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Rapid design and evaluation framework for wireless sensor networks

Mauri Kuorilehto [a,*], Marko Hännikäinen [b], Timo D. Hämäläinen [b]

[a] Nokia Technology Platforms, Visiokatu 3, FIN 33720, Tampere, Finland
[b] Tampere University of Technology, Institute of Digital and Computer Systems, Korkeakoulunkatu 1, FIN 33720, Tampere, Finland

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Abstract

The diversity of applications and typically scarce node resources set very tight constraints to Wireless Sensor Networks (WSN). It is not possible to fulfill all requirements with a general purpose WSN, for which reason the rapid development of application specific WSNs is preferred. We present a new framework called WIreless SEnsor NEtwork Simulator (WISENES) for the design, simulation, and evaluation of WSNs. The target WSN is designed in Specification and Description Language (SDL), simulated in WISENES, and implemented on target platform either through automatic code generation or manually. The high-level WSN model is back-annotated with the measured values from a real platform. In this way, very accurate WSN simulations can be performed with a rapid design cycle. WISENES itself has been verified with TUTWSN (Tampere University of Technology Wireless Sensor Network) and ZigBee protocols. The MAC protocol of ZigBee was designed in two weeks from scratch by one designer, which shows the effectiveness of WISENES. For accuracy comparison, the results show 6.7% difference between the modeled and measured TUTWSN prototype power consumption. WISENES hastens the evaluation of new protocol and application configurations, especially for the large scale and long-term WSN deployments.

Keywords: Wireless Sensor Network (WSN); Network simulation; Medium access control (MAC); Energy efficiency

1. Introduction

Wireless Sensor Network (WSN) applications are diverse ranging from toys to military systems. Typical challenges for WSN are large scale, constantly changing network topology, and error prone communications, while in WSN nodes processing and storage capacities, as well as energy resources are limited. Most often WSNs are demanded to be robust against environmental strains, and able to autonomously recover from error situations. Further, depending on the applications and the interaction with environment, time synchronization and security requirements can be strict [1,2].

Opposite to general expectations, an all-purpose WSN is not a reasonable goal, since it is impossible

* Corresponding author. Tel.: +358 71 800 8000; fax: +358 3 3115 4561.
E-mail addresses: mauri.kuorilehto@nokia.com (M. Kuorilehto), marko.hannikainen@tut.fi (M. Hännikäinen), timo.d.hamalainen@tut.fi (T.D. Hämäläinen).

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to meet all the real life constraints simultaneously. Instead, WSN protocol layers and their configuration parameters must be tailored to meet the specific application requirements. However, the design space is very large and makes the design automation the most important challenge for real working WSNs. A designer simply cannot handle all the parameters, functions, and their complicated dependencies without a tool support.

Prototyping can be applied to a single node functionality and small scale WSN testing. However, prototypes are not applicable for verifying the operation of e.g. a thousand-node network during a five year deployment. Even moderate sized networks benefit from extensive simulations, but the accuracy of simulation is very important. According to our experiences on real WSNs, the smallest and a minor-looking issue might cause severe changes for example in the network power consumption. Therefore, the accuracy of the design and performance estimations is not an option but essential for any real WSN.

Several legacy computer network simulators exist for the testing and modeling of communication protocols, but they omit WSN specific aspects. Proposed WSN simulators vary in their implementation, scale, and in the accuracy and coverage of the modeling of node platforms, protocols, and real world phenomena. Common features are the models for dedicated platforms, sensing, and wireless networking. However, none of the previous WSN simulators offers a complete and seamless design flow from abstract sketching to the real implementation.

Our WIreless SEnsor NEtwork Simulator (WISENES) framework is the first tool that enables the design, simulation, implementation and evaluation of WSNs with measured back-annotated information. WISENES is targeted to the design of deployable, real WSN networks. The main difference to the other proposed frameworks is that there is no need to carry out a separate high abstraction WSN modeling project and another development project for the actual implementation. Instead, WISENES supports all phases in the design flow. However, if preferred, WISENES can also be used for the plain simulations like other WSN simulators. In all cases, WISENES eases the assessment of the protocol and application interoperability, and the evaluation their applicability for different sensor node platforms.

The key benefit of WISENES is that the evaluation of protocols, applications, and their different configurations is carried out starting from the design phase. The framework defines rules and interfaces for a designer to the protocol stack and application implementation. The functionality, type, or composition of the protocols is not limited by the framework. Sensor nodes, transmission medium, and inspected phenomena are modeled separately in the WISENES framework. The WSN protocols and applications are implemented in Specification and Description Language (SDL) [3]. The models of high abstraction level SDL are compiled to executables used for both simulation and final implementation. Unlike in the other WSN simulators, target node platforms are not restricted to a specific pre-defined platform.

WISENES has been tested and its own performance evaluated with large TUTWSN (Tampere University of Technology Wireless Sensor Network) [4] and ZigBee networks [5]. For the evaluation of WISENES accuracy, real and simulated TUTWSNs are compared. However, the comparison of different WSNs themselves is not the primary scope of this paper.

This paper is organized as follows. Section 2 discusses the related work in the area of WSN simulation and presents the comparison of WISENES with the other WSN simulators. WISENES design is presented in Section 3 and Section 4 introduces the WISENES framework. The use of WISENES for TUTWSN and ZigBee protocol implementation is presented in Section 5. Section 6 gives the evaluation of WISENES, and the TUTWSN and ZigBee simulation results. Finally, conclusions are given and future work projected.

2. Related work

Legacy computer network simulators, such as ns-2 [6], GloMoSim [7], Qualnet [8], OPNET [9], OMNeT++ [10], Scalable Simulation Framework (SSF) [11], and J-Sim [12] enable the simulation of wireless network behavior and protocol stack operation but lack accounting for WSN characteristics. This is overcome in the simulators proposed specifically for WSNs, which we have categorized to *networking oriented* and *sensor node* simulators. The networking oriented simulators model the transmission medium in detail and are more suitable for the large scale WSN simulations. The sensor node simulators mainly simulate the operation of a single node but implement a lightweight communication model. Currently, there exist eleven relevant proposals for the networking oriented WSN