Poster Abstract: TUDμNet, a Metropolitan-Scale Federation of Wireless Sensor Network Testbeds

Pablo E. Guerrero,
Alejandro P. Buchmann
Databases and Distributed Systems
Technische Universität Darmstadt
<lastname>@dvs.tu-darmstadt.de

Abdelmajid Khelil
Dependable, Embedded Systems & Software
Technische Universität Darmstadt
khelil@cs.tu-darmstadt.de

Kristof Van Laerhoven
Embedded Sensing Systems
Technische Universität Darmstadt
kristof@ess.tu-darmstadt.de

***Abstract*—To address the real-world challenges in sensor network evaluation, testbeds have been proposed to enable experimentation without taking the typical deployment hurdles of robustly mounting the hardware, installing batteries, and instrumenting sensor nodes for data collection. In the recent past, several research institutions across Europe proposed to federate their testbeds. However, providing scalability and transparency despite the high heterogeneity in hardware and software between sites proves to be a tough problem. In this paper we introduce TUDμNet, a metropolitan-scale federation of sensor network testbeds that spans several buildings within a city. We describe its architecture, the current sites and the control infrastructure as solution for managing experiments at metropolitan scale.**

I. Introduction

Current research in sensor actuator networks has mainly concentrated on lab work and simulation experiments which are reproducible yet simplified in nature, and realistic deployments that show feasibility yet make it difficult to explore parameters. Sensor network *simulators* like COOJA [7] or TOSSIM [6] are able to scale up to thousands of nodes, but do not always capture all phenomena from the target environments. Working directly on *deployments* as in [8], [5] exposes the system to the conditions of the real environment, but logistical hurdles such as mounting hardware, installing batteries, programming (i.e., flashing) sensor nodes and instrumenting them for experiment data collection make it harder to repeat experiments. *Testbeds* have been suggested as an in-between solution that allow for experimentation in realistic scenarios as well as theoretical exploration.

Related work in testbeds includes examples such as TWIST [3], an indoor testbed including 204 nodes (TelosB and eyesIFX) where users resort to a set of scripts to indirectly program sensor nodes and collect debug data. MoteLab [9] includes around 190 TelosB nodes spread through offices in a three-story building, where test jobs are defined and scheduled through a web interface while debug data is logged into a centralized database for later evaluation. The Kansei testbed [1] features higher sensor node heterogeneity at a comparable scale (15x14 grid with Stargates and XSM nodes).

This work has been partially supported by the German Research Foundation (DFG) Research Training Group Nr. 1362, *Cooperative, Adaptive, and Responsive Monitoring in Mixed Mode Environments*, GKmM, as well as the Hessian LOEWE Research Priority Program *Cooperative Sensor Communication*, Cocoon.

	realism	scale	controllability	examples
simulator	+	+++	+++	TOSSIM, COOJA
target deployment	+++	++	+	GDI, Agro
single testbed	++	++	+++	MoteLab, TWIST, Kansei
testbed federation	++	+++	++	WISEBED
	++	++	+++	TUDμNet

TABLE I
Approaches to sensor network experimentation

In order to reach an even larger scale, the WISEBED EU project [2] aims at aligning several testbeds located in multiple european countries through a unified, loosely coupled management interface. The sheer variability in hardware and software encompassed by these testbeds highlights a challenge that remains open and is targeted in this work. (Table I summarizes the aforementioned experimentation approaches.) We present a metropolitan-scale federation of sensor network testbeds, TUDμNet, that spans several buildings within a city. We describe our control infrastructure as a solution for managing a variety of experiments at a metropolitan scale, present the ongoing work and planned applications.

II. TUDμNet Overview

Similarly to other testbeds, TUDμNet's architecture is structured in three tiers (cf Fig. 1). The first tier is composed of the sensor nodes which run the software being tested. This can be generated from a normal `build` system like Contiki's or TinyOS's. Our testbed currently contains a mixture of TelosB, Tmote Sky, JCreate and Z1 nodes, all based on the MSP430 micro-controller, and a variety of sensors populated in each node. The second tier is composed of simple gateways which are permanently connected to a number of sensor nodes via USB cabling. Between 2 to 10 sensors nodes are managed by a gateway, and each testbed is composed of (currently 1 to 30) of these gateways. For this tier we've opted for the Buffalo WZR-300NH router, on which we run OpenWRT customized with sensor node management tools (e.g., serial forwarder, BSL). Finally, a central server orchestrates the entire federation activities. The traffic between the various testbeds (and in turn their gateways) and the server is routed through MANDA, a

Metropolitan Area Network (of DArmstadt) operated at Gbit/s speed. TUDμNet currently encompasses three testbeds, chosen to fit certain well-defined scenarios. The first testbed is located at the CS Dept.'s office & lab building, which spans three floors. This is mostly for experimentation with networking and sensing/actuation aspects. The second testbed is located at the GKmM Lab at the Technology and Innovation Center (TIZ bdg.), where a disaster scenario arena is monitored with gas detectors uniformly spread through multiple planes. The third deployment is located at the Architecture Dept.'s solar house (the surPLUShome), an award-winning architectural design that produces surplus energy above what it uses. These sites are summarized in Table II.

	site		
	CS Dept.	GKmM Lab	surPLUShome
nodes	62 TelosBs, 20 Z1s	50 TelosBs	20 Z1s
sensors	light, humidity, temperature acceleration	light, humidity, temperature, CO CO_2	light, high precision temp., humidity and CO
focus	networking aspects, sensing & actuation	gas plume detection	environmental monitoring

TABLE II
CURRENT TUDμNET TESTBEDS

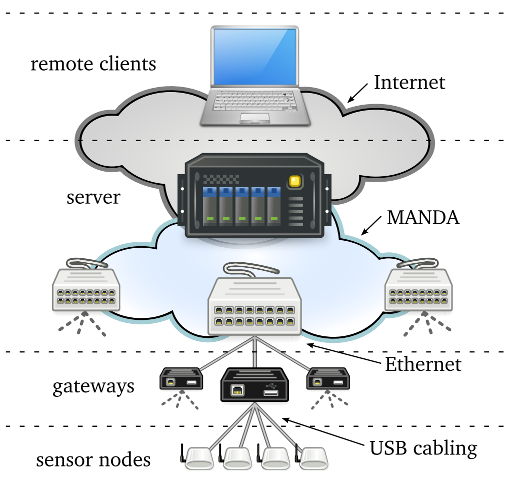

Fig. 1. TUDμNet's architecture

A. Logical Organization

Beyond the physical structure, TUDμNet organizes all its sensor nodes by means of node *zones*. We pick up the idea once started in MoteLab, and extend it with our concepts from Scopes [4], a network structuring mechanism for sensor networks. At their core, zones are simple subsets of a parent zone (at the top, the universal set contains all nodes). Fig. 2 depicts the current structure. The federation enables concurrent jobs (i.e., any two jobs that partially or totally overlap temporally), as long as they are scheduled for zones with disjoint sets of nodes. This requires a verification of node availability even among sibling zones, since these are not necessarily disjoint. As with any flat organization, as the system scales up, the benefits of a hierarchy become more evident. The hierarchy can be easily altered through the administrative interface.

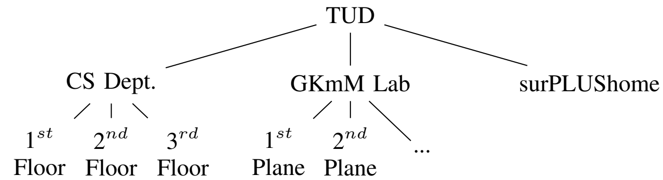

Fig. 2. Logical structure

B. Implementation

TUDμNet's core is based on that of MoteLab, on which we've implemented our concept of zones. Given that we perform the management of the zone hierarchy centrally, verifying the availability of nodes for a submitted job is straightforward. Authorized users can log into the system, upload binary images, schedule jobs at different zones and retrieve their job's data. We have implemented a number of features like *public/private* jobs (e.g. for sharing common jobs like data collection, setting node ids, etc.); a simple visualization of the federation zones' status as an overlay on a map; scripts for direct node access, among others.

III. CONCLUSIONS AND FUTURE WORK

Building a testbed federation, even at metropolitan scale, poses exciting challenges which require neat engineering solutions. Our hardware infrastructure, together with the concept of zones, offers a simple and manageable solution to federating multiple testbeds. We are working on a number of aspects, including expanding the geographic coverage; deploying nodes on remote controlled and autonomous vehicles as well as human-worn; further exposing node and sensor heterogeneity to the user; zone-based access control, and sensor node fault emulation.

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