Design and Implementation of Gateway for Wireless Sensor Networks: Zigbee and Bluetooth

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Abstract

In this paper, we design, implement and investigate an interoperable gateway for wireless personal area networks. The proposed system verifies the interoperability between increasingly resilient IEEE 802.15.4 based Zigbee system and IEEE 802.15.1 driven Bluetooth System under noisy RF environment. Furthermore, the designed interoperable system is also employed in smart metering application using Zigbee sensor nodes. A user friendly front end is designed using Python. The proposed system can be extended to incorporate IEEE 802.11 based WLAN, IPv4, GSM, Wimax and LTE.

Keywords: Zigbee; Bluetooth; Interoperable; Short-Range Wireless Networks; embedded ARM system.

I. INTRODUCTION

The need for mass geographical data collection in interoperable wired and wireless environments has become important for the evolving needs of a smart system, incorporating smart, energy efficient and cost effective wireless sensor networks (WSN) [1]. These networks in addition to being energy efficient also have to be self-healing and intelligent from the routing policies and data collection point of view. Currently, improved fabrication and tightly coupled integration in parallel with smarter implementation of micro controller units has made this possible. The equipment manufacturers have been successful in implementation of more efficient algorithms to perform the services of different layers in compliance with a specific protocol stack. Optimization is also being applied in a cross layer fashion to satisfy tight constraints that remote geographical areas place on wireless sensor networks [2].

Wireless sensor networks are evolving with diverse implementations and modes that are crafted to suit the requirements of specific applications. Currently, IEEE 802.15.4 specification of Zigbee protocol has been at the forefront in industrial and remote area WSN implementation. The need to make the data accessible, several methods are being devised to access the WSN data for independent nodes and present it in a standardized form such as extensible markup language (XML) structure. These requirements are to be accomplished by a host unit or terminal that is interfaced to the administrator WSN node, responsible for handling the tasks specific to WSN services and duties. The host or terminal interfaced to the administrator node will parse and access the data from the administrator through a hardware interface and then perform the duties of data organization and preparation to send via any another specified protocol. We design and implement a highly scalable and inter-operable gateway node to accomplish this task.

This paper presents the design and implementation of the gateway for wireless networks incorporating Zigbee and Bluetooth. The rest of the paper is organized as follows: Section II provides an overview of the wireless sensor networks and examines Zigbee and Bluetooth wireless networks. Section III presents the related work. Section IV presents the design and implementation of the gateway node. An application for the proposed design is presented in section V. Section VI concludes the paper.

II. WIRELESS SENSOR NETWORKS

Small- scale, geographically-distributed networks made up of several slave nodes wirelessly registered/paired to a local master node spawning only a few hundred feet constitute a typical wireless sensor network [3]. The distinguishing feature of such networks is the spatial-distribution of local nodes over a small geographical area for the purpose of monitoring physical activity and log data e.g. temperature, humidity and pressure. They can also be configured to perform control and automation through a system of relays and drivers [4].

These networks are created with tight constraints on the physical PHY and medium access layer MAC layer so that they require minimum energy to run and can implement medium access algorithms to obtain access of medium and ensure successful transmission. Typically, these networks use unlicensed 2.4 GHz band as the radio resource with an additional option in some countries, USA, Canada and Japan, that use the sub 1 GHz bands with smaller channel width to accommodate the needs of the industrial scientific medical band. The network layer of such networks is also designed and planned in such a way so as to implement an autonomous network where routing schemes are mainly multi-hop and flooding [5]. The application layer of such networks is user specific and usually incorporates a central processing unit working on the application layer or the transport layer that handles the protocol data unit of the layer below it and performs framing to achieve ease of data access and interpretation. A brief review of the two IEEE standards for wireless personal area networks i.e. Zigbee and Bluetooth is given.

A: ZIGBEE WIRELESS SENSOR NETWORK

The Zigbee protocol specification is described by IEEE 802.15.4 and is maintained by the Zigbee Alliance that is made up of a number of member companies and countries [6]. Zigbee specification identifies two types of network

nodes in terms of their capability as Fully Functioning Device (FFD) that has the capability to perform more network administration and management related tasks and a Reduced Functioning Device (RFD) that can perform a reduced set of tasks. Consequently, the Zigbee network hierarchy is a three-tier hierarchy where the top level node is identified as the Coordinator node, the bottom level node is identified as the End Device and the intermediate level node is the Router [7]. A Zigbee network basically is constituted of the coordinator and the end device. The need of the intermediate node i.e. the router arises when many devices are present and it is convenient for the master i.e. coordinator to communicate with them via a mid-level device to perform some of its functions. Sometimes multiple networks are managed by a coordinator through the use of the tree topology; hence these clusters of networks require a router to be present to make things easier. Zigbee networks can use both star/tree and mesh topology to setup a network. The most prominent feature of the Zigbee nodes on the network layer is the ability to perform ad-hoc networking via link state protocols [8].

B: Bluetooth Wireless Sensor Network

The Bluetooth protocol specification is described by IEEE 802.15.1 [9]. The Bluetooth standard is maintained by a group called Bluetooth Special Interest Group SIG that has many member companies. The Bluetooth specification defines a simple master slave hierarchy and accommodates high data rates, up to 2 Mbps and a few user specific profiles that pertain to different needs. Mainly, Bluetooth has found applications in billions of devices as a means of sharing and transferring data. With immensely easy system integration and wide spread support, the Bluetooth has found popularity as a cable replacement technology that is used in wireless audio headsets and for fast data transfer between bulky computer peripherals , most prominent one being the household printer [10].

III. Related Work

A number of researchers have designed, implemented, validated and applied different designs of multiprotocol gateway for various wireless standards including Wi-Fi, Bluetooth, Zigbee and Cellular Networks such as GSM, WCDMA and LTE/Wimax. Authors [11] design and present a gateway to exchange data between Wi-Fi and Zigbee for smart home design. Besides, it is also argued that the Wi-Fi-Bluetooth link is unstable, costly and prone to interference, whereas Wi-Fi-Zigbee link shows highly stable behavior due to its anti-interference capabilities with additional benefit of low cost. Hence, the Wireless Personal Area Network (WPAN) enabled latter link is preferred over Bluetooth enabled link. Researchers [12] design, implement and use a gateway protocol named BlueBee to exchange date between a Zigbee sensor and Bluetooth enabled device. The proposed designing is completed using UML. The application of proposed design is applied on a board that measures the room temperature and transmits to a Bluetooth enabled GSM phone. Authors [13] present a Zigbee-Bluetooth Gateway to be used in Body Area Network Applications. The benefits of ubiquitous Bluetooth (due to its presence in cell phones and other wireless devices) and low power consumption of Zigbee are united to achieve maximum benefits. Additionally, Body Area Networks present a highly useful area of application. Authors [14] design and implement a gateway for communication between Zigbee and GPRS. The proposed system is implemented on ARM processor to complete the specified task. The system software for the proposed system is implemented on Linux Board. In this paper, we design, implement and present a highly useful multiprotocol gateway that enables data exchange among all the major wireless standards including cellular IEEE 802.16, wireless personal networks IEEE 802.15.4, wireless LANs IEEE 802.11 and wireless Regional area networks IEEE 802.22.

IV. Design Of The Gateway Node

The proposed design of the gateway is based on a hybrid structure between wireless sensor network gateways [15] and an internet model common gateway interface CGI. This setup incorporates an ARM processor based Linux board, raspberry pi in this paper, that parses the data from the Zigbee master module interfaced to it, over the universal asynchronous receive and transmit, UART interface. It then saves the collected data in a plain text file and sends it over the Bluetooth network through the USB Bluetooth dongle mounted on the board`s USB interface. The raspberry pi is referred to as host gateway and the software that handles the operations of the gateway is operating at the application layer. It is written in the python programming language. Figure 1 shows the flow chart shown for the given scenario.

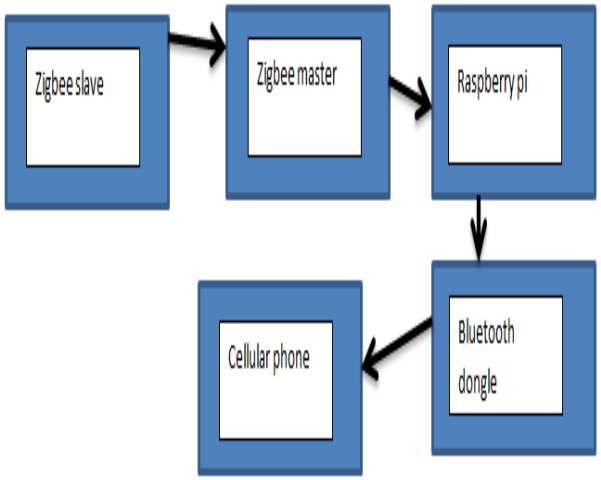

Figure 1 Flow Chart for the Gateway Scenario

The gateway node consists of the following sub components.

• The gateway host node which is an ARM processor based raspberry pi Linux board serving and functioning as an interface for master node to both the Zigbee and Bluetooth networks.

•The Zigbee network accommodated by a Zigbee module configured as the coordinator interfaced to the Linux board over the UART interface and also the general purpose input output GPIO interface, for control, present on the board and a standalone Zigbee module configured as the router. A TI CC2530 Zigbee module is used in our implementation.

•The Bluetooth network accommodated by the USB dongle that has the drivers and application specific Bluetooth profiles installed natively and a Bluetooth enabled cell phone as slave. The Bluetooth client installed in the Linux operating system natively handles the Bluetooth data transfers.

The Zigbee master node or coordinator node and the Bluetooth USB device are interfaced to the Linux board before it is switched on. After the operating system has been loaded, the gateway program is to be started by clicking its graphical user interface GUI icon named "gateway.sh" on the desktop as shown in Figure 2

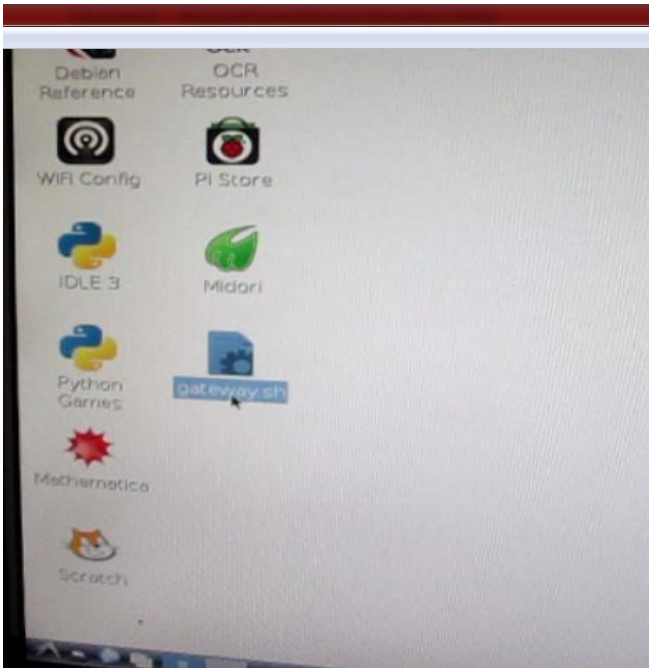

Figure 2 GUI icon of the gateway host program

After the connections have been ensured, the gateway operation can be performed through the user controls presented in the form of buttons on the host program GUI window. The user controls have been provided to trigger the gateway operation on user input. The gateway data send/receive operation can be invoked by clicking the appropriate button on the window as shown in Figure 3

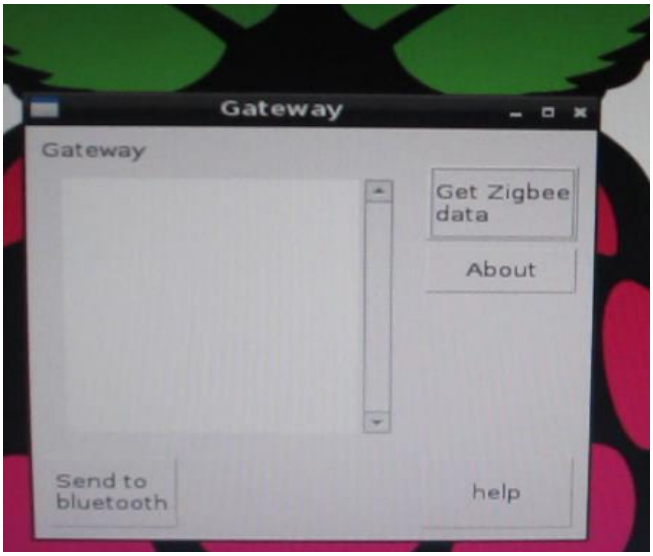

Figure 3 GUI host program window with given user controls

The operation proceeds as follows:

1. On clicking the "get Zigbee data" button, the program sends a command to the Zigbee master module via the general purpose input output GPIO pins. The Zigbee master in turn sends a message to the slave Zigbee node for data send request. Initially the devices are already paired to form a network when the raspberry pi boots up. The slave is to be separately powered up while the master node gets power from the Linux board.
2. The slave Zigbee responds to the master node with the data on which, a "Zigbee data parsed" message is echoed to the message screen as shown in figure 4. The data is saved in a plain text file.

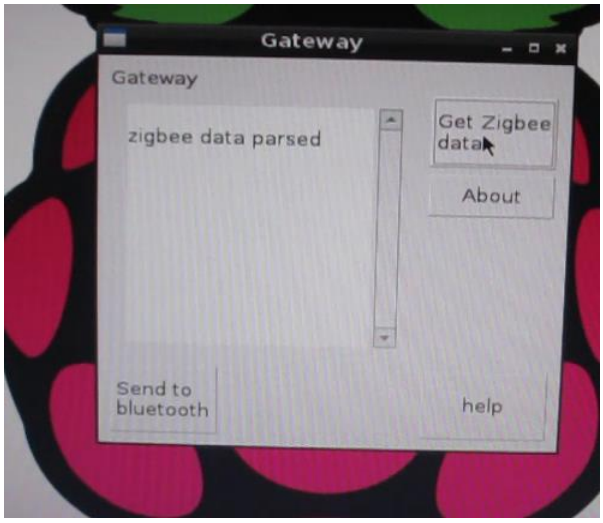

Figure 4 "zigbee data parsed" message display

3. The text file which has the Zigbee data saved is sent over the Bluetooth network through the USB interface to the Bluetooth device selected by the user after a host of nearby active Bluetooth devices are displayed based on a device search performed by the Linux board through the USB dongle as shown in Figure 5.

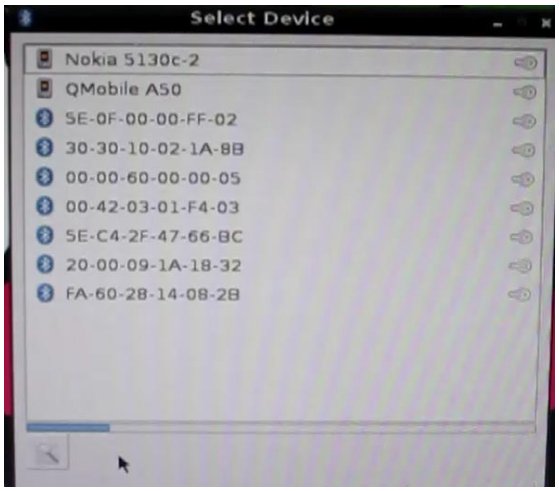

Figure 5 Listing of the available Bluetooth devices detected

4. This implementation chooses a Bluetooth enabled cell phone as a Bluetooth network slave hence a message is displayed that confirms the Bluetooth files send operation to the specific Bluetooth device, here a Nokia cell phone, as shown in Figure 6

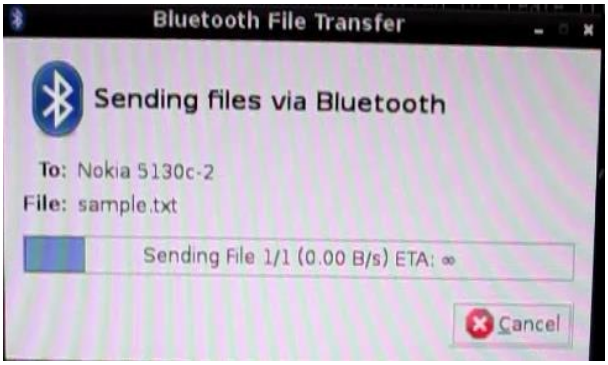

Figure 6 Dialog box acknowledging file send operation

The whole operation is based on user input so that it can be customized and changed as needed.

V. SMART METER APPLICATION

We validate test he system by implementing a wireless smart metering infrastructure prototype application by utilizing the analog to digital ADC capabilities of the Zigbee nodes by incorporating ADC value read function on the slave Zigbee and sense an arbitrary voltage value from a potentiometer and voltage supply combination source as shown in Figure 7.

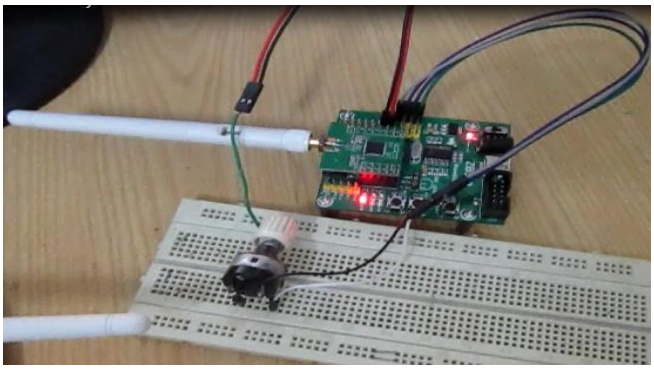

Figure 7 Slave Zigbee node setup to read voltage value from potentiometer and voltage source

The Linux board interfaced to both the Zigbee module and the Bluetooth USB dongle along with the slave Zigbee module that highlights the whole hardware layout of the project is shown in Figure 8. It should be further noted that the Linux board is also connected to a monitor, a USB hub that accommodates the Bluetooth dongle and mouse which are omitted here for simplicity.

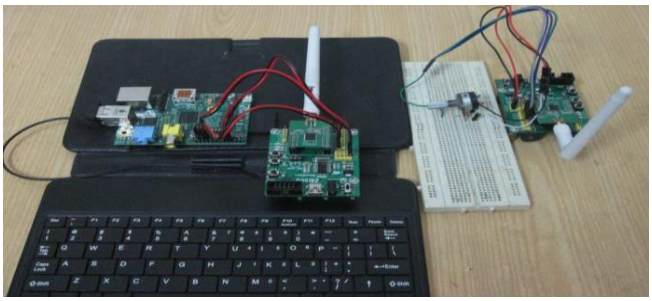

Figure 8 The gateway node

The data reception on the Bluetooth enabled cellular phone is shown in Figure 9. It is to be noted that the Zigbee application sends a 4 letter string without decimals to indicate the voltage. It is implied that the 4-digit string received is to be divided by 1000 or shifted 3 decimal places to get the voltage value measured by the slave Zigbee node in the smart meter prototype application.

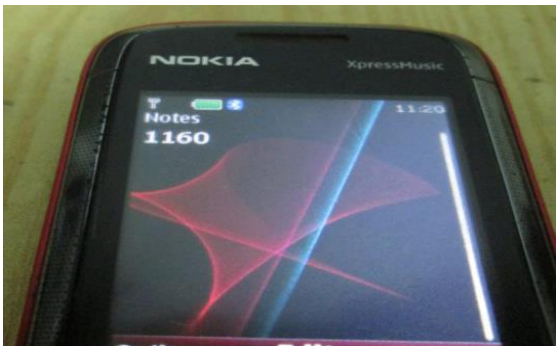

Figure 9 String "1160" sent by the Zigbee application is received as a text file note on a Nokia phone which corresponds to 1.160 volts value read by the slave node

VI. Conclusion

The design and implementation of an ARM Linux board based wireless sensor network gateway was proposed in the paper. The expansion of the gateway can be achieved to other protocols in addition to user friendly control of the operation. The proposed gateway can enable enhanced data access methods through the IP networks or uploading it directly to a website. It can also be monitored by a remote user using the telnet protocol since the Linux ARM board supports an IP network and the said application layer protocol. Additionally, further changes can be done remotely to the gateway operation by accessing the host program software routine and modifying to support newer applications.

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