Poster Abstract: MOTEL: Towards Flexible Mobile Wireless Sensor Network Testbeds

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***Abstract*—In this paper, we propose a novel architecture for wireless sensor network testbeds, called MOTEL. The main novelty compared to existing architectures is the possibility to include mobile sensor nodes. To support mobility, we deal with two main challenges: controlled mobility of sensor nodes, and the need to operate sensor nodes in the absence of a backchannel. We address these challenges together with traditional testbed requirements such as experiment repeatability, on-node logging, debugging and re-programming. MOTEL consists of two main components: MuRobA, a coordinated multi-robot architecture for enabling controlled mobility of the sensor nodes, and FLEXOR, a flexible sensor network architecture for enabling backchannel-free WSN experiments. MOTEL is work in progress and here we present the general architecture design of both MuRobA and FLEXOR, along with our first implementation and evaluation.**

I. Introduction and Motivation

Typical wireless sensor networks testbeds, such as the widely used TWIST [1], consist of several dozens to several hundreds of statically installed, backchannel assisted sensor nodes, and are remotely accessible for re-programming and result data gathering. Such backchannel based systems are convenient and easy to use, but they cannot incorporate node mobility. Moreover, they cannot completely substitute testing in a real world environment with its harsh properties such as battery unreliability, fluctuating radio transmission quality, specific topologies, limited access to the nodes and thus limited debugging and re-programming capabilities.

We propose a novel, flexible and extendable software architecture for mobility-enabled wireless sensor network testbeds, called MOTEL. Its main goal is to allow the rapid deployment of WSN testbeds in any environment, with current focus on indoor environments. Two main challenges need to be addressed: the eliminated backchannel and the controlled mobility of sensor nodes. We address the first one with FLEXOR, a flexible software architecture, which allows remote debugging, code exchange and data logging on sensor nodes without the need of a backchannel. The second challenge is addressed with MuRobA, a multi-robot architecture that allows planning and execution of well-defined mobility scenarios as opposed to the typically used random mobility.

II. Overview of MOTEL

Currently, MOTEL can be viewed as the combination of two independent components: MuRobA and FLEXOR. The sensor nodes run on FLEXOR (detailed in Section IV) and are piggybacked on robots, which run MuRobA. This can be seen in Figure 1, where sensor nodes are simply placed on top of robots. Both FLEXOR and MuRobA are highly modularized, platform-independent software architectures, which allows the usage of theoretically any sensor or robotic platform and any operating system or even simulator. We currently work with Memsic's TelosB as sensor network platform and with e-puck [2] as mobile robotic platform.

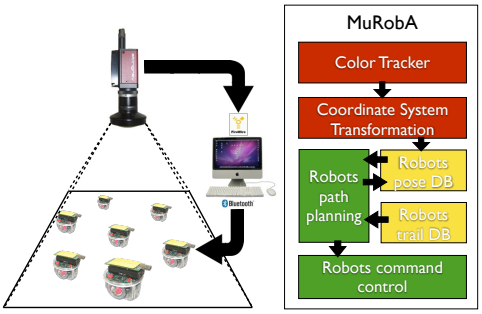

Fig. 1. Overview of MuRobA: the robot control system.

III. MuRobA: Multi-Robot Architecture for Coordinated Mobility

The overall MuRobA architecture is presented in Fig. 1. It consists of mobile robots, a camera attached to the ceiling, and a central computer. The computer analyzes the frames of the camera to estimate the current position and orientation of the robots and sends commands to the individual robots to follow predefined paths. In our current setup, we use a color camera equipped with a fish eye lens and working with a frame resolution of 2452x2056 pixels. With this setup, we are able to track all robots in a room of 9.80 m x 9.80 m. The camera is connected with the computer over a FireWire interface. The vision system tracks the position of colored paper patches placed on top of the robots. Figure 2 shows a sample camera image and the automatically detected robots in it. One particular issue is the mapping between robot IDs and detected color patches in the image. We chose not to use pre-assigned IDs or individually colored patches, but rather apply a system of trial and error: the control system gives a command to one of the robots to move and observes which

one really moves. This approach allows for rapid and fully automatic deployment of MOTEL in any indoor environment.

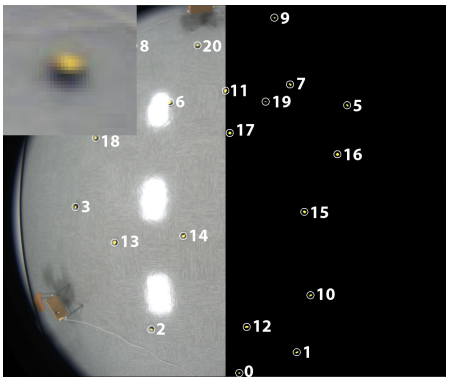

Fig. 2. Tracked robots from the ceiling camera.

The sensor nodes are placed on top of the robots and have no connection with them. The robots use a separate radio to communicate with the central control unit. They have their own micro-controller and power supply. This approach has the advantage that sensor network related experiment results – e. g. power consumption measurements or communication overhead – are not influenced by robot traits.

IV. FLEXOR: Flexible Runtime Management Software Architecture for WSN

The FLEXOR software architecture is designed to support the testing and management of WSN protocols and applications, mainly on MOTEL, but applicable to any WSN deployment. Its main goal is to provide run-time support to experiments on backchannel-free sensor networks in terms of on-node data logging, remote node control, and easy module exchange without explicit re-programming; tasks, which are usually enabled through the testbed backchannel. Our solution is to enable protocol/application exchange in a fast and low overhead manner and to allow for remote callback invocation in a multi-hop environment. FLEXOR relies on the fact that most real-world sensor network protocols and applications are the combination of a limited number of modules. Oftentimes, a testbed is used for comparing the performance of several protocols or algorithms, such as routing or link quality protocols. However, with native implementation, the hassle-free exchange of these modules is for all practical purposes impossible. FLEXOR, on the other hand, defines clear interfaces for the implementation of modules, so that they can be easily exchange during runtime. Furthermore, its core implements remote callbacks in multihop networks, which further allows us to control all nodes in the testbed without direct access to them.

The overall system architecture of FLEXOR is presented in Figure 3. We define clear interfaces for modules (components) and clear rules on how to inter-connect them (system specifications). All the required modules are pre-loaded on the system and reside inactive in its memory. A FLEXOR component called *ModuleManager* connects the modules on demand according to pre-loaded or run-time defined system

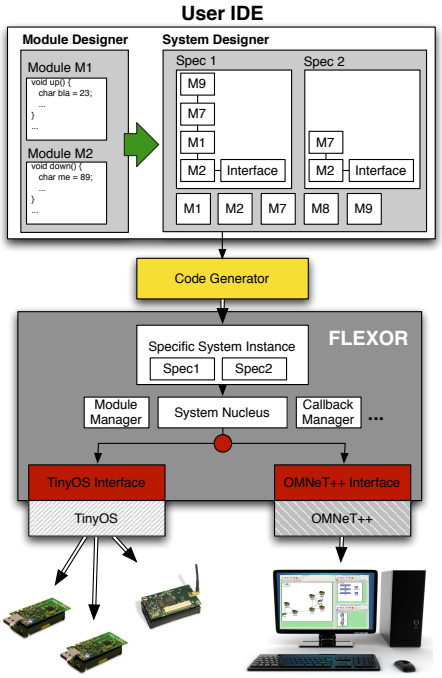

Fig. 3. FLEXOR system overview from the user to the hardware platform.

specifications. FLEXOR's core components enable local logging, remote parameter control, and callback invocation. These features make it possible to effectively assemble an ad hoc mobile infrastructure-free testbed that mimics the features of a real-world deployment.

FLEXOR is completely platform-independent and can be implemented over any embedded operating system, simulation system, middleware, etc.

V. Next Steps

Our immediate next steps include the full implementation of MuRobA and the evaluation and testing of the complete MOTEL. In future, we also plan to extend MOTEL by a physical connection between sensor nodes and robots, thus allowing steering the mobility from the sensor nodes and giving back some of the functionality of a backchannel. Furthermore, we plan automatic recharging stations for the robots, which will help us automating MOTEL and making it available as remotely shared testbed. Last, but not least, we work on the implementation of MOTEL for outdoor environments, which will require mainly a new localization system for MuRobA.

Acknowledgments

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