CORAL-SDN: A Software-Defined Networking Solution for the Internet of Things

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***Abstract*—Recent proposals enhances Wireless Sensor Networks (WSNs) with Software Defined Networking (SDN) practices, introducing new innovative network control strategies and protocols based on a central control logic, i.e., enabling WSNs as crucial facilities for the Internet of Things (IoT). In this direction, we demonstrate CORAL-SDN, an SDN solution for WSNs which: (i) uses intelligent centralized control mechanisms to adjust dynamically the protocol functionalities; (ii) supports elasticity to the challenging requirements of the WSNs; (iii) maintains a scalable architecture; and (iv) exhibits improved network management and operation in terms of performance and resource utilization. With this demo we provide a suitable environment for hands-on experimentation, featuring the CORAL-SDN protocol operation in real test-beds and highlighting the improvements that SDN brings to IoT.**

I. Introduction

WSNs today are becoming a key-enabling technology for the Internet of Things, introducing a new range of WSN applications integrated to the traditional Internet infrastructure. The transition of WSNs to the new era of IoT, introduces new challenges and imposes the exploration of novel ideas in terms of new applications. Major relevant issues are interoperability, heterogeneity, mobility, quality of service, and security.

Software-Defined Networking is a new approach that targets the above challenges, exploiting new flexible logically centralized network architectures. Recent research endeavors [1],[2] and [3] are blending SDN architectures with WSNs technologies forming a new approach for SDNs called software-defined wireless sensor networks (SDWSNs).

The SDWSN paradigm brings new ways in the WSNs architecture, control, management, and operation. For example, it allows new improved WSN routing and topology control protocols, by offloading network control intelligence to a central controller, reducing computational process for the low power motes, achieving energy efficiency. On the contrary the increased amount of control packets that SDN produces, impairs the low quality of radio communication. Moreover, the solutions integrating SDN with WSN are limited and they do not consider fundamental characteristics of wireless networks, such as mobility and radio signal issues.

To address the aforementioned challenges, we design and implement the OpenFlow-like CORAL-SDN protocol. CORAL-SDN decouples complexity from the network protocol and offloads it to network control software deployed at the surrounding fixed infrastructure. It supports dynamic deployment and configuration of SDN enabled topology and flow control mechanisms. In this demo, we investigate and evaluate experimentally the operation of a WSN using CORAL-SDN. Specifically, we apply network control using our two novel topology control algorithms [4] and two flow establishment and forwarding techniques that can be combined and adjusted on-demand. For the demonstration, we use our awarded[1] SDN experimentation facility CORAL [5], a general infrastructure facility for testing protocols and networking mechanisms for the Internet of Things using real testbeds.

In this demo, we show how CORAL-SDN: (i) improves WSN management, control, and operation in terms of performance and resource utilization; (ii) enhances network control intelligence through centralized control and dynamic protocol adjustments; (iii) enables elastic network operation utilizing cross-layer information; and (iv) supports scalable evolution through a modular extensible architecture.

II. The CORAL-SDN Architecture & Implementation

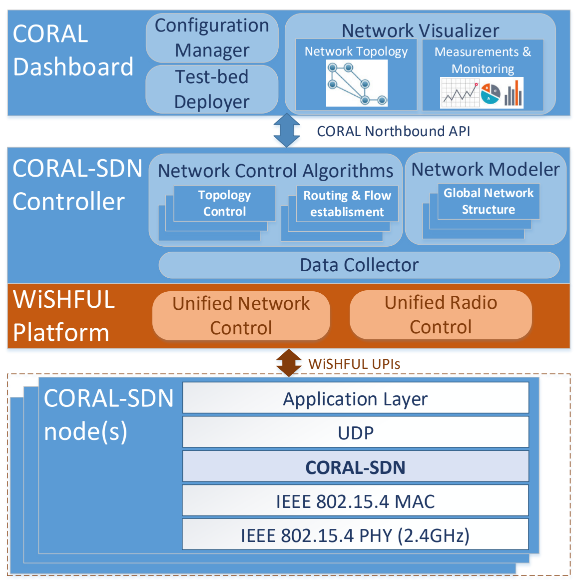

Fig. 1. CORAL-SDN Architecture Design

Fig. 1 depicts the CORAL architecture and the interfaces between the different components. We implemented the CORAL-SDN network stack using the C programming language. It operates inside IoT devices' firmware, compatible to Contiki-OS 3.0 and consists of the following layers: the *IEEE 802.15.4 PHY* and *MAC* layers**,** offering standardized low-power and lossy wireless communication and media access control in the band of 2.4GHz; the *CORAL-SDN* forwarding layer**,** our own protocol in the data plane side, that maintains the forwarding table; the *UDP* and the *Application* layers, that send sensor data measurements in UDP packets.

The *CORAL-SDN Controller* module, acting likewise as an SDN controller, is responsible for the centralized management

[1] eWINE Grand Challenge 1st runner up award – CORAL framework (*https://ewine-project.eu/grand-challenge/*)

of the network flow control. It materializes the intelligence of the networking layer protocols using alternative *Network Control Algorithms*. In particular, it handles the following tasks: (i) maintains an abstract view of the network connectivity in the *Network Modeler* using topology control algorithms; (ii) performs high-level network flow control; (iii) adjusts dynamically the protocol parameters; and (iv) incorporates, using the *Data Collector,* a variety of cross layer connectivity information, like the Received Signal Strength Indicator (RSSI) and the Link Quality Indicator (LQI). The CORAL-SDN controller is implemented in JAVA programming language and it is designed in a modular scalable approach that easily accommodates new algorithms and intelligent functionalities. It depends on the WiSHFUL platform (https://github.com/wishful-project) that provides *Unified Radio and Network Control*. The WiSHFUL platform enables a level of abstraction through a set of Unified Programming Interface commands (UPIs), capable of retrieving and altering data inside the network protocol stack. It supports heterogeneity decoupling the network infrastructure from the network management module.

On the northbound, the CORAL-SDN controller is connected with the *Dashboard* (Fig. 2), which constitutes a highly flexible GUI visualization tool based on the NODE-RED platform (i.e., https://nodered.org). This interface visualizes the network topology and shows various measurements. It also offers to the user management functionalities and configuration parameters discussed in the next section. More details of the CORAL-SDN architecture and operation can be found in [4] and [5].

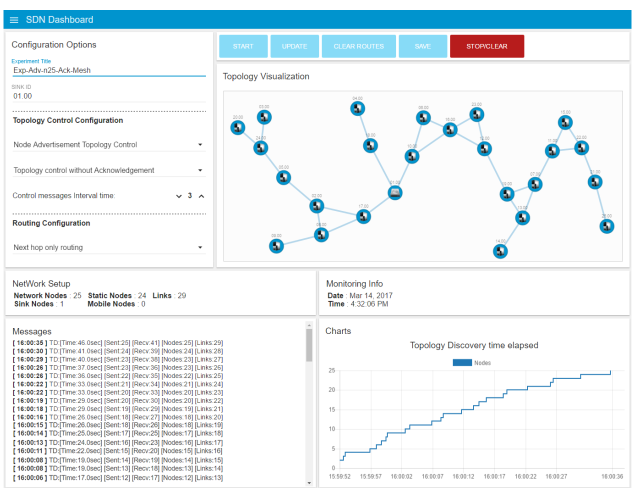

Fig. 2. The CORAL-SDN Graphical User Interface (Dashboard)

III. Demo Description

The demo can operate in two IoT WSN real test-beds: a) the IMEC w-iLab.2 (http://wilab2.ilabt.iminds.be) test-bed based in Ghent, Brussels, equipped with forty (40) RM090 motes, and b) the SWN (https://www.emulab.swn.uom.gr/) test-bed based in the University of Macedonia, Thessaloniki, Greece, equipped with fifteen (15) Zolertia RE-Mote sensor motes. For demonstrating very large scale scenarios (>50 nodes) the system collaborates with the Cooja WSN emulator.

The demo storyline is divided in the following two parts: (i) the main operation of the CORAL-SDN protocol; and (ii) the dynamic configuration of the protocol operation options.

The demonstration starts with the deployment of the protocol firmware into the appropriate testbed, using the *Test-bed Deployer* implemented in ansible playbooks (i.e., https://www.ansible.com/). The CORAL-SDN controller is placed in a powerful testbed computer and communicates with the sink node via the USB port. After the deployment, we initiate the network operation using the *Dashboard*. The CORAL-SDN initially applies the topology control mechanisms and construct the network connectivity graph. Then, we start a network packet generation process for the demo purposes, where network nodes send randomly packets to the *sink node*. All protocol actions are logged and visualized on the dashboard using charts, graphs and text. The interface visualizes the data and control packet transmissions using different lines and colors on the visual topology graph. The outcome reveals the improvements that the centralized intelligent network management brings, in terms of performance and resource utilization.

In the second part we demonstrate the following network configuration options using the dashboard *Configuration Manager*: (i) *operating algorithm* selection options where we can choose the type of topology control, e.g., the topology control algorithms based on node advertisement or on neighbor request, flow establishment algorithms like the next hop only or full path establishment; (ii) *algorithm configuration parameter options,* e.g., routing decision options like the RSSI level, the LQI or the hops' number ; (iii) *network environment parameters* like the wireless operation channel or the antenna channel check rate; and (iv) *experiment options* like the data packet size or the data transmission frequency. All these options are dynamically applied to the protocol and affect its performance instantaneously providing elasticity. Further investigation is possible through the results that are logged.

Our experimental results show that software defined techniques can improve the network control in IoT networks, while providing robust and vigorous solutions.

Acknowledgments

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