Distributed Smart Transducers for Industrial Automation

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***Abstract*—Smart transducers (sensors or actuators) are continuously improving in performance and cost efficiency. However, they are still not readily incorporated into factories for industrial automation, given reservations regarding the interoperability of different vendor devices. The IEEE P1451 standard was developed to unify the description and manipulation of transducers to solve this problem. In this demo, we demonstrate the interoperability among multi-vendor transducers. It is achieved by implementing IEEE P1451 transducers services interface hosted on network capable application processers (NCAP). Furthermore, it presents the implementation of Plug-and-Play functionalities in NCAP for wireless transducers interfaces (WTIM).**

Introduction

Improved performance and cost efficiency of sensors has led to widespread sensor applications ranging from industrial automation to remote environmental monitoring [1]. Fast and easy access to sensing data and information across heterogenous sensor networks is important for the correct functioning and interoperability of many sensing applications. Interoperability can be defined as the ability of nodes to communicate and exchange sensor data effectively among multiple heterogenous networks [2]. This interoperability is difficult to achieve given the substantial number of sensor vendors and each network using different data formats and interfaces. To use defined data formats derived from standardized description and simple flexible interfaces are the key elements of solutions to this challenge.

The family of ISO/IEC/IEEE 21450/21451 or IEEE P1451 standard provides a solution for enabling interoperability.. It defines a set of common interfaces and standardized message formats added on to smart transducer nodes. Hence, these heterogenous smart transducers can communicate in wired or wireless networks which creates a vendor neutral communication environment [3-5]. IEEE P1451 wireless sensor networks (WSNs) consist of network capable application processor (NCAP) and several wireless transducer interface modules (WTIMs). Here a transducer can be a sensor, or an actuator. A transducer module is considered "smart" (STIM), if it is described by a machine-readable transducer electronic data sheets (TEDS), has digital control and outputs and provides triggering, status, and control for proper functioning of the transducer. A WTIM provides the command and data interfaces to a single transducer or multiple transducers.

To demonstrate this remote interoperability, we employ the IEEE P1451-1.6 MQTT services for communication between an IEC 61499 control application running on the NCAP at Silicon Austria Labs (SAL) in Austria and sensors at University of Beira Interior (UBI) in Portugal. The demonstrator uses the IEEE P1451 common network services at the NCAP to read data and TEDS from the sensors. The demonstrator is used to evaluate the interoperability of different sensors with the NCAP irrespective of specific locations and vendors by using the IEEE P1451 family of standards.

Standard Overview

If IEEE P1451 is applied to WSNs several WTIMs communicate with one NCAP. The NCAP operates as a gateway for the attached nodes to the user network. All WTIMs in the WSN are devices containing transducers, signal conditioning, ADC conversion and a non-volatile memory to store the node information in a TEDS. The TEDS contains meta information, information to calibrate the sensing channels and configuration information of a radio interface along with information to identify individual WTIMs.

An NCAP has a network interface to connect to the external user network (IEEE P1451-1.x) and offers the transducer services which allow common control commands between the NCAP and WTIM (IEEE P1451-0). The communication module implements the physical communication capabilities for smart transducers e.g., in wired IEEE P1451-2 or wireless networks IEEE P1451-5. Common network services including discovery, transducer data access, TEDS access, event notification and transducer management to address, control map all available WTIM devices. Additionally, the common network services allow "plug-and-play" capabilities to add new transducers into the operated network.

Material and Equipment

In this section, the components used in the demo are described, which are listed below.

- UBI setup - Raspberry Pi 3b+ (NCAP) and MSP-EXP430f5529 (TIM)
- SAL setup - Raspberry Pi 4 (NCAP), NORDIC nRF52840-Dongle (WTIM), and Laptop (Dashboard Application)
- IEEE P1451 Parts – IEEE P1451-0 and IEEEP1451-1

Raspberry Pi's were used to host standalone NCAPs. A STIM was implemented on MSP-EXP430f5529 board from Texas Instruments. It provides data from temperature sensors, and LED states. A WTIM network using nRF52840-Dongles from NORDIC Semiconductor is implemented within SAL. Additionally, a dashboard application developed in Node-Red is hosted on a laptop. The TI communication API and transducer services were implemented according to the definition provided in IEEE P1451-0 and IEEE P1451-1.

Demo Structure

In this section, we describe the setup, components, and implementation of the interoperability demo for IEEE P1451 systems, see Figure 2. The demo contains two NCAPs independently developed and deployed. One NCAP is deployed at UBI, which will be referred to as UBI NCAP. It integrates a voltage sensor, temperatures sensors, and 6 LEDs to interact with. The NCAP is hosted on a Raspberry Pi 3b+ Model. The TIMs and NCAP are serially connected via standard UART port.

Another NCAP is located at SAL, which will be referred to as SAL NCAP. It integrates a temperature sensor and a LED through a WTIM. The NCAP is hosted on a Raspberry Pi 4. The NCAP was developed using a component-based design approach of IEC 61499 programming language. A dedicated function block (FB) library was developed to implement IEEE P1451 transducer services and common network services. The FBs allow iterative development and testing of the transducer services in an IEC 61499 application. Bernhard et al. [6] explores different approaches to integrate IEEE P1451 system with model driven engineering of control application using IEC 61499 FBs. They suggested that an automatic mapping can be performed between available field level transducer and high-level requirements for the process variables specified at the application layer. Which simplifies the control application development and decouples it from technical system. An IEC 61499 control application was developed to connect with IEEE P1451 transducer FBs to standard NCAP devices. Here we interconnect UBI NCAP and SAL NCAP devices. These FBs at the NCAP utilize IEEE P1451-1 common network services to read data and TEDS from the remote transducers. The demo is a simple control application to monitor the temperature values from UBI NCAP and SAL NCAP and to set the status of LEDs if the temperature values overshoot certain threshold. A dashboard application for visualization of temperature values, LED status, and TEDS was developed for the demo.

The dashboard and the control application are the consumers of IEEE P1451 transducer service interfaces provided by UBI NCAP and SAL NCAP. Service interfaces are exposed to the communication network by MQTT protocol. A general scheme for MQTT Pub/Subtopics and message structures to map IEEE P1451 transducer services was proposed in the demo. For example, a MQTT Pub/Subtopic for "readTeds" service interface may look like:

"IEEEP1451/TransducerServices/TedsManager/ReadTEDS/*NCAPId*/*TIMId*/*ChannelId*/MetaTEDS"

In the topic "NCAPId," "TIMId," and "ChannelId" are used as placeholders of unique identification for NCAPs, Transducers and channels connected to the NCAPs. NCAP

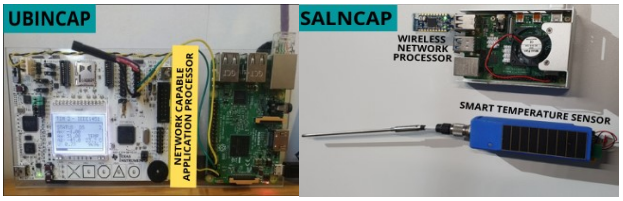

Figure 1 UBI NCAP and SAL NCAP

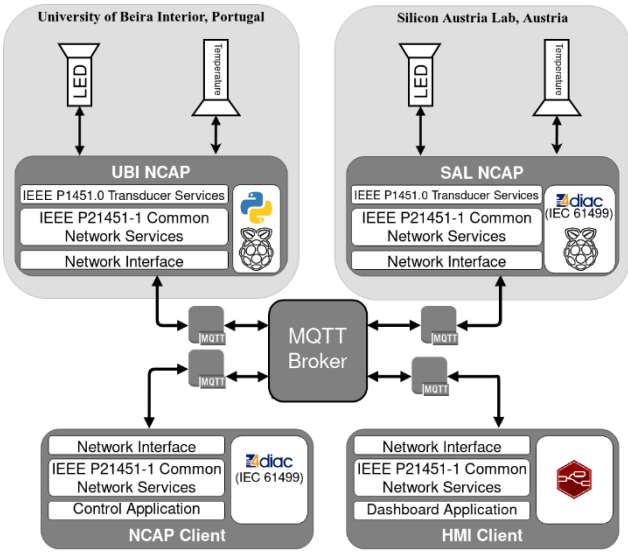

Figure 2 Interop Demo Setup

publish their TEDS on specific topics (e.g., MetaTEDS, TransducerChannelTEDS, UserDefinedTEDS etc.) with retain flag set to true. It enables a broker to store the last published message and push it to later subscribing clients. This feature is extremely valuable for all the static data of the TEDS.

Outlook

At SAL, we are also developing a solution to support "Plug-and-Play" functionality between WTIMs and NCAPs.

References

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