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Wireless Protocol for Enhanced Control of Lighting Devices

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Abstract: There are several proprietary protocols available in the market for the implementation of building automation systems used for enhancing the facilities available in a building. DALI (Digitally Addressable Lighting Interface) is a wired lighting protocol which sends and receives data to and from a digitally addressable ballast to control it. The protocol standard was called for to integrate all the lighting interfaces in a single building with the DALI supporting upto 64 devices to do so. Our current research is done to improve the cost efficiency of implementing this protocol by implementing it wirelessly using 2 XBee RF modules and using the IEEE 802.15.4 standard to transmit the address of the ballast along with different data packets to control their dimming. The 2 XBee modules are used to transmit RF data packets between the host PC and the remote DALI interface (Arduino setup). The Arduino board continuously runs the code to read the serial data from the packet received and thus, produce a corresponding digital output that has been used to control the dimmable ballast. The DALI standard uses a 19 bit data frame but the 802.15.4 protocol requires the data transmitted via. the XBee modules to be an API (Application Programming Interface) frame. We were successfully able to transmit RF data packets from our PC host and produce different digital outputs to control the dimming settings of our ballast.

Key words: DALI, automation, networking, XBee, API, ballast

INTRODUCTION

The use of wireless technology for the control of building services is an important cornerstone in the development of field of automation. The United States and most of the member nations of the EU (European Union) use open standards like BACnet, KNX, Zigbee etc in implementing home automation systems. Use of this system also compliments the human development index of these countries thus, asserting its importance in today's world.

The implementation of DALI which is a wired two way (master-slave) communication protocol wirelessly along with the building of an interface circuit to communicate with the ballast devices is the main aim of this research. Since, 8 bits are only allotted for addressing the slave devices, 64 devices can be connected to the wireless network implemented here.

We have used the XBee modules for communicating with the ballasts which is connected to the DALI interface circuit. The scope of this project is to connect this network to a computer in the capacity of a node which will transfer and receive data from a main computer which can have many such sensor network nodes and will help in increasing the number of devices that can be communicated with through the help of this protocol.

Literature review: Building services are customarily controlled separately, making building automation the set of control and communication technologies linking different subsystems to implement a centralized monitoring and control centre. The primary purpose of having a single control point which provides access to all building services is to establish feasibility. Remote monitoring allows for quick detection of corrupt devices helping prevent long physical searches and saving personal time (Bellido-Outeirino *et al*., 2012). This continuous monitoring enables preventive and predictive maintenance, thereby reducing operational and maintenance costs. Our research focuses on the development of a Wireless Sensor Network (WSN) which also integrates DALI protocol (Bellido-Outeirino *et al*., 2016).

The DALI (Digitally Addressable Lighting Interface) standard focuses on a single aspect of BA, lighting control. It became an independent standard in 2009 and it expanded its application range to high intensity discharge lamps, LEDs, incandescent lamps, etc. It is a very simple and easy to build standard, moreover, it allows a two way communication which provides us with feedbacks about the status of individual DALI devices. Building services are usually controlled separately, thus, increasing the cost to implement the system. Since, DALI compliant devices

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are easily available in the market, this protocol is more feasible to implement. Despite the feasibility, DALI is a wired protocol resulting in a wired connection with all its slave devices (Shete and Rana, 2015).

Zigbee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios. Zigbee specification is made to be simpler and less expensive than other wireless personal area networks, unlike Bluetooth and Wi-Fi which are expensive in comparison. The mainly used application of Zigbee is where short-range low-rate wireless data transfer is needed.

Its range is limited to 10-100 m due to low power consumption, depending on power output and environmental characteristics. Zigbee devices can transmit data over long distances by passing data through a mesh network of intermediate devices to reach more distant ones. Zigbee is mainly used in low data rate applications which require long battery life. Zigbee has a defined rate of 250 kbps. Zigbee was conceived in 1998, standardized in 2003 and revised in 2006 (Nourildean, 2012; Domingo-Perez *et al.*, 2012).

In this study, we have developed our own IEEE 802.15.4 based WSN. The nodes Which compose the WSN would have a Microcontroller Unit (MCU) and an IEEE 802.15.4-compliant transceiver. The DALI communication protocol was implemented on the MCU. The forward frame of a DALI message has 6 bits dedicated for addressing the slave devices for which the message is intended thus allowing a total of (2^8) 64 slaves devices to be connected to the master. The IEEE 802.15.4 based WSN has two layers namely PHY and MAC within it. The central point of the system will be the PAN (Personal Area Network) which will wirelessly communicate with our WSN. Therefore, an additional layer, namely the network layer is added to the PHY and MAC layer. Thus, a number of WSNs can be connected with the PAN which ultimately increases the number of end devices that can be incorporated in the system.

MATERIALS AND METHODS

Proposed solution: This study discusses the approach taken to build the wireless lighting control system along with the procedural methods for the hardware implementation. The Personal Area Network (PAN) can be connected to similar WSN (Wireless Sensor Network) nodes which ultimately increase the number of slave devices that can be connected (Anuja and Murugeswari, 2013). Figure 1 represents the top level block diagram of the proposed solution. The PC host holds an XBee

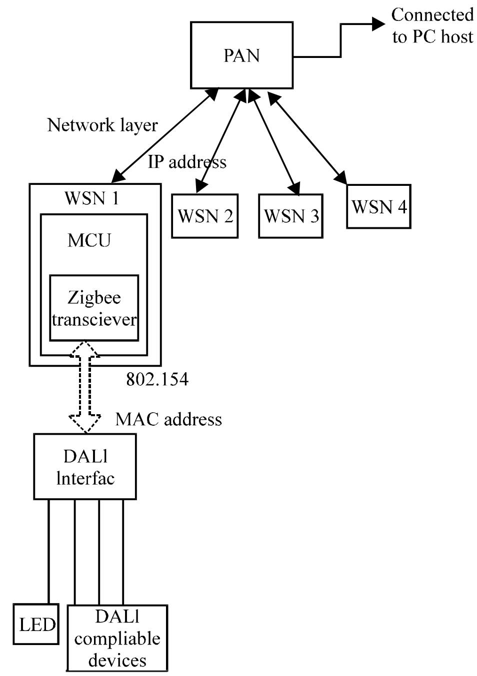

Fig. 1: Represents the top level block diagram of the proposed solution

module mounted on an USB explorer. The RF data packets to be transmitted are sent using the XCTU utility software which not only lets us configure the RF modules to communicate with each other but also creates API frames that can be sent via. the DOUT and DIN pins of the RF module. The Wireless Sensor Network (WSN) node has 2 important components, namely the Arduino board and the XBee shield. These 2 components combine together to receive the RF data from the Router module and decode the packet to output a 3 bit digital output. The value of this digital output depends on the code written to decrypt each sent API frame.

Finally, the digital output is sent to a DAC circuit which can be built on a trainer kit and uses simple resistive components and the 741 op-amp IC. R-2R ladder DAC was rigged up for this purpose. The DAC circuit also has an inverter circuit cascaded to it in order to inverse the negative output voltage produced. This output is given to a ballast in the photometric lab that takes a 0-10V supply as input and outputs at different intensity values for corresponding input voltages.

Hardware implementation: The router AT is used to send the API frame from the PC host to the receiving coordinator that is mounted on the XBee shield. The coordinator AT module receives the RF data transmitted and the XBee shield is used to interface the module to the

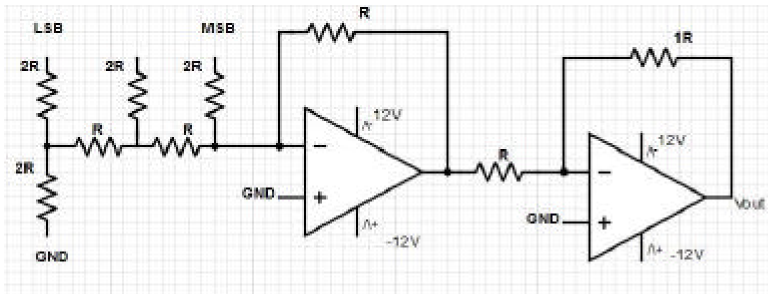

Fig. 2: The implemented circuit

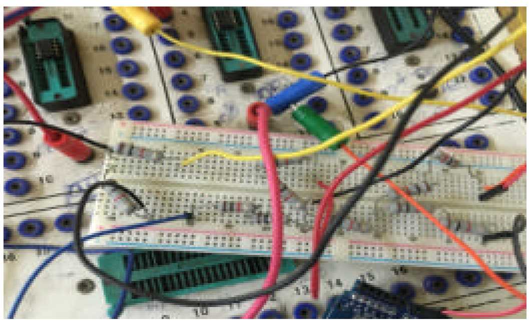

Fig. 3: The R-2R ladder

Arduino board. The purpose of the shield is to interface the Arduino with the RF module pins. Also, the shield automatically connects the DIN and DOUT pins of the receiving RF module to the Tx and Rx pins of the arduino board and leaves out the pin 0 and 1 on the shield for serial communication, if required (Zhang, 2011).

Now, the code reads the data in the packet sent and accordingly, produces digital output on the pins 6-8. The digital output is then sent to a DAC circuit which has been made using an R-2R ladder. The R-2R ladder is built for providing a gain of 2 which is then given to an inverter circuit to inverse the voltage. The value of R is 1.04 kΩ. The picture below shows the 3 bit DAC along with its circuit diagram. The Arduino board sends 0 V (LOW) and 3.3 V (HIGH) to the DAC circuit made out on the breadboard (STM., 2012).

The implemented circuit of the R-2R ladder shown in Fig. 2 and 3. Figure 4 shows the DAC circuit which transforms each digital value into a specific DC voltage for controlling the dimming setting of DALI based LEDs. The XBee shield in the above figure is used to mount the XBee module to the arduino board. It acts as the receiver that uses the C++ code pushed on it to decode the wirelessly transmitted data frames.

Software implementation: We have used the XCTU utility software to configure the RF modules in our PAN

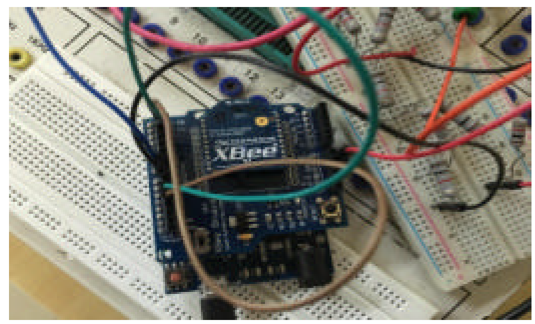

Fig. 4: The DAC circuit which transforms each digital value into a specific DC voltage

network. The series 1 XBee modules support only the 802.15.4 and digimesh standard. The series 2 modules can be used for implementing the Zigbee protocol but this firmware can't be uploaded on the series 1 kit.

The XBee module configuration is done to bring them in the same network by setting their PAN ID and channel ID. Also, the source and destination address of the modules are provided and all these commands are then uploaded on the board. Teraterm is a console that can be used to configure these settings using command line language. But this is a more easier way and reduces the hassle of learning this language. The transmitting router's name ID is set as router AT. The receiving module's name is set as coordinator AT. The coordinator settings are similarly changed to bring these 2 modules in the same network. The modules are detected by mounting them on a USB explorer and are then discovered on XCTU (Anonymous, 2012). Once the settings are completed, the router AT and coordinator AT module will be able to communicate with each other.

Once the modules are configured and the hardware properly set up, the console page of the XCTU Software is opened to transmit RF packets via. the XBee modules. The Arduino board is uploaded with the source code and the XBee shield jumper is set at XBee position or

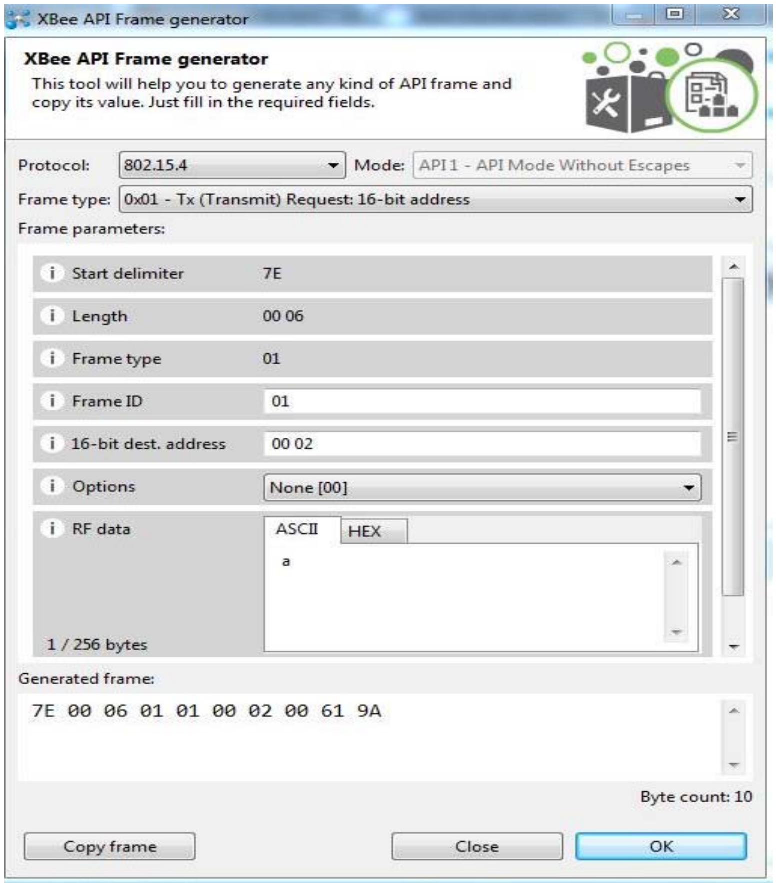

Fig. 5: The API frame generator

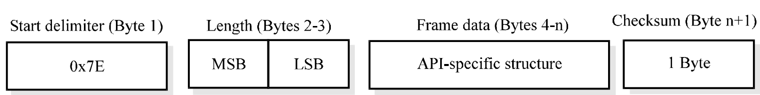

Fig. 6: The details of frame

USB position. XBee position in case the Arduino board is supplied by battery of USB position if the board is supplied with power from PC (Faludi, 2010). The API frame generator used to make each frame is shown in Fig. 5.

The dimming settings are controlled by sending any character from 'a' to 'f' where 'a' corresponds to minimum voltage or most dim and 'f' to maximum light output. The details of the frame shown in Fig. 6 is shown below:

- Start delimiter: this field is always 0x7E
- Length: the length field has a two-byte value that specifying the number of bytes contained in the frame data field
- Frame data: the content of this field is composed by the API identifier and the API identifier specific data. The content of the specific data depends on the API identifier (also called API frame type)
- Checksum: byte containing the hash sum of the API frame bytes

RESULTS AND DISCUSSION

Table 1 represents the different output voltages that were transmitted for each RF packet and the DAC R-2R bridge equivalent output voltage that the ballast is provided with. Figure 7 represents the minimum and maximum dimming settings that can be achieved on a single device using this setup corresponding to the output states of 0 and 7, respectively.

Table 1: Output voltages for each RF packet

Output	Equivalent state	Output Voltage (V)
0	000	0.41
1	001	1.66
2	010	2.91
3	011	4.16
4	100	5.41
5	101	6.66
6	110	7.91
7	111	9.16

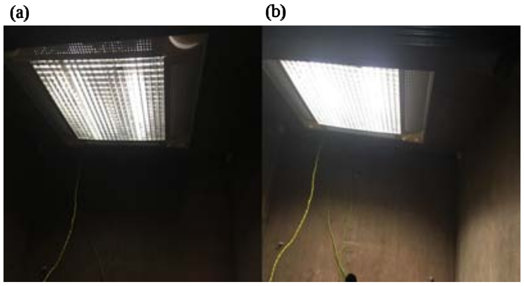

Fig. 7: a and b) The mibimum and maximum dimming settings

CONCLUSION

DALI is a wired protocol which uses serial communication between the master and the slave devices thus making use of Tx and Rx pin of the microcontroller. The serial output of the microcontroller is sent to the configured XBee modules which act as radios in transmitting the serial data wirelessly to the interface circuit. Working on the interface circuit increases the complexity and also the timeline of our work. The DALI message frames can be instead received by the XBee module and then transferred to another microcontroller which then decodes the forward frame from its ASCII encoded format and the data can be sent to a computer for control of lighting devices.

We used the IEEE 802.15.4 standard to transmit our data while learning the drawbacks of the RF modules that had been purchased. The s1 module has a limitation in the number of protocols it can support. Thus, an API frame was used. An API frame is a standard frame type that is used to form data packets. IEEE 802.15.4 is not the only protocol which makes use of this but other standards like WIFI can transmit and receive these API frames.

The research done here allows us to remotely control a lighting device which means that both the router and coordinator modules have to be in each other's range. But since, API frames have been transmitted all the time, the router AT module can receive this information even over WIFI. So, an API data frame can even be generated over internet and then used to transmit data to RF modules. The signal strength of the 802.15.4 standard is weaker than WIFI but if the RF modules are configured manually with the source address of network providing internet, the lighting modules can be controlled by creating its designated app. So, the data packets can be directly sent from the remote application and that would eliminate the need of generating frames using XCTU.

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