Simulating the Internet of Things in a Hybrid Way

Michael Kirsche
Computer Networks and Communication Systems Group
Brandenburg University of Technology Cottbus, Germany
eMail: michael.kirsche@tu-cottbus.de

***Abstract*—This research statement describes the author's PhD project, which aims at bridging the current gap between system level simulation (e.g. Cooja) and generic simulation environments (e.g. OMNeT++) when simulating Internet of Things applications. The proposed hybrid combination of currently available systems and the integration of accurate protocol models will allow for an accurate and holistic simulation of Internet of Things systems.**

I. Introduction

Wireless sensor networks (WSN) provided researchers with a variety of topics and challenges over the last decade. As they now come into a period of increased practical employment, researchers face additional challenges in closing the gap between scientific environments and real life deployments. Closing this gap is today mainly based on shifting the original focus of research on customized and non-standard-conform communication and networking protocols, inadequate to resemble or directly interact with long term Internet-based standards, to the use of downscaled, yet fully compliant, Internet protocols like TCP/UDP and IPv4/v6 for WSNs. The IPv6 Low-Power over Wireless Personal Area Networks (6LoWPAN) [1] standard was a major step in this direction of connecting wireless sensor networks to the Internet. 6LoWPAN and the timely introduction of small-scale IP stacks like uIP [2] enable the so-called *Internet of Things* (IoT), which stands for a direction integration of resource constrained sensors and actuators into the Internet. This leads both to new possibilities as well as new challenges, especially in the area of pre-deployment simulation-based system analysis and validation.

Accurate simulation of sensor nodes is nowadays often coupled to the operating system running on top of the node. Most of the specialized WSN operating systems provide a more or less complex simulation environment for developers; Cooja [3] for Contiki OS [4] and TOSSIM [5] for TinyOS [6] being two of the most well-known representatives of this class of embedded operating system simulators. Both simulators are similar in their main purpose – simulating the behavior of a WSN operating system – yet their approaches vary and differ from generic simulation frameworks like OMNeT++ [7] or ns-3 [8]. Cooja, for example, includes different levels of abstraction for simulation purposes. It enables developers to simulate networking protocols as well as the operating system itself and the machine code running on the node thanks to accurate microcontroller simulators like MSPsim [9]. While machine- and operating system-level simulation is a strong point of Cooja, simulation frameworks like OMNeT++ provide users with a much wider variety of network and communication protocols and Internet system representations. Both types of simulators thus have their specific strongholds and associated weak points. It is easy to create accurate simulations on the network protocol layer for complex topologies and diverse systems with OMNeT++, while operating system representation is completely left out in OMNeT++ and accurately covered by Cooja. A combination of both approaches to provide an accurate and holistic simulation environment for Internet-based systems as well as sensor nodes and networks should hence be favored. This combined holistic simulation environment is the basic idea behind the author's PhD project.

II. Scenario

The author proposes a hybrid simulation environment to conduct IoT simulation studies and further enhance pre-deployment system analysis. When we look at possible IoT deployments (refer to [10] for an example listing), we notice that large scale deployments need more than just sensor nodes and border routers. The complexity of these deployments includes various types of sensor networks as well as Internet-based systems (e.g. data storage, processing or analysis units). The integration of sensors and actuators into the Internet leads to an increase in complexity for the developer and the researcher too, since he has to take interaction with multiple systems and different communication architectures into account. What we hence need for a simulation of Internet of Things applications is an adequate representation of Internet-based systems and (at the same time) an accurate modeling of underlying wireless technologies and communication protocols inside the WSN. We are therefore interested in the correct representation at node, system and network protocol level at the same time, to provide researchers with a solution that enables them to test their application protocols during the pre-deployment phase.

An example scenario for this was already described by the author in [11]. In the depicted scenario, the Extensible Message and Presence Protocol (XMPP) is used as a border crossing application protocol to bring together the Internet and the worlds of sensors and actuators. To test the actual implementations and protocol mechanisms, we need more than just currently available OMNeT++ models for sensor network protocols or Cooja-based simulations that are isolated from Internet-based systems. We need to take the interconnection of both worlds (Internet as well as WSN) into account, to bridge the gap between the two worlds and enable a transboundary simulation from the single node itself to the interconnection of multiple WSNs with Internet-based systems.

III. Approach and Contributions

Several steps are planed to reach the goal of the described hybrid simulation environment to conduct Internet of Things simulation studies. The first step is the "integration" of an accurate operating system simulator into a generic simulation environment. The author chose Contiki and OMNeT++ for this. Contiki has proven to be an adequate choice for IoT scenarios and has a wide support for embedded sensor and actuator hardware. OMNeT++, on the other hand, is a widely used simulation library with a big community and a large set of available simulation models and extension frameworks. The integration of Contiki into OMNeT++ is part of an ongoing research effort. Our current status is that we managed to integrate the first essential parts of Contiki for an accurate IoT simulation of the lower layers, namely 6LoWPAN and parts of the uIP stack. We want to emphasize that "integration" here means a tightly coupled cooperation between both simulators, as we can hardly integrate the complete system single-handedly or even rewrite one of the simulators for a direct code inclusion. We favor ways of combining both simulators or at least important parts necessary for the simulation of IoT systems. Through our integration, we can hopefully achieve an accurate representation of the sensor node's operating system and microcontroller performance in the generic OMNeT++ framework, which provides support for the application layer protocols and connected Internet-based systems.

A second step is the accurate representation of protocols from the different layers of the used network stacks. We try to use real life protocol implementations as far as possible here. Although certain lower layer protocols like IEEE 802.15.4 are modeled quite accurately in OMNeT++ [12], we think that using actual implementations, wrapped inside our simulation environment, will provide for an even better accuracy. The wrapping approach resembles the *Network Simulation Cradle* described in [13]. We want to omit the typical problems (refer to [14] for additional details) of modeling simplifications and protocol behavior abstraction that counteract the need for accurate simulation results. This combination of wrapped real life protocol implementations and inclusion of accurate hardware-level and operating system simulation is hopefully a major contribution as certain aspects of communication protocol behavior are yet uncovered by simulators like OMNeT++. One of the main aspects we are concerned about are the runtime characteristics of protocols, especially on resource constrained systems (i.e. how long does a protocol operation last on a microcontroller). With the integration and combination of accurate hardware and operating system simulation approaches into OMNeT++, issues like the non-existence of protocol runtime characteristics can ideally be omitted, which in the end leads to more accurate simulation studies when compared to real life deployments.

IV. Final Remarks

Recent publications like [15] show that there is an increased interest in the covered topic. The authors of [15] discussed three different approaches to overcome the limitations of today's available simulators. While we share their basic opinion that the currently available simulation support for Internet of Things applications and systems is insufficient and improvements are necessary, we differ in our choice of the underlying software and the basic approach.

Providing developers with accurate IoT simulators and validation approaches for their protocol implementations is indeed necessary. To fulfill this need, the author proposed a hybrid simulation environment, based on a combination of available generic frameworks and system level simulators together with support for real life protocol inclusion. This might reduce the gap between research and practical deployments and strengthen the option of simulative studies for the IoT area. In conclusion, we think that the described strategy and the planed contributions can be a stepping stone for a hybrid simulation environment for the Internet of Things domain.

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