A Holistic Framework for Realistic, Reproducible, Real-world Sensor Network Experimentation

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I. Problem Statement

In order to correctly investigate and understand wireless sensor network (WSN) protocols such as data collection, dissemination, and IPv6 integration, real-world experiments need to be executed in a comparable and systematic way. Current WSN sites are built around specific scenarios and environments. In that sense, each site is unique with regard to its network properties, topological and hardware characteristics. This coupled with the real vagaries of the wireless communication very often leads to significantly different performance results of evaluation of protocols or applications within and across sites [5], [4]. Furthermore, the choice of experimentation sites which suit best a particular evaluation follows *the more is better* approach, rather than being systematically made. A systematic selection of experimentation sites is needed in order to ensure exposing the system under test to significantly different experimental conditions.

The goal of my dissertation is to architect a holistic framework for realistic and comparable real-world WSN experimentation. The contribution of my research consists of a set of experiment methodologies and control semantics that allow:

1) mapping experiments results within and across sites and then re-creating comparable situations for each instance when a site experiment is conducted;
2) automatic selection of experimentation sites - out of a set of sites - that are most adequate and diverse to run a specific experiment in order to ensure generality of the results.

We refer to the term site as a generic WSN deployment, like an indoor or outdoor testbed or a real WSN operating in the field. Although in principle the latter can be also used for experimentation, it is usually not preferred for this purpose because of its short-lived and often battery-operated nature.

II. Approach

As a core mechanism of the framework, I will devise a systematic methodology to assess the properties of WSN sites [3]. Network properties, topological characteristics (e.g., network diameter) as well as hardware characteristics of the nodes available in a network will be systematically measured, processed into aggregate-level statistics and used for comparing and translating results between sites. These systematic assessments will further enable protocol designers to choose the more appropriate and diverse experimentation sites on which to test their approaches. Then, as next mechanism towards higher reproducibility, I will consider the metropolitan-scale federation of WSN testbeds, TUDμNet [1]. It offers a testing environment of four sites at metropolitan scale, which gives the researchers the possibility to evaluate the very same software across all four sites simultaneously, something which tends to exceed what most protocols are tested against. My goal is to identify basic experiment description semantics and mechanisms with which the proposed federation can pursue accurate test job execution and control, as well as the exporting of jobs for their execution at other, external experimentation sites. Fig. 1 illustrates an example of a process of evaluating WSN code in TUDμNet. The nodes' firmware is submitted to the testbed server along with an *experiment script* that allows *fine-grained churn control* as well as *controlled environment actuation*. A set of testbed *site characterization parameters* together with the raw output data are fed back into a *site repository* after the experiment. Next, I describe the individual framework mechanisms defined as separate work packages.

A. Site Characterization

As observed by several authors [5], [4], it is usually infeasible to compare the results obtained when evaluating the performance of WSN protocols on different real-world experimentation sites. This is mainly due to the fact that no standard methodology exists to describe the experimental conditions under which results have been obtained. The lack of such methodology also makes it hard for protocol designers to choose the more appropriate experimentation sites on which to test their approaches. This work package addresses this problem by providing a holistic methodology to systematically assess the properties of WSN sites [3], [2]. The properties of each site include both its high-level but also low-level network properties, topological characteristics (e.g., network diameter) as well as the hardware characteristics of the nodes available in the network, among others.

B. Fine-grained Churn Modeling and Control

Sensor network protocols need to deal with network dynamics such as topology changes and node churn. Topology changes are caused by the highly dynamic and unpredictable bursty wireless links. They vary between poor and good delivery ratios, thus causing nodes to adjust their preferred neighbors (e.g., the parent node in a tree). Real-world wireless communication phenomena such as interference, multi-path

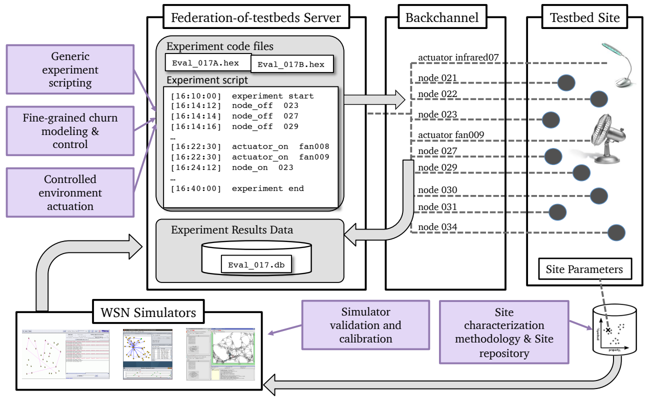

Fig. 1. Overview of the elements that are planned to be introduced to support realism and reproducibility (left), and where they influence the process of evaluating particular WSN code: The nodes' firmware is submitted to the server along with an *experiment script* that allows *fine-grained churn control* as well as *controlled environment actuation*. A set of *testbed site characterization* parameters are fed back together with the raw output data after the experiment.

reflection, and fading, among others, are a natural cause for topology changes. We refer to node churn as the changes in the set of the participating nodes due to node joins, graceful exits and failures. It is typically a result of software/hardware faults or defined as part of the application logic (e.g., mobile nodes). Evaluating a protocol's agility in reacting to these dynamics is thus necessary. However, it is difficult to reproduce similar situations on a normal deployment. In this project, I will:

1) characterize churn models observed in sensor network applications;
2) devise mechanisms to semantically describe the identified (in addition to user-defined) execution scenarios, i.e., the desired spatio-temporal changes in the test job's node set;
3) extend the TUDμNet core software to enable a reproducible experiment execution that effects the specified churn changes into the corresponding nodes with predictable precision (not only with regard to the nodes but also the exact point in time). We will consider node firmware reprogramming and erasing techniques, as well as features of the USB backchannel to power off/on targeted nodes, among others.

C. Generic Experiment Scripting

In this work package I will investigate the ability to submit an experiment script file along with the sensor nodes' firmware. This allows reproducing experiments that depend on certain events according to a timed script. The approach will build on top of the fine-grained churn modelling allowing emulation of node failures at particular times during the testbed experiment. It will offer researchers the possibility to script further the control of the experiment via external actuators and in that way influence sensor readings (e.g., turning on lighting or heating units to influence light, infrared, or temperature sensors). The generic scripting will not only facilitate the experimentation process but also increase controllability of experiments. In the context of my dissertation, I will:

1) construct semantics for formulating the experiment scripts;
2) integrate new code components in the federation that allow submitting and executing these scripts.

D. Controlled Environment Actuation

For this last work package, I will start with augmenting the testbed deployments at two of the indoor sites in TUDμNet, and use off-the-shelf actuators that can immediately be integrated in the USB backchannel. By extending the testbeds with additional actuators, in particular relais-controllers and fans, it will be possible to exert control on the environmental conditions that the system under test can later try to detect. This automatization will not only allow more remote usage of the testbed by non-local WSN researchers and reduce event generation costs, it will also enhance reproducibility of the results and can thus be expected to contribute to more rigorous experiment design. In a second phase of this work package, more of such actuators will be explored and integrated in the available testbeds, including the outdoors site, to verify that the actuation components available from the scripting capabilities delivered by work package II-C remain valid across a wide variety of scenarios.

III. Short Bio

I am a second year PhD student at the Databases and Distributed Systems group in the Computer Science department at the TU Darmstadt, Germany, working under the supervision of Prof. Alejandro Buchmann and Prof. Silvia Santini. My main area of work is experimentation in Wireless Sensor Networks. I hold a master degree of Electrical Engineering and Information Technology from TU Darmstadt. I expect to graduate within the next three years.

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