Implementation of 802.15.4 for Designing of Home Automation and Power Monitoring System

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***Abstract*—Innovation in the field of wireless technologies has revolutionized automation in industrial, commercial and residential sectors. With the proliferation of wireless technologies, it is important to implement an appropriate wireless protocol according to the application area. This paper provides a brief overview of the existing home automation systems and describes ZigBee (over IEEE 802.15.4) technology, along with its comparative study with other protocols. It suggests, ZigBee is an emerging technology in the field of Home Automation system (HAS). It also demonstrates the designing and implementation of HAS for remote controlling and monitoring of various domestic loads/appliances using ZigBee protocol. An efficient method of power utilization through real-time power monitoring with the help of a PC-based GUI application is illustrated.**

Keywords - **Automation, Wireless Technologies, ZigBee, Home Automation System (HAS), Power monitoring.**

I. Introduction

In the past few decades,a lot of research has been carried out on various wireless communication protocols which has resulted in development of the automation field. Hence, Home Automation System (HAS) based on the wireless sensors networks (WSN) becomes feasible. The implementation of wireless protocols in home and industrial automation systems is rapidly increasing due to various advantages [1] such as:

- Cost effectiveness
- Easy placement and installation
- Compact size and portability
- Scalability feature which provides easy extension
- Various comfort benefits and feasibility
- Mobile device connectivity

All wireless protocols have different suitable areas of application.The implementation of any particular wireless technology depends on various metrics such as data rate, coverage area, power consumption, scalability, capacity etc. Jin-Shyan Lee *et al.* [2] have not only compared the different short-range wireless protocols viz. Bluetooth (defined by standard IEEE 802.15.1), UWB (defined by standard IEEE 802.15.3), ZigBee (defined by standard IEEE 802.15.4) and Wi-Fi (defined by standard IEEE 802.11a/b/g) but have also given a detailed comparative study [3] along with the pros and cons of each technology. Among all these technologies, ZigBee is an efficient technology [3] and it is most suitable for designing of the home automation system (HAS) [4]. Hence we have implemented the system using the design considerations of ZigBee protocol.

The system implemented *viz.* HAS consists of two modules i.e. one Transmitter and one or more Receiver modules. The transmitter module consists of User computer and RF device. It is used for exchanging the control commands via RF device which is interfaced to the user computer via serial connector (RS-232 cable) or BAFO cable.The receiver module is placed at the remote end which consists of RF device, Micro-controller unit, Power measuring unit and relay circuitry. RF device at receiver side interfaced with a micro-controller, receives commands from user side for controlling the loads via relays.

The HAS involves domestic loads having rating up to 230V(AC)/5A. Hence, it deals with single phase system, but it can be extended up to three phase system as well.The power consumption of any load can be estimated by measuring the load current. Our system estimates the power consumption and routes it back towards the user side for plotting the graph.It provides real - time power monitoring with the help of PC based GUI application.

This paper is organized as follows. Section II deals with the existing home automation systems, Section III provides the detailed comparative study of different wireless technologies. Section IV describes our implemented system whereas the outcome and hardware implementation of our system is presented in Section V. The Final Section concludes our paper.

II. Existing home automation systems

With the rapid development of wireless network technologies, the Home Automation systems (HASs) are becoming more advance and feasible for controlling and monitoring the loads efficiently. Yang Li et la. [4] has described Wireless Sensor Network (WSN) based home automation system with the implementation of CC2430 Chip. It provides novel approach for connecting the outer home network with the inner ZigBee network using home gateway. Some research papers [5]–[7] have focused on home networks rather than focusing on home automation. They have explored, how the home networks can be utilized by users for management of the access control, while sharing data and devices.Whereas in [8] architecture of more efficient energy saving Home Energy Management

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System (HEMS) is discussed. It elaborates the establishment of HEMS network with ZigBee hub and home server.Some of the papers have exploited the use of Internet along with ZigBee. For example [9] has described the PLC based HEMS which combines home network and Internet for efficient control of appliances.

Despite rapid development in technologies HAS have not been adopted widely. K. Gill *et al.* [10] not only provides the reasons for this slow adoption but also describes the flexible home automation architecture. This architecture combines ZigBee based HAS and WiFi network through a common home gateway. Incorporated home gateway enriches the system with various features such as network interoperability, remote access to the system and a simple and flexible user interface. Also [11] has described the GSM based HAS. Such a wireless network ,basically contains a GSM/GPRS gateway and three kinds of wireless security sensor nodes ; door security nodes, infrared security nodes and fire alarm node. Hence it provides automation along with the security, but GSM based systems require strong network without which the user is unable to access the remote system. In home automation, apart from the GSM based system, DTMF principle is implemented by many other systems [12] [13] [14]. As communication in such kind of system occurs over a fixed telephone line, it doesn't require Internet facility or establishment of dedicated infrastructure which is the primary advantage of the system.At the same time,it suffers from various disadvantages such as; users are not facilitated with a graphical user interface;hence they have to remember a password or an access code along with the list of valid commands associated with corresponding control action. Selecting an inaccurate command leads to the undesired control action. Hence, many HASs have been developed using various technologies for efficient control and monitoring of domestic loads.

III. Comparative Study of Various Wireless Technologies

The different Wireless technologies are mainly characterized by the range of operation and maximum data rate provided by it.According to these primary factors the area of application changes. Fig.1 depicts comparison of the three short-range wireless technologies on the basis of these factors.

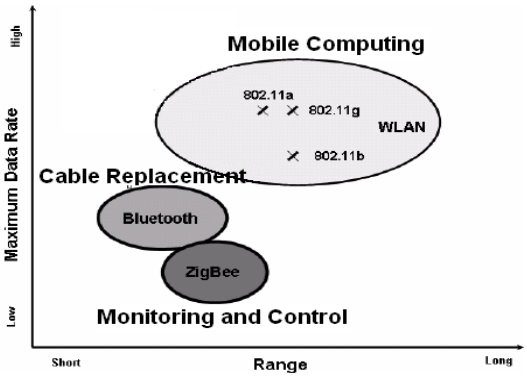

Fig. 1. Comparison between the different short range wireless technologies

Table I below summarizes [2], [3] [15]–[17], [19] the key differences between the three short-range wireless technologies. As shown below, Wi-Fi provides higher data rates as compared to ZigBee and Bluetooth which provides lower data transfer rates.Hence WiFi is suitable in for multimedia access application. ZigBee and Bluetooth are intended for Wireless Personal Area Network (WPAN) communication (about 10m), while WiFi is designed for WLAN (about 100m). The range of ZigBee depends on implemented network topology as well as on the chip set used. It can be extended up to 100m using dedicated transceiver chips such as XBee-PRO module [17].

TABLE I
COMPARISON OF THE BLUETOOTH, ZIGBEE, AND WI-FI PROTOCOLS

Standard	**Bluetooth**	**ZigBee**	**WiFi**
Application Focus	Cable Replacement	Monitoring and Control	Web, Email, Video
IEEE standard	802.15.1	802.15.4	802.11a/b/g
Frequency band	2.4 GHz	868/915 MHz; 2.4 GHz	2.4 GHz; 5GHz
Number of Channels	79	1/10 ;16	14 (2.4GHz)
Spreading	FHSS	DSSS	DSSS,OFDM
Signal Modulation	GFSK [20]	O-QPSK [20]	OFDM;DSSS, CCK; DSSS, CCK,OFDM [20]
Encryption	40-bit RC4 , stream cipher	128-bit AES, block cipher	128-bit RC4, stream cipher (WEP)
Max signal rate	1 Mb/s	250 Kb/s	54 Mb/s
Nominal range	10 m	10 - 100 m	100 m
Channel bandwidth	1 MHz	0.3/0.6 MHz; 2 MHz	22 MHz
Number of RF Channels	79	1/10; 16	14 (2.4GHz)
Data protection	16-bit CRC	16-bit CRC	32-bit CRC
Max number of cell nodes	8	more than 65000	32
Node acquisition time	3s	30ms	2s
Node wake-up time	3s	15ms	1s
Network topology	Star, piconet, scatter-net	Star, mesh, cluster-tree	Star

1

Table II below provides the comparison of the electrical parameters for the different chip sets of BlueCore2 [15] from Cambridge Silicon Radio (CSR), XB24-B [16] and XBee-PRO [17] from Digi International Inc. and CX53111 [18] from Conexant (previous Intersils Prism).It also emphasis on the range and bit rate supported by particular chip.

[1]FHSS-Frequency Hopping Spread Spectrum
DSSS-Direct Sequence Spread Spectrum
OFDM-Orthogonal Frequency Devision Multiplexing
GFSK-Gaussian Frequency Shift Keying
O-QPSK-Offset-Quadrature Phase Shift Keying
CCK- Complementary Code Keying
AES-Advanced Encryption Standard
RC4-Rivest Cipher 4
WEP-Wired Equivalent Privacy
CRC-Cyclic Redundancy Check

TABLE II
CURRENT CONSUMPTION OF CHIPSETS FOR EACH PROTOCOL

Standard	Bluetooth	ZigBee	ZigBee	WiFi
Chipset	BlueCore2	XB24-B	XBee-PRO	CX5311
Range (m)	10	40	90	100
VDD (volt)	1.8	3.3	3.3	3.3
TX (mA)	57	40	205	219
RX (mA)	47	40	47	215
Nominal TX power (dBm)	0 to 10	-25 to 0	0 to 18	15 to 20
Bit rate (Mbps)	0.72	0.25	0.25	52
Battery Life (days)	1 - 7	100 - 1000	100 -1000	0.5 - 5

As the HAS deals with the control and monitoring of domestic loads, the data rates provided by Bluetooth and ZigBee are suitable for designing of HAS.Though the power consumption of both the protocols is comparable but the range of deployment and the network scalability offered by ZigBee is large as compared to Bluetooth [21], [22]. The comparison of the above parameters leads us to select ZigBee as the wireless interface technology for our deployed system.

IV. Implemented System

The implemented system using Zigbee protocol is divided into two parts *viz.* User Control Unit (UCU) and Home Automation Controlled Unit (HACU). The functional block diagram of our deployed system is shown in Fig.2.

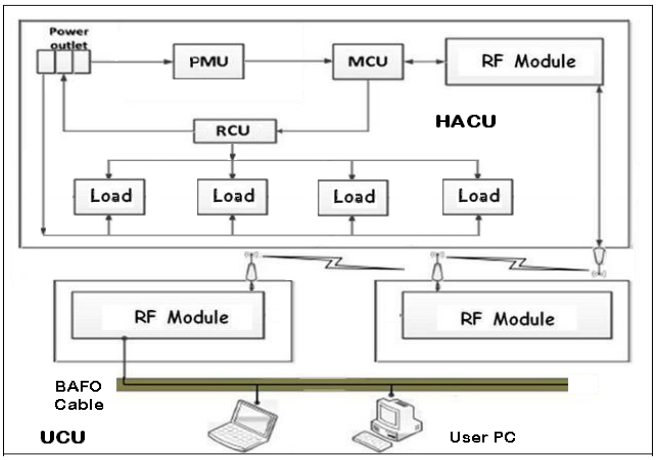

Fig. 2. Block diagram of the ZigBee based Home Automation System (HAS)

A. User Control Unit (UCU)

The UCU mainly consists of User terminal and ZigBee RF module interfaced with PC via UART (Universal Asynchronous Receiver/Transmitter) port. Module of XBee Series2 of Digi Inc. [16] is used as RF module. The open source X-CTU software [23] is used for programming of XBee modules. In X-CTU Application Programming Interface (API) mode is adopted for following purpose:

- Configuring the XBee Radios as PAN Co-ordinator, Router or End Device
- Deciding the desired baud rate
- Analyzing the initial range test
- Measuring the RSSI value

Network can be established only after the configuration of the modules. In our HAS, the module connected to the PC is configured as ZigBee Coordinator in API mode. Using Net Beans profile, the Java based GUI application is developed on PC which enables the user to control the load remotely. Fig. 3 below shows the GUI window and real time power graph when all loads are turned off. This GUI application performs switching operation of the load as well as indicates their status. It also receives data from the Power Measurement Unit (PMU) through HACU side RF module and plots the real-time power consumption graph.

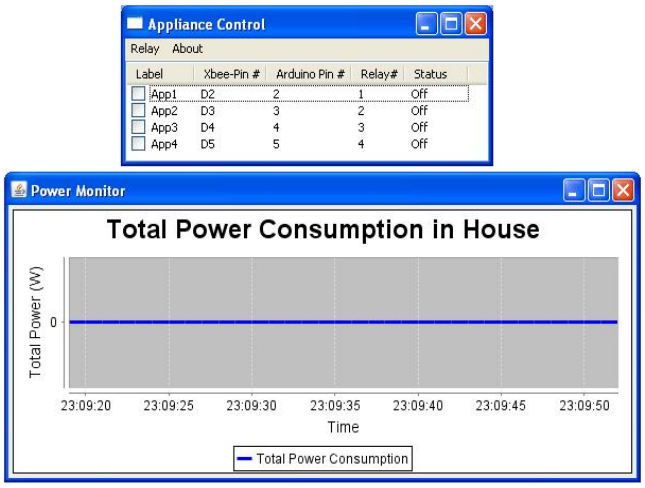

Fig. 3. GUI indicating the status of the loads and real time power consumption graph

B. Home Automation Controlled Unit (HACU)

Both UCU and HACU are linked wirelessly by ZigBee RF modules with 'Star' topology. As shown in Fig. 3, at HACU side, the ZigBee RF module is interfaced with the Micro controller Unit (MCU) and is configured as ZigBee Router API. The HACU mainly consists of following sub units:

1) Micro-Controller Unit (MCU): In this system, Arduino controller board with ATmega328 micro-controller serves as an MCU. It is used to drive the relay circuitry to turn the load ON/OFF. The purpose of using Arduino board is as follow:

- Arduino is an open-source electronics prototyping platform [24]
- Provides flexibility of hardware used
- Easy interface with XBee RF modules
- Arduino programming language is similar to the C programming language

The UCU RF Module sends the control commands in the form of packages to the HACU RF module which forwards those packets to the MCU. The controller executes the commands and operates different relays accordingly. It also reads the data from PMU and transmits it back to the UCU for plotting of real time power consumption graph.

2) Relay Control Unit (RCU): The RCU mainly consists of relays and the relay driving circuitry. Relays are used for performing the switching action on the different loads as well as to provide isolation between the control circuit and load. In our system, RCU is designed for controlling four different loads. Status of each load depends on relay switching action and it is reflected back on the GUI.

3) Power Measurement Unit (PMU): The PMU is designed with the use of current sensor and Operational Amplifier circuitry for measurement of power in single-phase. The same has been illustrated in Fig. 4. The op-amp is used to amplify the current sensor's output into the significant value and the precision rectifier is used to rectify the negative cycle of wave so that it does not damage the MCU.

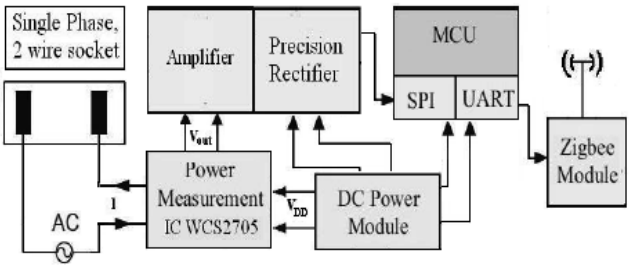

Fig. 4. Power Measuring Unit (PMU) block diagram

The output of the op-amp is provided at the analog pin of the micro controller which reads the electrical parameters and processes them further in order to calculate the power. This reading is then forwarded to the UCU terminal to plot the power consumption graph in real time. The PMU consists of Current sensor IC WCS 2705 which has the sensitivity of 255mV/A [25]. It has the capability of sensing both the AC as well as DC current. Here it is used to convert the desired load current into corresponding equivalent output voltage which is further read by the MCU and transmitted back to the UCU for power plotting.

V. Hardware Implementation and GUI Application of HAS

As discussed in previous section, the UCU enables the user to control the loads by using Java based GUI which is installed on user PC. Fig. 5. depicts the implemented HAS which has UCU and HACU, at left and at right side respectively. The following figures depict the resultant outputs of the implemented Home automation System (HAS).

The GUI is designed in order to enable easy access to the user for control and monitoring of the appliances/loads. Java software is used to program and interface the X-Bee module transmitter to the X-Bee module transceiver at the Application end. The GUI assists the user and depicts the real time scenario at the load side which helps them to take an appropriate action. The user can select any particular appliance/load using the GUI and turn it "ON/OFF" as per the requirement.It enables him to estimate the power consumption of the desired load.

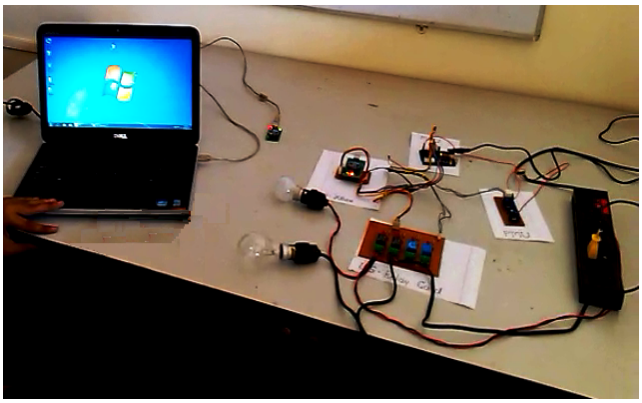

Fig. 5. Implemented ZigBee based HAS along with GUI Application

The variation in power consumption graph and in GUI window can be observed for each condition. For demonstration purpose, two different loads of 60 Watt (Load1) and 10 Watt (Load2) are used.

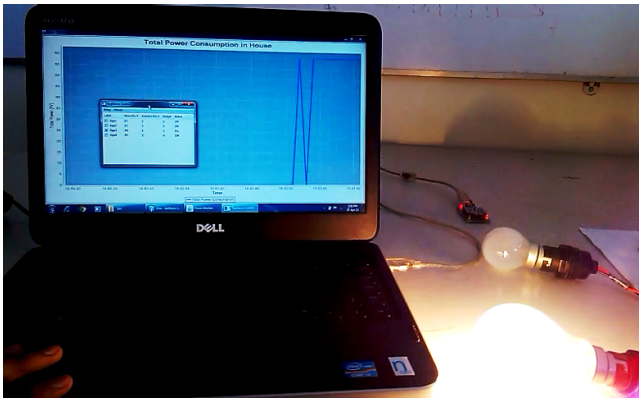

Fig. 6. GUI and Real time power consumption graph when Load1 is turned "On"

As soon as Load1 is turned 'On' as seen in Fig.6 , power plot immediately shifts to 60 Watt level and GUI window status for Load1 has changed to 'On'. Hence, the graph immediately shoots up indicating 60 Watt.

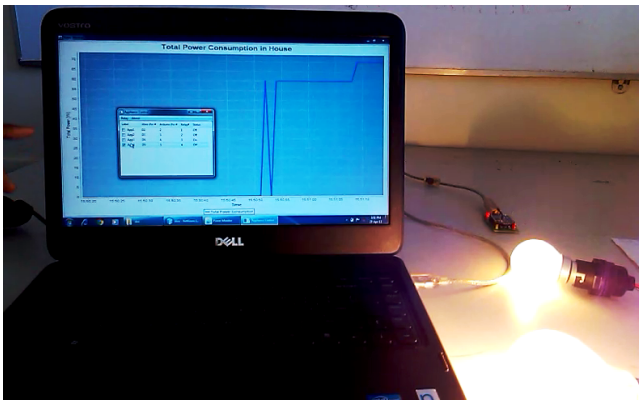

Fig. 7. GUI and Real time power consumption graph when Load 1 2 are turned "On"

Similarly, Fig. 7 depicts the resultant change in the power plot when both the loads are turned 'On'. It can be observed that the power plot indicates 70 Watt level and GUI window status for both the loads *viz.* Load1 and Load2 is depicted as 'On'. Hence, there is a step change in the graph with an increment of 10 Watt, thereby showing 70 Watt of the power consumption.

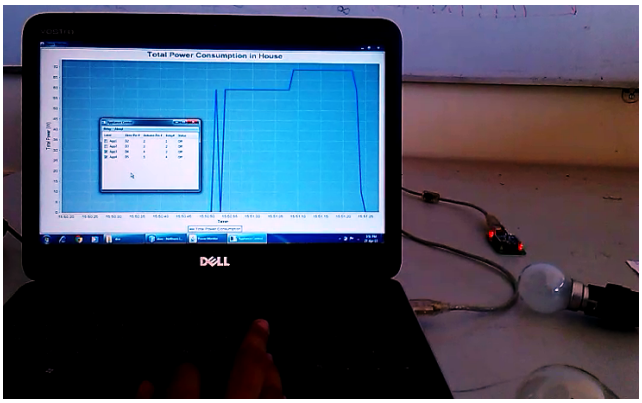

Fig. 8. GUI and Real time power consumption graph when Load 1 2 are turned "Off"

With further operation of the implemented system, when load1 and load2 (60 Watt and 10 Watt) are turned off, GUI window status has changed to 'Off' status for both the loads. Since the loads were turned 'On' before turning them 'Off ', the Power plot has shifted from 70 Watt to zero level as depicted in Fig. 8.

VI. Conclusion

The different wireless technologies have been designed for various purposes out of which ZigBee is an efficient short range wireless technology in terms of power consumption, scalability. It also provides a suitable data rate for control and monitoring purpose. This paper describes an embedded wireless home automation system (HAS) architecture using the ZigBee technology for remote control and power monitoring of the domestic loads. The hardware implementation of the system along with it's outcome is discussed. As the HAS provides GUI window and real time power consumption graph, the user can control the loads easily as well as can detect any variation in the power consumption of the rated load. As a result, the user can repair/replace the load in case of false rating or malfunctioning which leads to the efficient utilization of power. This helps to save and conserve the energy. Hence it can be concluded that the ZigBee (over IEEE 802.15.4) is an efficient technology in the designing of the home automation system.

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