Wireless Sensor Network Based on IEEE 1451.0 and IEEE 1451.5-802.11

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Abstract - This paper describes a wireless sensor network (WSN) based on the Institute of Electrical and Electronics Engineers (IEEE)'s 1451.0, 1451.5, and 802.11 standards. The implementation of the IEEE-based WSN was developed at the National Institute of Standards and Technology (NIST). The WSN consists of two wireless nodes - the Network Capable Application Processor (NCAP) node and the Wireless Transducer Interface Module (WTIM) node. In operation the NCAP node communicates wirelessly with the WTIM node using the IEEE 1451.0 and IEEE 1451.5 interfaces through the IEEE 802.11 wireless communication modules. In the paper two case studies illustrate the implementation of the request and response of the sensor data and Transducer Electronic Data Sheet (TEDS) using the client-server model. The work described provides a foundation and some guidelines for implementing a wireless sensor monitoring application based on the IEEE 1451.0 and 1451.5 standards.

Keywords - IEEE 1451.0; IEEE 1451.5; NCAP; WTIM; TIM; TEDS; sensors interface; sensor standard; smart transducer; wireless sensor network; IEEE 802.11

1 Introduction

The Institute of Electrical and Electronics Engineers (IEEE) Instrumentation and Measurement Society's Technical Committee on Sensor Technology has developed a family of Smart Transducer Interface Standards called IEEE 1451. The standards define a set of open, common, network-independent communication interfaces for connecting transducers (defined as sensors or actuators) to microprocessors, instruments, and control/field networks [1]. The IEEE 1451 family provides a set of protocols for wired and wireless distributed sensor applications. Figure 1 shows the architecture for the suite of IEEE 1451 standards. According to the architecture, IEEE 1451 defines a Transducer Interface Module (TIM) and Network Capable Application Processor (NCAP). The TIM can be a wired or wireless IEEE 1451.X module consisting of up to 255 transducers, signal conversion and processing electronics, and Transducer Electronic Data Sheets (TEDS). The TEDS provide transducer ID (identification), measurement range, location, calibration and user information, and more. The NCAP can access the TIM and pass the transducer information to the network. There are three possible ways to access the sensors and actuators from a network: IEEE 1451.1, IEEE 1451.0 Hyper Text Transfer Protocol (HTTP), and a proposed Smart Transducer Web Services (STWS) [2].

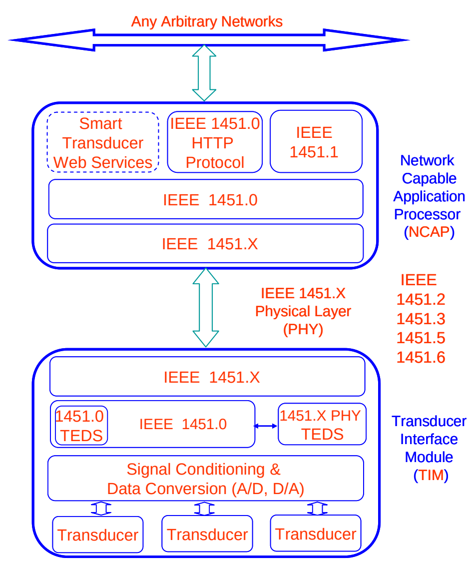

Figure 1. IEEE 1451 family

The IEEE 1451.0 standard defines a set of common functionality, commands, and TEDS for the IEEE 1451 family. This functionality is independent of the physical communications media. It includes the basic functions for the NCAP to read and write to each transducer and its TEDS, and to send configuration, control, and operation commands to the TIM. The STWS allow direct network access to the TIM through IEEE 1451.0 using web services. Through a communication interface module, IEEE 1451.0 can talk to the IEEE 1451.X on the NCAP. The IEEE 1451.X on the NCAP can talk to the IEEE 1451.X on the TIM through the IEEE 1451.X physical interfaces. This interface provides a means for interoperability between the communication modules of the NCAP and TIM. The IEEE 1451.X refers to a physical interface, which is a device or part of a device that is in compliance with IEEE Std. 1451.2-1997 [3, 4], IEEE Std. 1451.3-2003, or IEEE 1451.5 (IEEE 802.11, Bluetooth, and ZigBee)**, etc. The main goal of IEEE 1451.0 is to enable the access of transducer data through a common set of interfaces whether the transducers are connected to systems or networks via wired or wireless means.

2 Related Work

Recent advances in wireless communications and electronics have enabled the development of small (in size), low-cost, low-power, and multifunctional sensor nodes that can communicate over short distances. Smart, wireless, networked sensors will become more widely used, collectively processing vast amounts of previously unrecorded data to help monitor the condition of the environment, machining systems, and other applications. Standardized transducer interfaces, high-level programming languages, and wireless network technologies are serving to shape the next-generation, wireless monitoring landscape. The first Wireless Sensing Workshop was held in June 2001 at the Sensors Expo/Conference in Chicago, Illinois. The need for a standard protocol for wireless sensor networks (WSN) was echoed. A suggestion was made to create a wireless sensor interface standard IEEE 1451.5 and to use the IEEE 802 family as a guideline for managing the IEEE 1451 framework [5]. Consequently the first draft of IEEE 1451.5 was introduced at the 2004 Sensors Expo/Conference. Through the vigorous standardization effort, the IEEE 1451.5 draft was finally approved as an IEEE-SA (Standards Association) standard in March 2007 [6]. A modular approach to the development of IEEE 1451.5 wireless sensors based on Bluetooth is discussed in reference [7]. An implementation of IEEE 1451.0 and 1451.5 is presented in reference [8].

3 Architecture of IEEE 1451 Wireless Sensor Network

3.1 Architecture

Figure 2 shows the architecture of the IEEE 1451 WSN. The NCAP is a device that could contain one or more wireless radios based on 802.11, Bluetooth, or ZigBee. It can talk to one or more Wireless Transducer Interface Module (WTIM). Each WTIM contains the corresponding radio(s) matching those in the NCAP, along with the other components of a TIM.

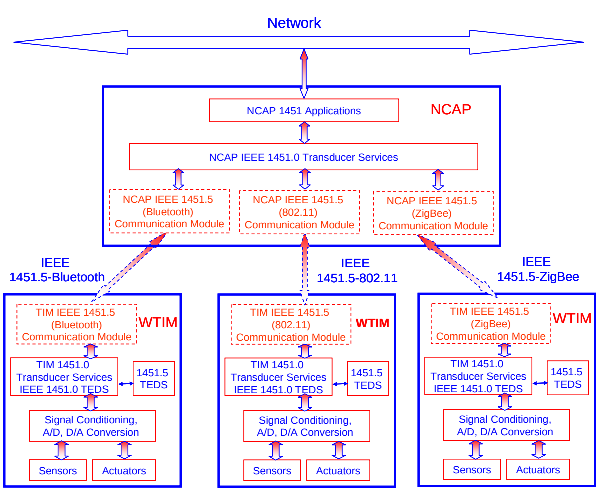

Figure 2. IEEE 1451 wireless sensor network

3.2 IEEE 1451.0 Standard

The IEEE 1451.0, approved as an IEEE standard on March 23, 2007, defines a set of common operations and TEDS for the IEEE 1451 family. It aims to facilitate interoperability and compatibility among the suite of IEEE 1451 standards. Since the functionality defined in IEEE 1451.0 is independent of the physical communications media between the transducers and NCAP, it is easy to add other proposed IEEE 1451.X physical layers to the family [9, 10]. The IEEE 1451.0 `TransducerServices` contain methods to read and write transducer channels, read and write TEDS, and send configuration, control, and operation commands to the TIMs. The `ModuleCommunication` Interface between IEEE 1451.0 and IEEE 1451.X contains three interfaces: `Comm`, `Receive`, and `Registration`. The `Comm` interface can be divided into `NetComm` and `P2PComm` interface. The `ModuleCommunication` Interface is a symmetric interface that is implemented on both the NCAP and TIM sides.

3.3 IEEE 1451.5 Standard

The IEEE 1451.5 standard is a wireless sensor interface standard, which defines a set of wireless communication specifications between the WTIM and NCAP. It adopts popular 802.11, Bluetooth, and ZigBee as its wireless communication protocols. It could accept other wireless protocols such as ultra-wide band, as needed. Through the NCAP, sensor information can be made available for network and web access. The IEEE 802.11 radio specification for the IEEE 1451.5 provides a description of the functions, protocols, and interfaces that are to be performed by the 802.11 communication module between the WTIM and the NCAP.

4 Implementation of IEEE 1451 WSN

4.1 WSN Based on IEEE 1451

Figure 3 shows the implementation of a WSN based on IEEE 1451.0 and 1451.5-802.11 using IEEE 1451.2 sensors. This WSN consists of one NCAP node and one WTIM node. An IEEE 1451.2 sensor is connected to the WTIM via a serial port. The NCAP can communicate wirelessly with WTIM through IEEE 1451.0 and 1451.5 protocols using the client-server and publisher-subscriber communication models. The client-server and publisher-subscriber communications between the two nodes can be implemented using Transmission Control Protocol / Internet Protocol (TCP/IP) and Transmission Control Protocol / User Datagram Protocol (TCP/UDP), respectively.

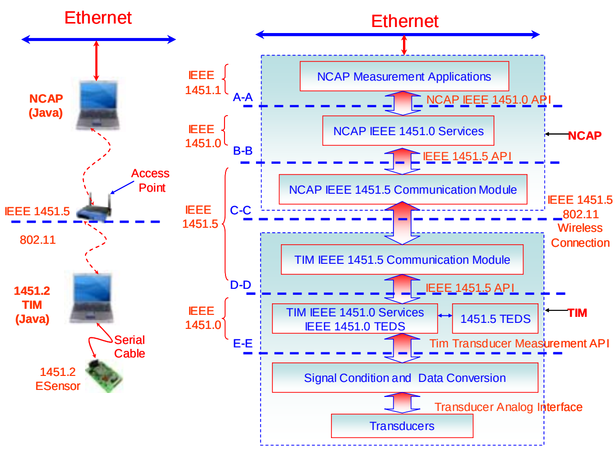

Figure 3. WSN based on IEEE 1451.0 and 1451.5-802.11

The NCAP or WTIM in Figure 3 each contains an IEEE 1451.5-802.11 communication module. The `NCAPDot5WIFINetComm` of the NCAP and `TIMDot5WIFINetComm` of the WTIM implement the interface `NetComm` of IEEE 1451.0. For the `NetComm`, we developed six help classes to perform network communications. `NetOneWayPublisher` and `NetOneWaySubscriber` are used for one-way publisher-subscriber using TCP/UDP. `NetTwoWayPubClient` and `NetwTwoWaySubServer` are used for two-way publisher-subscriber using TCP/UDP. `NetTwoWayClient` and `NetTwoWayServer` are used for two-way client-server using TCP/IP. These help classes can easily be used to reduce overhead for communications.

4.2 Class Diagrams of WSN

The class diagram of the NCAP node is shown in Figure 4. The NCAP node consists of one `NCAPDot5WIFIApp`, one `NCAPDot5WIFINetComm`, a few of the 802.11 help classes and other classes. The `NCAPDot5WIFIApp` implements `TransducerAccess`, `TedsManager`, `TimDiscovery`, `NetRegistration`, and `NetReceive` interfaces of IEEE 1451.0. The `NCAPDot5WIFINetComm` implementing the `NetComm` interface communicates with the WTIM using 802.11 help classes. The class diagram of the WTIM node is shown in Figure 5. The WTIM node consists of one `TIMDot5WIFIApp`, one `TIMDot5WIFINetComm`, and other classes. The `TIMDot5WIFIApp` implements the `NetReceive`, and the `NetRegistration` interfaces of IEEE 1451.0. The `TIMDot5WIFINetComm` implementing the `NetComm` interface communicates with the NCAP using six 802.11 help classes. These class diagrams of the NCAP node and TIM node can be used to automatically generate Java source code.

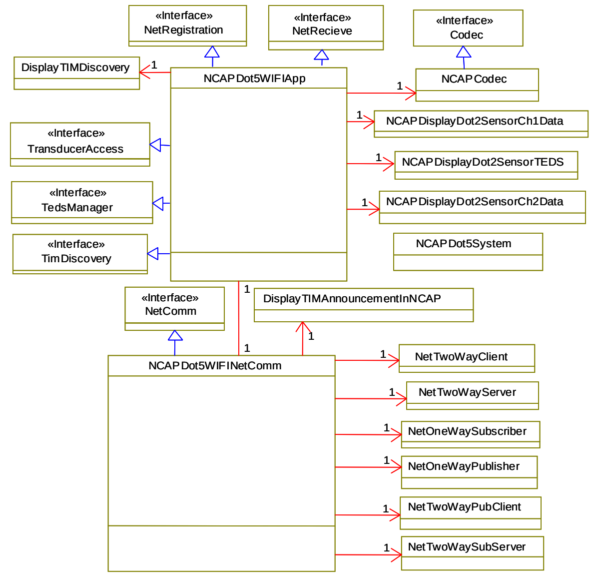

Figure 4. Class diagram of NCAP node

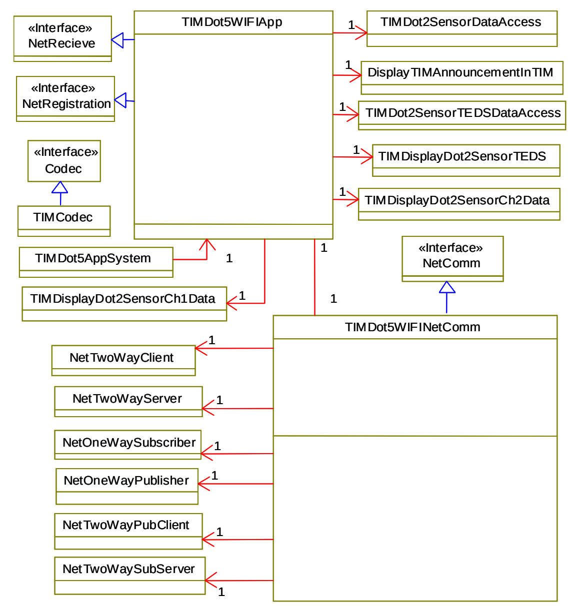

Figure 5. Class diagram of WTIM node

5 Case Studies

IEEE 1451.2 sensor data and TEDS reading are taken as case studies to test the implementation of the IEEE 1451 WSN. When a WTIM starts up, the communication module of the TIM first registers to the TIM; second, the TIM initiates a TIMAnnouncement to the NCAP. Then the NCAP follows with a TIMDiscovery. The detailed information for TIMAnnouncement and TIMDiscovery can be found in reference 2. The two case studies are described in the following sections. The wireless communications between the NCAP and WTIM are implemented through `NetTwoWayClient` and `NetTwoWayServer` help classes.

5.1 Case 1: Request-Response of Sensor Data

Figure 6 shows some sensor readings on a user interface. The NCAP sends the WTIM a request to read sensor data on transducer channel 2 of the IEEE 1451.2 device. When the WTIM receives the request, it reads the sensor data via a serial port and sends the data to the NCAP. The value and status of the transducer channel 2, in this case, an illumination reading of 11, is shown in Figure 6.

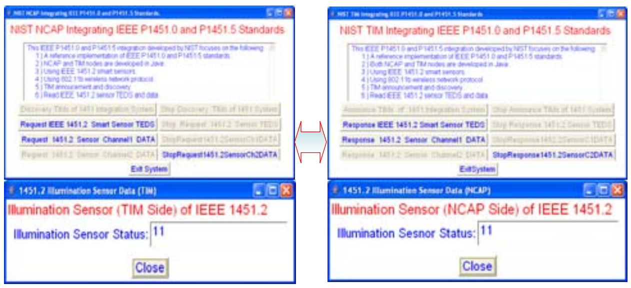

Figure 6. Request-Response of sensor data

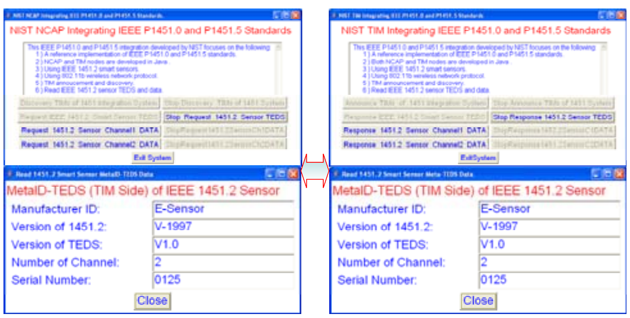

Figure 7. Request-Response MetaID TEDS

5.2 Case 2: Request-Response of MetaID TEDS

Figure 7 shows the user interfaces and results of TEDS reading. The NCAP sends the WTIM a request to read the 1451.2 MetaID TEDS. When the WTIM receives the request from the NCAP, it reads the MetaID TEDS via the serial port and returns the sensor TEDS to the NCAP.

6 Conclusions

This paper describes a wireless sensor network based on the IEEE 1451.0 and IEEE 1451.5-802.11 wireless sensor standards. The wireless sensor network consists of two wireless nodes, the Network Capable Application Processor (NCAP) node and the Wireless Transducer Interface Module (STIM) node. The NCAP communicates wirelessly with the WTIM adhering to the IEEE 1451.0 and IEEE 1451.5 standards using the 802.11 wireless communication modules. Two example cases were discussed and used to illustrate the communications of sensor data and Transducer Electronic Data Sheets (TEDS) data using the client-server model. The work described in this paper provides a foundation for implementing wireless sensor applications based on the IEEE 1451.0 and 1451.5 standards. Our future work will involve the implementation and application of wireless sensor networks based on IEEE 1451.5 for manufacturing systems.

** Certain commercial equipment and software are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

REFERENCES

[1] Lee, K., “IEEE 1451-A Standard in Support of Smart Transducer Networking”, Proceedings of the 17th IEEE Instrumentation and Measurement Technology Conference, Baltimore, MD, May 1-4, 2000, Vol. 2, p.525-528.

[2] Eugene Song, Kang Lee, “An Implementation of Smart Transducer Web Services for IEEE 1451-based Sensor Systems”, Proceedings of 2007 IEEE Sensors Applications Symposium, San Diego, California, USA, 6-8 February 2007.

[3] IEEE STD 1451.2-1997, Standard for a Smart Transducer Interface for Sensors and Actuators–Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats, IEEE Instrumentation and Measurement Society, TC-9, The Institute of Electrical and Electronics Engineers, Inc., New York, N.Y. 10016, SH94566, Sept. 25, 1998.

[4] http://ieee1451.nist.gov/

[5] James D. Gilsinn, Kang Lee, “Wireless interfaces for IEEE 1451 sensor networks”, SIcon’01 Sensors for Industry conference, Rosemont, Illinois, USA, Nov. 2001.

[6] IEEE 1451.5, Standard for a Smart Transducer Interface for Sensors and Actuators–Wireless Communication and Transducer Electronic Data Sheet (TEDS) Formats, IEEE Instrumentation and Measurement Society, TC-9, The Institute of Electrical and Electronics Engineers, Inc., New York, N.Y. 10016.

[7] Sweetser, D., Sweetser, V., Nemeth-Johannes, J., “A modular approach to IEEE-1451.5 wireless sensor development”, Proceedings of 2006 IEEE Sensors Applications Symposium, Feb 5-7, 2006, pp 82-87.

[8] Song, Eugene, Kang Lee, “An implementation of the proposed IEEE 1451.0 and 1451.5 standards”, Proceedings of 2006 IEEE Sensors Applications Symposium, Feb 5-7, 2006, pp 72-77.

[9] IEEE 1451.0, Standard for a Smart Transducer Interface for Sensors and Actuators–Common Functions, Communication Protocols, and Transducer Electronic Data Sheet (TEDS) Formats, IEEE Instrumentation and Measurement Society, TC-9, The Institute of Electrical and Electronics Engineers, Inc., New York, N.Y. 10016.

[10] James Wiczer, Kang Lee, “A Unifying Standard for Interfacing Transducers to Networks – IEEE-1451.0”, 2005 ISA Expo and Conference, Chicago, IL.

Brief Bio

Kang Lee received his BSEE and MSEE from the Johns Hopkins University and University of Maryland, respectively. Kang is the Leader of Sensor Development and Application Group at the National Institute of Standards and Technology (NIST). He is responsible for R&D in smart sensor networking, distributed measurement and control systems, and sensor-RFID integration. Kang is the Chairman of the IEEE Instrumentation and Measurement Society’s Technical Committee on Sensor Technology and responsible for the establishment of the suite of IEEE 1451 smart sensor communication and interface standards.

Eugene Song received his Ph.D. from the Tsinghua University, Beijing. Eugene is a guest researcher at NIST. He was a professor at Hebei Institute of Technology, P. R. China. He has published over 50 technical papers. His current research interests include networked smart sensor interfaces, IEEE 1451 smart transducer standards, and distributed measurement and control systems.