

A Real-Time Wireless Sensor Network based on 802.15.4/ZIGBEE to Control Home Automation Environment

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Abstract— Greenhouse facilitates precise monitoring and controlling of various parameters, so as to cultivate quality con-science crops without slaying resources. The cabling laid for the sensors, deployed inside the Greenhouse is not feasible. Hence the need for an automated system employing wireless communication and remote sensing is imperative. This paper proposes a Wireless Sensor Network (WSN) based embedded system and deals with the implementation of ZigBee network (over IEEE 802.15.4) for remote controlling of the Greenhouse parameters. The detailed information regarding establishment of ZigBee network in Star topology as well as in Mesh Topology, inside the Greenhouse is illustrated. It also demonstrates the real time monitoring of parameters such as temperature, humidity, as well as the total power consumption of the system, with the help of a PC based GUI application developed on Java platform.

Key words: Green House, Real Time Monitoring, WSN, Embed-Ded System, Zigbee (IEEE 802.15.4), Topology, GUI

I. INTRODUCTION

Due to the research and advancement in the field of automation, it has facilitated development in wireless communication. Automation along with the use of Wireless Sensor Networks (WSNs) have superseded the traditional manual control systems hence gaining popularity in industrial, domestic as well as in agricultural sector. This has led to an integrated way leading to new solutions, better performance and an absolute system. In the field of automation WSNs have revolutionized the design of emerging embedded systems in terms of various factors viz. scalability, mobility, power consumption etc.

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor the physical or environmental conditions, such as temperature, vibration, pressure, motion etc. As described in [1] and stated by Palanisamy *et al.* in [2] the unique characteristics of WSNs are:

- Can store and harvest limited power
- Ability to withstand callous environmental conditions
- Ability to cope with node failures
- Mobility of nodes is possible
- Dynamic network topology
- Heterogeneity of nodes
- Large scale deployment
- Unattended operation and self-governing ability
- Node capacity is scalable, only limited by bandwidth of gateway node.

Since environmental diversity exists and there are changes in the ecological conditions from region to region,

there is a variety in the cultivation of crops. The main objective of the green house is to breed plants in any particular region independent of its existing environmental conditions. For this purpose an automatic embedded system is required to facilitate the smooth maneuver of cultivation. Ral Aquino-Santos [3] *et al.* have discussed the applications of WSN in greenhouse control environment and stated it can be a cost effective option for development of the greenhouse control system.

The detailed comparative study [4] of the different short-range wireless protocols *viz.* Bluetooth (over IEEE 802.15.1), UWB (over IEEE 802.15.3), ZigBee (over IEEE 802.15.4) and Wi-Fi (over IEEE 802.11a/b/g), it is found that ZigBee is an efficient protocol in field of automation. Being a controlling and a monitoring system our proposed model is implemented with ZigBee protocol. It consists of two modules i.e. one is user side module in which the transceiver is connected to the user PC to control the various greenhouse appliances remotely and the other is greenhouse side module to which sensors are interfaced. It monitors all the parameters, fetches the real time sensed value and depicts the same on LCD display.

This paper is organized as follows; Section II provides the details regarding the ZigBee protocol and its super frame structure whereas our proposed system design is discussed in Section III. Section IV elaborates the network establishment using ZigBee protocol in detail. Section V presents the result analysis and outcome of the system and the final Section presents the conclusion of the paper.

II. ZIGBEE PROTOCOL

ZigBee standard (IEEE 802.15.4) is formed by the ZigBee Alliance Company in 2002. Though the ZigBee standard is formed in 2002 but the complete ZigBee protocol specifications were ratified in December 2004 [5]. It is a low data rate WPAN (LR-WPAN) standard which provides data rate up to 250 Kbps in the global 2.4-GHz Industrial, Scientific, Medical (ISM) band.

A. Features of ZigBee

ZigBee is self-configuring, self-healing system of redundant and low-power nodes [7] has various unique features which some of them are as follow:

- Ultra low power consumption and scalability [8]
- Supports star, mesh and cluster tree topologies
- Self-organized, multi-hop, and reliable mesh networking [9]
- Provide long battery life

B. ZigBee Protocol stack

ZigBee has layered architecture shown in Fig.1. It uses the IEEE 802.15.4 PHY and MAC layers to provide reliable wire-less data transfer. The ZigBee Alliance specifies the

Logical Network, Security and Application Software to complete the communication suite. PHY layer performs modulation (Offset Quadrature Phase Shift Keying (OQPSK)) and transmits the packets. Similarly on receiver side it receives the packet and performs demodulation. [10]. MAC layer uses Carrier Sense Multiple Access- Collision Avoidance (CSMA-CA) technique for accessing the Network. Network layer provides network configuration, message routing [10] and manages devices in the network. Further the interoperability and inter compatibility between similar products from different manufacturers are provided by ZigBee profiles defined in application layer [6].

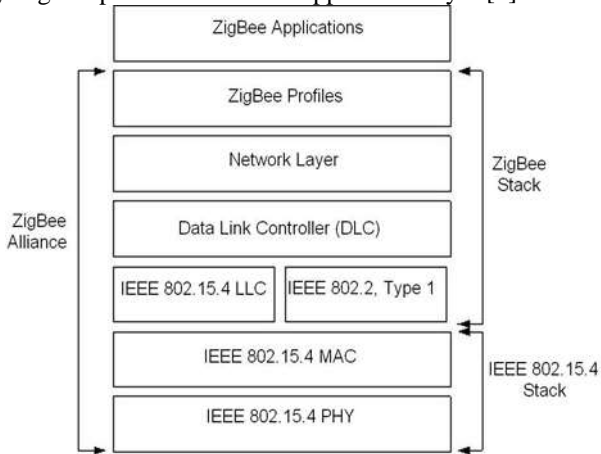


Fig. 1: ZigBee protocol stack

C. ZigBee Superframe structure

In hard real time application system it is always preferable to implement centralized access protocol type instead of random access such as CSMA/CA as missing a single deadline causes serious consequences [11]. Hence 802.15.4 can be operated in an optional super frame mode which is suitable for hard real time application, which requires dedicated bandwidth to achieve low latency [10]. such application should get some dedicated bandwidth and guaranteed time slots on deterministic basis instead of probabilistic one. This is possible in Contention Free Period (CFP) only. PAN coordinator can allocate such slots (maximum 7) known as guaranteed time slots (GTSs) which forms the CFP. Sometimes channel access can be denied because of low priority or unavailability of GTSs. It can be resolved using implementation of CSMA/CA in Contention Access period (CAP). Beacon frame is transmitted at the starting of each superframe (refer fig. no. 2) for synchronization purpose. Along with the beacon frame there are other types of frame such as data, acknowledgment and MAC command which plays very crucial role while network establishment.

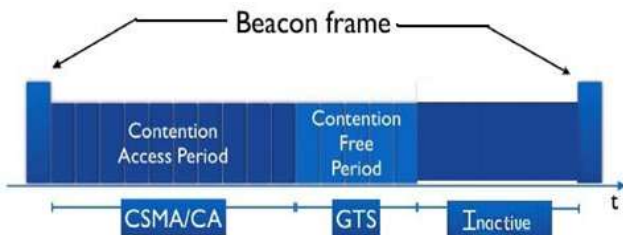


Fig. 2: IEEE 802.15.4 super frame structure

D. ZigBee Devices

Devices used in ZigBee protocol are categorized on the basis of their functionality [5] as follows:

- Full-function Device (FFD): The FFD has full functionality and it can communicate with other FFDs and RFDs. It can therefore act as a PAN coordinator, a coordinator and a router or even as a RFD.
- Reduced-function Device (RFD): The RFD can communicate only with the FFD viz. network coordinator or router. As their functionality is governed by these coordinators, communication between two RFDs cannot be established.

Among all the PAN devices, it is only the PAN coordinator that has best computational resources. It is the only network element which is able to establish communication with other networks in the vicinity.

III. SYSTEM DESIGN

Our designed system is implemented with ZigBee protocol. It mainly consists of two systems viz. Portable Controller Node (PCN) system and the Sensor and actuator Node (SAN) system. The block diagram is as shown in Fig. 3 below:

A. Portable Controller Node (PCN) system

PCN system mainly consists of user laptop/PC and ZigBee transceiver module interfaced with PC via UART (Universal Asynchronous Receiver/Transmitter) port. Module of XBee Series2 of Digi Inc. [12] is used which is configured as PAN coordinator API. It transmits user control commands serving as Controller node. The XBee modules are programmed using X-CTU software in Application Programming Interface (API) mode [13] which helps to construct a real wireless network. A Java based GUI application is developed on PC which facilitates the real time monitoring of various greenhouse parameters using sensor nodes as well as remote control of appliances using actuator nodes.

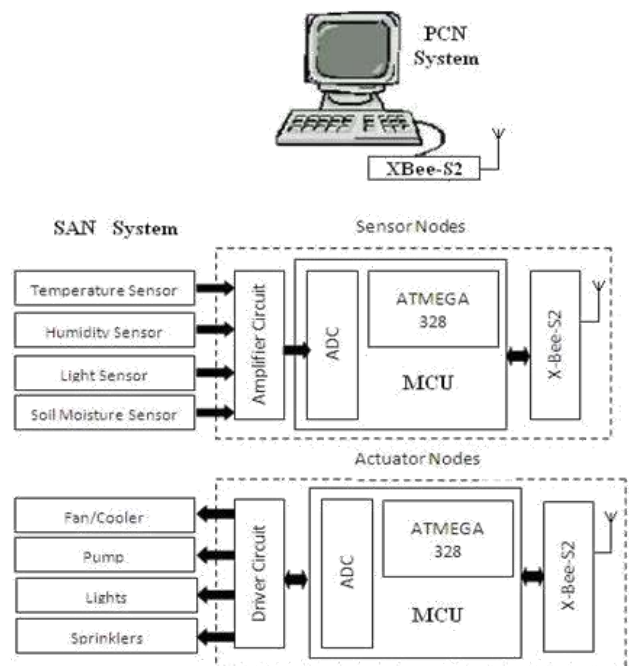


Fig. 3: Another part of SAN system is Actuator node

B. Sensor and Actuator Node (SAN) system

Both PCN and SAN systems are wirelessly linked by ZigBee with star topology. If greenhouse area and appliances to be controlled are far away then the sensor and actuator node can be implemented separately, whereas they can be integrated as one node if distance is less in SAN system.

1) Sensor Node:

As shown in Fig.3 various sensors such as temperature, humidity, light, soil moisture, sense the respective parameters inside the green house and transmit it to the PCN system. These sensors are integrated with the ATmega328 and XBee module to form the sensor node. Its a 8 bit micro controller unit (MCU) [14] with 32 Kbytes of 'in system flash' and 1 Kbyte of EEPROM memory. It has in built 10 bit Analog to Digital Converter (ADC) which converts input analog sensed value to corresponding digital value. It provides these readings to the MCU for further processing.

MCU continues to update these values on the LCD and whenever it receives any command from the PCN system it first checks the present status and then provides appropriate control signals. These signals are provided to the actuator node for switching operation of the corresponding appliances. Fig.4 depicts the implementation of sensor node and LCD display indicating the sensor values where TEV indicates temperature inside the greenhouse in Celsius, LI shows the luminous intensity of sunlight in lux. Also the MLV displays the moisture level content in the soil. HUV indicates the humidity level of air which should not be too arid or too damp, so as to create apt conditions inside the greenhouse.

2) Actuator Node:

Another part of SAN system is Actuator node as shown in Fig.3. It is integrated with ATmega328

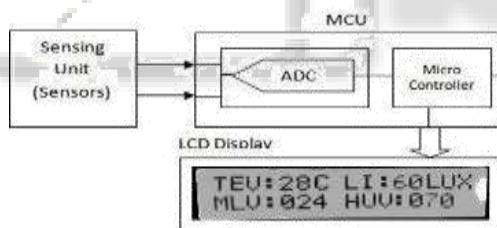


Fig. 4: LCD displaying Sensor values

MCU, XBee transceiver and relay driving circuitry for control-ling the appliances.Sensor node transmits the sensed values in form of packet to the PCN system for plotting real time graph and to actuator node for control action.

Depending on these values, the actuator node takes the corrective measures or user can manually send the control signals with help of GUI built at PCN system in order to stabilize the greenhouse parameters. Hence it performs switching operation of appliances such as cooler, pump, heater, sprinkler using relay driving circuitry. The purpose of using Arduino Atmega328 in SAN system is ; it is an open-source electronics prototyping platform which has programming language quite similar to C.It is flexible and provides easy hardware interface [15].

3) Sequence of operation:

At SAN system, the XBee transceiver module is interfaced with the Arduino MCU and is configured as ZigBee Router in API mode. The process flow of operation at SAN can be

summarized as follow: Real time status of greenhouse parameters is updated and transmitted to PCN system periodically by sensor node.

- On the basis of real time monitoring user can send the control commands to actuator node.
- Actuator Node receives control commands in form of packets from PCN system via ZigBee transceivers.
- The commands are processed by MCU of actuator node.
- MCU checks the present status, threshold value and compares them to take an appropriate action.
- Then actuator node performs the switching operation of appliances if its necessary.
- Present status of the appliances is retransmitted back to the PCN system and the GUI window is updated automatically.

IV. ESTABLISHMENT OF ZIGBEE NETWORK

In our system communication between PCN and SAN system is established by ZigBee network. PCN side Transceiver is connected to the user PC via BAFO cable and is configured as the network PAN Coordinator. Each ZigBee network should have at least one PAN Coordinator which is unique in the network. It performs various operations such as structuring the network, establishing an addressing scheme, keeping the ad-dressing tables. In order to establish network along with PAN coordinator at least one ZigBee Router(in case of point to point configuration) or two or more, ZigBee routers and ZigBee EnDevices (in case of point to multi point configuration) are required. We have configured PCN side Transceiver as PAN coordinator which exchanges the commands with SAN side Routers.

We established the network using star topology where PCN is a central controller node. Whenever system is powered on first time, PCN chooses unused PAN Identifier and becomes the PAN coordinator. It starts establishing the network by broadcasting the beacon frames to sensor and actuator nodes (1st phase) as shown in Fig.5 [16]. These nodes can either be ZigBee End Device (RFD) or ZigBee Router (FFD). If these nodes want to join the network, they can send the request to PCN (2nd phase).Then PCN will add these nodes as child nodes in its neighbor list and will send the response in 3rd phase. In the 4th phase sensor and actuator nodes will add PCN as parent node in their neighbor list and will return the acknowledgment to PCN.

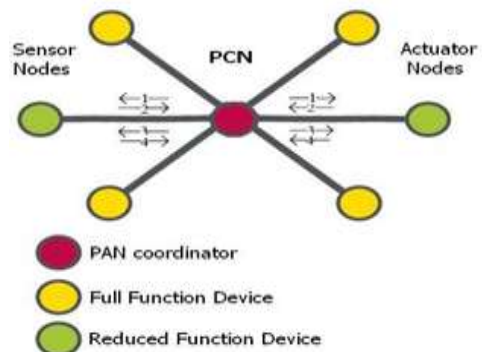


Fig. 5: Establishment of ZigBee Network

A. Configuration of XBee modules

The configuration of the XBee modules is initial step while establishing the ZigBee Network. XBee-S2 modules are

used in our system which have two modes of operation; Transparent (AT mode) and API mode. API mode is enabled in which modules are configured as PAN coordinator, Router or End Device by using X-CTU software. Configuration of XBee transceiver as PAN coordinator is as depicted in Fig.6.

The PAN ID must be identical for all the XBee radios, as in this system it is 1234. Also the Baud rate should be same; default baud rate being 9600 is modified as 115200 uses X-CTU API mode. For operating the Coordinator in broadcasting mode its DL - Destination Address Low has to be FFFF for Router, DL address is set to 0 which is the default DL Address for a Coordinator.

B. Range of the Established Network

Established network can be characterized by the Network span (range) and the implemented topology. The range of the network depends on environmental conditions, network topology and range specifications of implemented transceiver module.

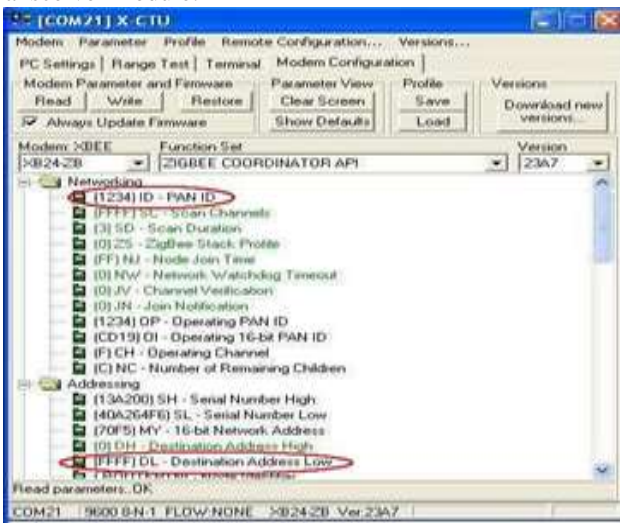


Fig. 6: Configuring XBee transceiver as PAN coordinator

Adverse environmental conditions reduce the Received Signal Strength Indicator (RSSI) value and weaken the signal. Increase in the transmitted Signal Power can overcome the adverse effect, but it will hamper the ultra-low power consumption feature of the ZigBee protocol.

The range of the system is also limited by transceiver mod-ule. The XBee-S2 module provides 40m [12] indoor range which can be extended up to 90m by implementing XBee PRO modules [17]. Implementation of particular transceiver depends on requirement of the system.table I provides details regarding XBee-S2 and XBee-PRO modules.

Parameter	XBee-S2	XBee-PRO
RF data rate	250 Kbps	250 Kbps
Indoor range	40 m	90 m
Outdoor range**	120 m	3200 m
Transmit current	35 mA/ 45 mA *	205 mA
receive current	38 mA/ 40 mA*	47mA
Transmit power	1.25 mW	63 mW
Receiver Sensitivity	-96 dBm*	-102 dBm

Table 1: Comparison of Xbee Radios

Another factor which influences the network span is the topology of the network. For small scale application

and limited network span star topology is suitable hence it is implemented in our system as it is competent for controlling one green house. The network span can be increased further with the use of mesh architectur

C. Mesh Architecture Implementation

The network span can be extended using ZigBee's self-forming and self-healing mesh network architecture [18] as depicted in Fig.7. In mesh topology control commands and data can be transmitted from one node to another node using multiple paths. Whereas the star topology is useful when endpoints are closely clustered and communicate with a single router node. This helps in reduction of the battery consumption at client nodes. Our system is limited to Green House Con-trolled Unit1 (GHCU1) where star network is used but the mesh network can extend it to many Greenhouse units Even it can monitor the data simultaneously. PAN coordinator communicates with all the routers and updates the information with their help to maintain reliable communication inside temperature. It can be easily recognized that controlled temperature provides more stabilize parameter reading.

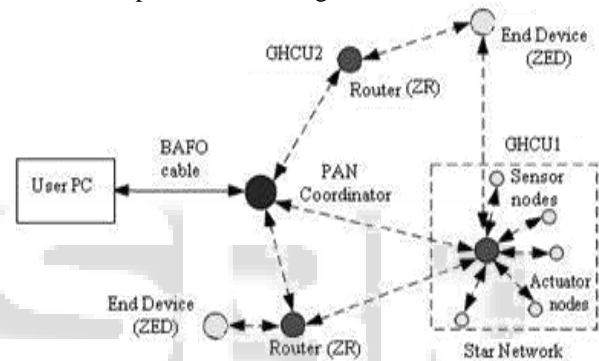


Fig. 7: Implementation of ZigBee Star and Mesh network for GHCU



Fig. 8: Real time monitoring of temperature at PCN system

D. Humidity Monitoring and Other Parameters

Humidity normally expressed in terms of RH (Relative Humidity) is a ratio of actual moisture in the air to the highest amount of moisture that can be held by the air at the same temperature. Variation in humidity directly affects the transpiration rate of the leaf. HIH4000 is used as humidity sensor [20] which is ideally suited for low drain, battery operated systems. It merely draws 200 micro Ampere current.

V. RESULT ANALYSIS

The aim of the designed WSN based system is the real time monitoring of various greenhouse parameters such as temperature, humidity, soil moisture level, light intensity.

These parameters had been displayed on the LCD (refer Fig.4) at SAN system. Along with that using reliable wireless communication over 802.15.4, these were successfully transmitted to the PCN system to fulfill the aim of real time monitoring of these parameters at remote place. The system also provides the remote control of various appliances using GUI based application and actuator nodes.

Transmitting the sensed parameters of SAN system towards PCN and plotting real time graph was the primary aim. Hence we instead of using very accurate and sophisticated sensors, we have implemented readily available sensors. The result obtained is discussed further.

A. Temperature Monitoring

National Semiconductor's LM35 IC [19] is used for sensing the temperature inside the green house. Good sensitivity, linearity and operation over a wide temperature range make LM35 suitable for the system.

The real time temperature monitoring using Java based application at PCN system is as depicted in Fig.8. One sensor is implemented outside and other one is inside the green house. Black line indicates the uncontrolled outside ambient temperature whereas the red line indicates the controlled

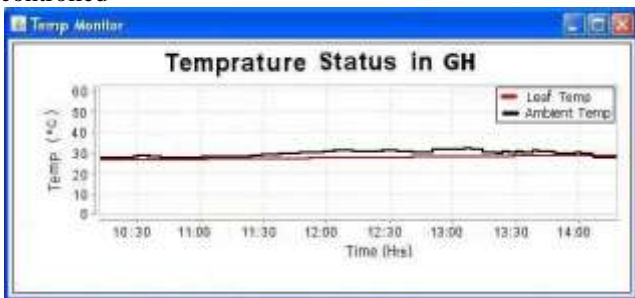


Fig. 9: Real time monitoring of humidity at PCN system

The real time humidity monitoring at PCN system is as depicted in Fig.9. The uncontrolled humidity was monitored for the span of 5 hours and graph was plotted by application accordingly. Also the additional feature of observing the parameters simultaneously is provided by system as depicted in Fig.10.



Fig. 10: Simultaneous plotting of temperature and humidity parameters at PCN system

In our system the copper probes are used as soil moisture sensors and are interfaced to the MCU via ADC. For sensing light intensity, a Light Dependent Resistor (LDR) is used. It is made up of Cadmium Sulphide (CdS) in which two CdS photo conductive cells having spectral response [21] similar to that of a human eye are used. It works on the basic principle of negative co-efficient property i.e the cell resistance falls with increase in light intensity. These parameters were sensed and displayed on LCD (refer Fig.4).

B. Power Monitoring

The unique feature of real time power monitoring [22] in green house is incorporated in the system. It enables the user to estimate the total power consumed by various appliances as well as helps him to recognize any malfunctioning of appliance. The system provides GUI for controlling the appliances as shown in Fig. 11. For testing purpose two loads (Incandescent bulbs) of power rating 60 Watt/load, were used. Fig.12 depicts the total power consumption in green house.



Fig. 11: GUI developed for controlling the appliances



Fig. 12: Real time power consumption monitoring at PCN system

VI. CONCLUSION

The 802.15.4 viz. ZigBee is an efficient wireless protocol in terms of power consumption, scalability and it also provides a suitable data rate for controlling and monitoring purpose. Hence, we can say that the advent of 802.15.4 revolutionized the automation industry. This paper describes a Wireless Sensor Network (WSN) based embedded system built using the ZigBee technology and emphasis on hardware implementation of sensor and actuator nodes. It also describes the network establishment using ZigBee protocol. A GUI application de-veloped on the Java platform facilitates controlling of various appliances remotely in order to stabilize the greenhouse parameters. Hence our proposed system provides real time monitoring of various greenhouse parameters along with the remote control of appliances using GUI based application as well as providing amount of power consumed.

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