Development of Embedded Gateway for Wireless Sensor Network and Internet Protocol Interoperability

Sigit Basuki Wibowo, Guntur Dharma Putra, Bimo Sunarfri Hantono

Department of Electrical Engineering and Information Technology
Universitas Gadjah Mada
Yogyakarta, Indonesia
sigitbw@ugm.ac.id, guntur.dharma@mail.ugm.ac.id, bhe@ugm.ac.id

***Abstract*—Wireless Sensor Network (WSN) usage for buildings and household has been increasingly popular because it offers various benefits, such as home automation and home surveillance. Therefore, in order to increase WSN usage flexibility, remote controlling which enables remote administration is required. In fact, generally WSN is controlled by a coordinator (sink node) that is located closely to the WSN area itself.**

By utilizing iterative development, which is suitable for main and supporting application development with several iterations, this research proposes WSN and Internet Protocol (IP) interoperability that enables remote controlling and managing through Internet. Eventually, this research creates a web-based application which will be implemented to a wireless Access Point (AP) for easier WSN remote controlling. Furthermore, it could accommodate WSN from various vendors by software only solution.

***Keywords*—Wireless Sensor Network, Internet Protocol, WiFi, interoperability.**

I. Introduction

Wireless Sensor Network (WSN) is a distributed autonomous sensor nodes that is able to wirelessly communicate each other through radio frequency.

WSN usage for buildings and households are increasingly popular as it offers wide functionality [1,2]. Popular WSN implementation in household application is home automation [2,3], an automation process for all household routines. Another example of WSN implementation is home surveillance [4,5], a method to monitor every inch of user's house in real time.

Primarily, WSN is controlled by a sink node that is closely located to the networks. However, WSN implementation for smart home occasionally needs remote controlling, as the house owner is not always available at home.

Furthermore, a sink node also has several limitations, specifically, in terms of controlling multiple WSN from different vendors. For instance, an IQRF sink node is not able to handle other WSN than from IQRF [6]. So do XBee sink nodes, it couldn't handle other WSNs from different manufacturers.

The Internet Protocol (IP) offers WSN a flexibility and interoperability to other devices, even to devices other than sensor nodes, such as computers and mobile phones. However, the IP protocol consumes so much electricity than particular WSN does. There are a couple methods to integrate IP and WSN, for instance, to build an IP gateway that is directly connected with WSN's sink.

This work is focusing on building a remote controlling systems for WSN that also is capable to provide interoperability between WSN and IP. This method is also called proxy-based architecture approach. Furthermore, the proposed system has to be able to integrate several WSNs from multiple vendors into a particular gateway with affordable cost.

The rest of this paper is organized as follows: chapter 2 discusses about related works. Then, chapter 3 describes the methodology used in this work. Chapter 4 illustrates the proposed system design overview. The result and discussion is alleged in chapter 5. Finally, concluding remarks and future works are stated in the 6th chapter.

II. Related Works

A survey concerning IP based WSN had been carried out to figure out a solution of this problem [7]. That survey alleged that there are two solutions available: proxy based approach or direct implementation of IP to each sensor nodes. However, the second has several problem in terms of high energy consumtion and IP complexity.

A proxy (gateway) based approach is carried out to overcome the IP limitations that occur when IP is directly implemented in WSN communication stack. A research [8] carried out a proxy based approach that is capable to accomodate IPv4 and IPv6. The research then showed positive result, an IPv6 based client connected to the gateway were able to communicate with the WSN. Another work tried to integrate WSN and IP with affordable cost [9]. This work made use of widely used household wireless Access Point (AP) as a gateway for the WSN.

The objectives of utilizing gateway for WSN vary among others. The research [10] and [11] proposed a research to develop WSN gateway for data aggregation from entire connected sensor nodes.

This research proposes a WSN gateway design that supports IP with affordable cost for implementing smart home concept which is described in [2] and [3]. From various WSN gateway user interfaces [12], this research proposed a web based interface that has a high flexibility since the gateway

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then is accessible to any connected devices that support web based interface using web browser.

III. METHODOLOGY

This research utilizes iterative and incremental software engineering concept. In this particular concept, application codes are designed, developed, and also tested in an iterative cycle. In each iterative cycle, additional features can also be designed, developed, and tested until a fully functional application is achieved.

The application then will be developed incrementally, feature by feature, and tested to ensure that every feature is running correctly. Every developed application will also be tested to ensure that every application is able to communicate each other. The iteration will be continued until entire features and applications are able to operate for WSN and IP interoperability.

A. Tools and Materials

This research is utilizing WSNs from two manufacturers, IQRF [13] and XBee [14]. XBee is also deployed with Arduino Uno and Arduino Relay Shield that acts as relays. The gateway is TP-LINK Wireless AP MR3020 with custom operating system, OpenWrt [15], to increase AP flexibility.

B. Research Flow

Research flow-chart describing research steps from beginning until the end is illustrated in Fig 1.

As seen in Fig 1, this research steps involve literature study, requirement analysis, application and system development, and finally evaluation and improvement.

IV. SYSTEM DESIGN OVERVIEW

A. Use Case

The developed application only involves an actor, as seen in Fig 2. To utilize all features in this application, each user has to log in.

There is only an actor that is involved in this application, as seen in Fig 2. Sign in is required for user to utilize all features in the application. Provided cases are listed as follows: read temperature, add and remove IQRF sensor, add and remove XBee sensor, turn on-off relay, and add-remove users. These functionalities are described in Fig 2.

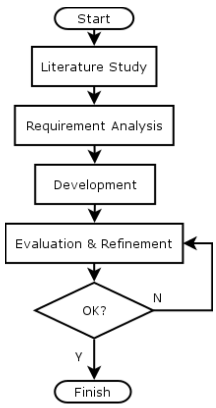

Fig 1 *Research flow-chart.*

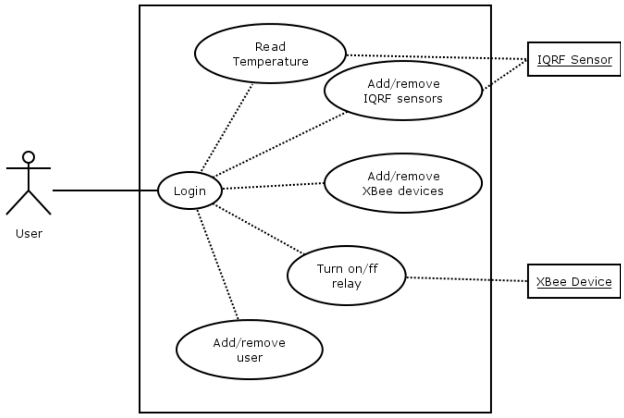

Fig 2 Use case diagram of the developed system.

As seen in Fig 2, addition or removal for XBee sensors is not involving any XBee sensors (no connecting line between those two), as this process only requires database record removal process that occurs merely in the gateway. However, addition or removal of IQRF sensor also involves the IQRF sensor nodes (there is a line connecting those two) as this process also involves IQRF sensor unbounding.

B. System Architecture

There will be three applications that will be developed. The applications are listed as follows: C based application for each IQRF sensor node and Arduino Uno, web based application that act as primary interface for the user, and Python based application for connecting sensor nodes to web based application.

The application for IQRF itself consists of two portions, an application for coordinator sensor and application for particular sensor. The source code is then compiled for uploading process after the application has successfully coded. This research utilizes iHome, an application for smart home concept implementation [16].

Furthermore, Arduino Uno needs a particular program to turn on and/or off specific relay by using ZigBee based communication. This program is coded in C. Whole compiling and uploading processes were carried out by using Arduino Uno's compiler and downloader.

Web based application is developed using PHP for the server side and JavaScript for the client side. In order to achieve a responsive web page, a page that can adapt its own size according to web browser's screen size, the pages are coded in HTML5 and CSS3 standard with the help of Bootstrap CSS library [17]. Asynchronous JavaScript and XML (AJAX) method is also implemented to achieve more dynamics web pages.

While Web based application is developed employing the latest standard of web programming, the Python based application is developed using PySerial library as it requires serial communication to serial port, the only interface to communicate with the sensor nodes. Architecture design diagram is illustrated as seen in Fig 3.

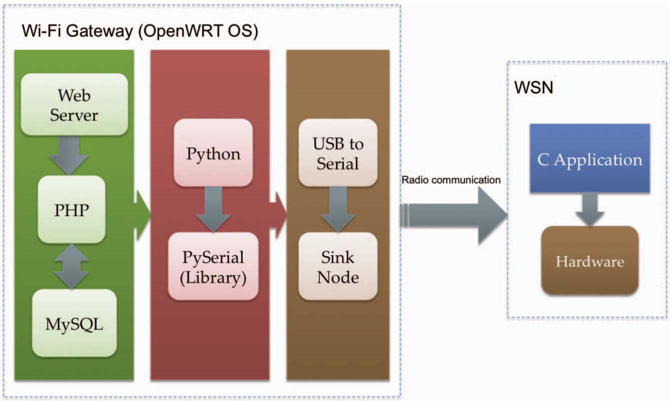

Fig 3. System architecture diagram.

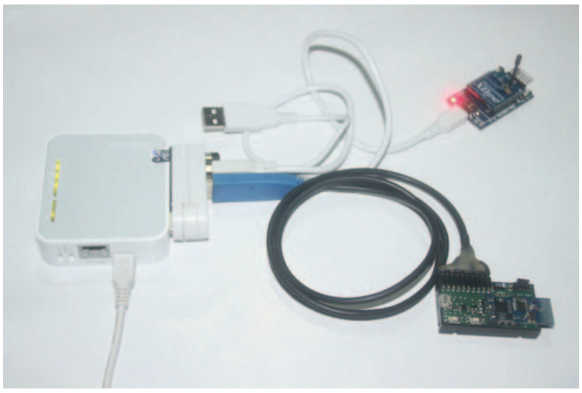

Fig 5. Fully functional WSN gateway.

Fig 3 illustrates interoperability approach that is employed in this research. As seen in Fig 3, communication between sink-node and web based application (green) is bridged by USB to serial and Python based application as each WSN sink-node is utilizing serial data communication to communicate with the gateway. Sink node communicates with remote nodes through wireless communication. Wireless communication protocol depends on the WSN vendor used by sink node. In this approach, entire applications are running on top of OpenWrt operating system. This approach is able to deliver multiple vendors WSN interoperability by only utilizing single gateway. The example diagram of whole system consists of WSNs from two vendors and WiFi network is presented in the Fig 4. As stated in the previous paragraph, sink node from every vendor connect to gateway through USB port.

Other interoperability approach can be carried out by using Internet gateways from every vendor in a system. This approach will utilize the provided web service to achieve cross platform WSN interoperability. However, this approach costs more than the first approach does since this approach requires every expensive WSN Internet gateway to be present. Therefore, this approach is not suitable for this research since one of the objectives of this research is to provide WSN interoperability with affordable cost. Moreover, most WSN Internet gateways are proprietary devices and it is nearly impossible to tweak the web service if the web service needs several improvements.

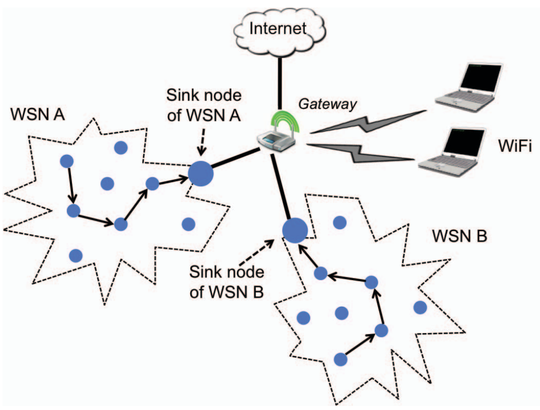

Fig 4. Integration of two WSNs and WiFi

V. Result and Discussion

A. Results

The gateway utilized in this research is also equipped with a USH Hub, as seen in Fig 5, in order to plug in USB flash drive, IQRF coordinator, and XBee coordinator.

The order of plugged in device is listed as follows (from top to bottom): USB flash drive, XBee coordinator, and IQRF coordinator. This order must be exactly same as this order since the application only supports this device sequence.

The main interface for the end user is a responsive web application that is accessible through web browser. Fig 6 shows an example of the responsive web page.

Dashboard page displays an IQRF sensor and an XBee device, as seen in Fig 6. Complete status and switch button for XBee device are portrayed on the left hand side. Users are able to see the XBee relay status and even turn it on or off with just a single click. On the right hand side, a thermometer-like gauge is displayed to monitor current temperature from IQRF.

B. Application Performance Analysis

The experiment involves a set of gateway (AP) that has been equipped with IQRF and XBee coordinator, two IQRF sensor nodes, and a XBee relay.

The first experiment is to add a new XBee relay and turn the first relay on by using a mobile phone. As seen in Fig 7, the first relay is on (red LED) and phone screen is also showing the same condition.

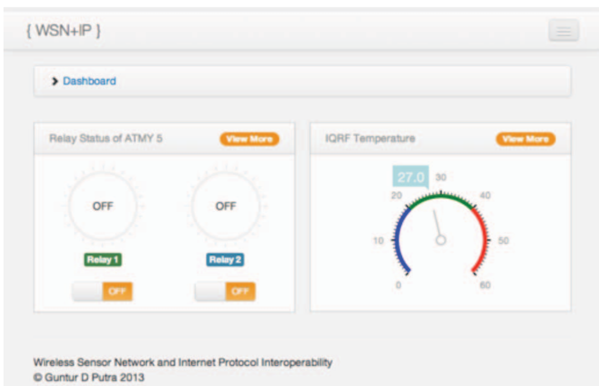

Fig 6. Dashboard page.

Fig 7. Experiment using mobile phone.

The experiment to check IQRF sensor functionality is to add two new IQRF sensor nodes via web application and to read the temperature. An IQRF sensor is held in hand to increase the temperature. Fig 8 below shows the result of this experiment.

Since this application supports AJAX method, the needle in the temperature gauge will automatically adjust to the current temperature without refreshing the page.

Based on the experiment, all features are running correctly. However, the experiment is not aimed to measure temperature accuracy but to check overall system functionality.

C. System Scalability

By default, this system only supports WSN and IP interoperability between two WSN vendors, thus it is not possible to add a new WSN from other than mentioned vendors before.

However, the developed system has scalability in terms of device addition. User can easily add new IQRF sensors or XBee devices using web interface.

VI. CONCLUDING REMARKS

This research has shown that multiple vendors WSN and IP interoperability can be achieved by utilizing a gateway having a web server containing web application that is also supported by Python based applications to communicate with several WSN, which has been loaded with C application.

Next research can utilize other AP than TP-LINK MR3020 as a gateway and compare its performance with current AP. Next research can also use more WSN from more vendors to achieve broader interoperability. Furthermore, next research can also be carried out by using different approach to read serial ports, for instance, building a custom C program.

Fig 8. Two IQRF sensors are displaying a temperature measurement.

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