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Z-Monitor: A protocol analyzer for IEEE 802.15.4-based low-power wireless networks

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ABSTRACT

Network sniffers are invaluable tools for designing, testing, commissioning and running distributed embedded systems. They become even more useful if these systems build on low-power wireless networks (LoWPAN), particularly when these scale in density and/or space and impose stringent quality-of-service requirements. This paper presents Z-Monitor, a low-cost and open-source network/protocol analyzer for LoWPANs. Z-Monitor is better than existing solutions since it combines the following features all-together: it covers the most widely used LoWPAN protocols, namely IEEE 802.15.4, 6LoWPAN, RPL and ZigBee; packet sniffing can be performed by any IEEE 802.15.4-compliant node, e.g., TelosB or MicaZ, requiring no extra hardware; the code is in Java (host PC), so it is OS-agnostic, and is freely available as open-source; Z-Monitor provides an user-friendly graphical user interface and a complete set of functionalities; nonetheless, Z-Monitor software architecture and programming approach are modular, so it is easily adaptable and extensible. We demonstrate and validate Z-Monitor in several LoWPAN network scenarios/settings and sites, ranging from a small-scale laboratory test-bed to a 400+ real-world deployment.

1. Introduction

Low Power Wireless Personal Area Networks (LoWPANs) are networks compliant to IEEE 802.15.4 [1] and characterized by *infrastructure-less*, *low-cost*, *low-power*, *low data rate* connectivity which make them suitable for a wide range of applications, paving the way for the implementation of the ubiquitous computing paradigm in real world environments. Ensuring that the LoWPANs are operating at the desired performance level in the design-and-test phase, as well as quantitatively demonstrating to the end-users that the application requirements are still met once the LoWPAN is deployed and active in the real environment is of paramount importance. Consequently, both network designers and system administrators need appropriate tools for network monitoring and protocol analysis [2,3]. These tools enable: (i) supporting system designers and

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network programmers in debugging protocols and algorithms, (ii) tracking the network behavior and promptly identify misbehaving elements, (iii) analysing network performance, and (iv) performing network management operations.

LoWPANs are typically composed of devices that conform to the IEEE 802.15.4 standard. With reference to the well known ISO-OSI protocol stack model [4], while the IEEE 802.15.4 standard only focuses on the lowest layers specifications, i.e., Physical layer (PHY) and Medium Access Control (MAC) sub-layer, upper layers (from the Network up to the Application) are defined by multiple standards, including ZigBee [5], 6LoWPAN [6,7], ISA100 [8] or WirelessHART [9].

ZigBee and 6LoWPAN/RPL are the most referred standards in the field of LoWPAN technologies. However, quite little is available on the market for their monitoring and debugging. Some commercial products exist for LoWPAN monitoring, but they suffer from several limitations, such as their *high cost* (hundreds of dollars in several cases), their requirement for *specific sniffing hardware* or their *proprietary nature*, which prevents users/application-oriented adaptation. To the best of our knowledge, no open and modular solution is available to enable network monitoring and debugging providing full support for the IEEE 802.15.4-based protocol family.

Consequently, motivated by the need to provide the network designers and developers community with a framework to monitor IEEE 802.15.4-compliant LoWPANs [10–13], in this paper we present our solution, Z-Monitor [14]. Accordingly, the contribution of this paper is twofold:

- to present the design features of the tool, whose primary goal is to be a LoWPAN protocol analysis tool, open source, free to use, modular, extensible and not constrained to the use of specific sniffing devices;
- to demonstrate the usefulness of this monitoring tool in different network scenarios.

A preliminary version of this tool has been presented in [15]. Since then, we have extended the tool to support a client-server approach for the implementation of the distributed sniffing mode. This paper builds on [16], extending it with a comparison with more solutions and more detailed experimental evaluation. We also add a detailed performance evaluation through several experimental testbeds to demonstrate the efficiency of the new features.

The rest of this paper is organized as shown in Table 1 and detailed next. Section 2 overviews the most relevant research efforts and commercial products in network monitoring. Section 3 outlines the basic concepts of the LoWPAN protocols considered in this paper. Section 4 details the software design of Z-Monitor, describes its main components and presents the standalone and distributed sniffing modes. Section 5 demonstrates the effectiveness of Z-Monitor through experiments in different LoWPAN testbeds, including a large scale and dense deployment covering three floors of an office building. Finally, Section 6 concludes the paper.

Table 1
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2. Related work

Several packet analyzer tools have been proposed to monitor IEEE 802.15.4-based networks. In what follows, we first present the most relevant products available in the market. Then, we survey the most recent research works related to the performance assessment of LoWPANs.

2.1. Related products

In this section, the most popular tools for IEEE 802.15.4 network monitoring and analysis are described.

Four commercial tools are briefly reviewed next, as representative classes of tools among those available in the market.

Sensor Network Analyzer (SNA) [17] is a monitoring software for ZigBee-based LoWPANs from Daintree Networks, a ZigBee Alliance's member. The SNA has advanced visualization capabilities and the ability to show the multihop network by evidencing the wireless links connecting the nodes. It also enables the end-user to view all devices and interactions simultaneously. It shows critical performance metrics, such as *end-to-end latency* or *packet loss*. The Daintree SNA product is a comprehensive solution for ZigBee and IEEE 802.15.4 testing, analysis and commissioning. However, as a software tool, it has been discontinued in 2010, it needed a special hardware adapter to sniff the packets, which made its cost relatively high, and it supported the ZigBee protocol only.

Perytons Network Analyzer (PNA) [18], also referred as 6LoWPAN sniffer, is a sniffing tool specifically designed for the 6LoWPAN protocol. PNA allows analysis of the network layer, encompassing the identification and visualization of the network topology, temporally aligned packets flow and message structure. PNA can export log files that can be