Dependence-based Multi-level Tracing and Replay for Wireless Sensor Networks Debugging*

Man Wang[1] Zhiyuan Li[1]
[1]Department of Computer Science, Purdue University, West Lafayette, IN, 47906 U.S.A
{wang80,zhiyuanli}@purdue.edu

Feng Li[2] Xiaobing Feng[2]
[2]Key Laboratory of Computer Architecture, Institute of Computing Technology, Chinese Academy of Sciences Haidian District, Beijing, China
{lifeng2005,fxb}@ict.ac.cn

Saurabh Bagchi[3] Yung-Hsiang Lu[3]
[3]School of Electrical and Computer Engineering, Purdue University, West Lafayette, IN, 47906 U.S.A
{sbagchi,yunglu}@purdue.edu

Abstract

Due to resource constraints and unreliable communication, wireless sensor network (WSN) programming and debugging remain to be a challenging task. Runtime errors must be constantly monitored, often by checking for violations of certain invariants. Once an error is detected, diagnosis must be performed to identify the origin of the error. Deterministic replay is an error diagnosis method which has long been proposed for distributed systems. However, one of the significant hurdles for applying deterministic replay on WSN is posed by the small program memory on typical sensor nodes. This paper proposes a dependence-based multi-level method for memory-efficient tracing and replay. In the interest of portability across different hardware platforms, the method is implemented as a source-level tracing and replaying tool. To further reduce the code size after tracing instrumentation, a cost model is used for making the decision on which functions to in-line. A prototype for the tool targets C programs is developed on top of the Open64 compiler and is tested using several TinyOS applications running on TelosB motes. Preliminary experimental results show that the test programs, which do not fit the program memory after straightforward instrumentation, can be successfully accommodated in memory using the new method such that the injected errors can be found.

Categories and Subject Descriptors D.2.5 [**Testing and Debugging**]: Debugging aids

General Terms Algorithms, Reliability.

Keywords Wireless sensor network; program debugging; invariants; dependence analysis; resource constrains.

1. Introduction

Wireless sensor networks (WSN) are gaining increased attention for possible use in applications such as structural health monitoring, environmental surveillance, scientific observation, and others [27,28]. A wireless sensor network typically consists of a large number of unattended wireless sensor nodes. Despite the increasing efforts [6,20] made to ease the development and simulation of WSN applications, sensor network programming and debugging is still a difficult task in view of resource constraints and unreliable communications on wireless sensor nodes.

Deterministic replay (or record-replay) is an error diagnosis method which has long been proposed for distributed systems. Under this method, nondeterministic events are recorded throughout the system operation. When an error is reported, the program can be re-run, with the recorded events restaged to allow the programmer to inspect the executed statements and the state change they cause such that the source of the error, namely the incorrectly written statements or unexpected events causing the error, can be located. The replay method significantly reduces the amount of information to record at run time.

In this paper, we make two main contributions to replay-based diagnosis on WSN. Firstly, we present a dependence-based multi-level tracing and replay scheme to significantly reduce the required program memory for record and replay in WSN applications. The severely limited program memory on WSN motes (48 KB on the popular TelosB motes, for example) has forced most existing schemes for run-time logging on WSN to record only coarse information which is far from sufficient for deterministic replay. This makes it difficult to pin-point the source of the errors which are detected at run time. Our scheme, lends an effective solution for the memory size problem. Secondly, based on our multi-level scheme, we develop a source-level tracing and replaying tool which is independent of the hardware platforms and the cross compiler (except for a system library call to make certain memory accesses atomic). The source-level tracing, compared to assembly-level tracing, offers high portability of the

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tool. It also enables the user to take advantage of many existing source-level debuggers, such as GNU's gdb, when replaying on a desktop machine.

The rest of the paper is organized as follows. Section 2 defines the problem addressed by this paper and gives an overview of our solution. Section 3 discusses how to reduce instrumentation based on dependence information and proves its effectiveness under a number of assumptions. Section 4 discusses multi-level tracing in case such assumptions are not satisfied. Implementation and experimental results are presented in Section 5. Section 6 summarizes related works on WSN debugging and deterministic replay and we conclude in Section 7.

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