control a mobile person moving in a WSN area, the mobile entity must be able to handoff between different supporting/anchoring nodes or networks while performing its movement. Therefore, the existence of a proper mobility protocol to control the handoff procedure is required.

Several proposals have appeared in the literature that attempt to control and accelerate the handoff procedure. These proposals can be classified based on the protocol stack layer the information they use to handle mobility belongs to. Therefore, there are solutions that are based on the Network Layer and solutions that are based on the MAC sub-layer of the Data Link Layer.

2.1. Network-based mobility handling

Internet Protocol (IP) mobility can be approached from three points of view: the first one, and also the most common solution, is to deal with the handoff procedure locally at the Network Layer of the mobile entity (MIPv6 [7], HMIPv6 [8]). The second approach uses information from Data Link Layer to speed up the handoff process (FMIPv6 [9]), and the third solution is based on a non-invasive method known as network-based mobility (PMIPv6 [10]). Even though, the aforementioned solutions were not designed for sensor networks, some of their characteristics can be used in a WSN mobility solution. In addition to that, some effort was done to integrate the Internet Protocol with the WSN [11] so that to exploit the benefits offered by the use of the IP protocol. The IETF 6LoWPAN [12] working group performed the most significant effort to this direction. The challenge for IP integration is to find ways to manage and overcome the limitations posed by sensor networks, like low power consumption, low duty cycles, low memory, and limited bandwidth. Some approaches to support mobility in 6LoWPAN have been defined. In general, those approaches [13–19] are lightweight extensions of IPv6 based solutions (MIPv6, HMIPv6, FMIPv6, PMIPv6). The main target of these approaches is to com-