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A Smart Self-Adjusting Sensor Network based on ZigBee Communications

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Abstract— **Wireless Sensor Networks (WSNs) is an emerging and powerful technique for today's real world applications with interactive environments because of rapid introduction of network enabled digital technology. Recently, the scope of WSN technologies has been expanded to places such as home monitoring, remote environmental monitoring and target tracking. The design of a WSN depends significantly on the application, and it must consider factors such as the environment, the application's design objectives, cost, hardware, and system constraints. During the dynamic node deployment, conventional routing protocol schemes fail to address the network characteristics like network density and node mobility which changes significantly over time and space. So to maintain a stable connectivity and maximizing the network communication throughput through wireless, with effective and reliable delivery is difficult to handle and thus it become a real challenge.**

A wireless ad hoc network is decentralized wireless network, which does not rely on a pre-existing network infrastructure due to frequent changes in the dynamic environments. Instead, each node participates in routing by forwarding data, which is made dynamically based on the network connectivity. Node density has a great impact on the efficiency and performance of wireless ad hoc networks by influencing some factors such as capacity, network contention, routing efficiency, delay, and connectivity. ZigBee is an emerging wireless communication technology which supports low-cost, low-power and short-range wireless communication. Thus, ZigBee enables new opportunities for wireless sensors and control networks. To address the above architectural constraints, through the co-existence of the new emerging technology, ZigBee and the Dynamic Ad hoc network protocol inspires us to propose a new Smart Self-Adjusting Sensor (SSAS) Network system and thus we design and implement it.

For experimental purpose, by using some smart home services we are going to demonstrate the feasibility and effectiveness of the proposed SSAS system. This shows, safety and energy efficiency can be achieved. Because of its graphical user interface and multiple sharing of the Andriod application makes the system more flexible. Thus multiple members can have the status of their own appliances simultaneously by using hand held Andriod based mobile device.

Index Terms— **Wireless Sensor Networks (WSNs), Dynamic Node-deployment, Self-adjusting, Dynamic ad hoc network, Smart home services, Android based Mobile devices**

I. INTRODUCTION

Wireless sensor networks (WSNs) has grown into a hot research area at a tremendous pace, particularly with the rapid development in Micro-Electro-Mechanical Systems (MEMS) technology which has facilitated the development of smart sensors. Smart sensor nodes are low power devices equipped with one or more sensors, a processor, memory, a power supply, a radio, and an actuator [1]. A sensor network is a large network of small sensor nodes, capable of sensing, communication and computation. WSNs are wireless networks composed of numerous spatially distributed sensors with limited data gathering and processing capability to monitor and/or activate in a given environmental area. WSNs have become increasingly important because of their ability to monitor and manage situational information for various intelligent services [2]. Therefore, WSNs has been applied in many fields, such as the military, environment monitoring, and healthcare monitoring [3]-[5].

Nowadays, WSNs are gradually being used in the home for safety and energy management services. For example, lighting is automatically controlled through information such as the resident's movement or the intensity of illumination gathered by WSNs [6], and consumer devices are monitored and controlled by WSNs installed in the home [7]. The design of a WSN depends significantly on the application, and it must consider factors such as the environment, the application's design objectives, cost, hardware, and system constraints. During the dynamic node deployment, conventional static routing protocol schemes fail to address the network characteristics like network density and node mobility which changes significantly over time and space, so it becomes a biggest challenge to maintain a stable connectivity and thus maximizing the network throughput.

The rest of the paper is organized as follows: the Section II describes a short academic research is done for mitigation of WSNs constraints, especially reducing consumption of battery energy, effective throughput and stable connectivity; in Section III, we present overall the system architecture; in Section IV we show the implementation and test bed of the proposed model. And in Section V, we discuss the experimental results; in Section VI we have a conclusion and future work.

II. ACADEMIC RESEARCH

Zigbee is new emerging Wireless mesh networking standard which is based on IEEE 802.15.4 has extreme characteristics of low-cost, low-power and short-range wireless communication. By comparing the different wireless technologies shown in the Fig.1, we highlight features of new emerging wireless technology where the low cost allows the technology to be widely deployed in wireless control and monitoring applications, the low power usage allows longer life(multi-year) with smaller batteries, and the mesh

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networking provides high reliability and more extensive range. Thus, ZigBee enables new opportunities for wireless sensors and control networks.

Different Wireless Technologies And Their Comparison

Characteristics	ZigBee (80215.4)	Bluetooth (802.15.1)	Wi-Fi(802.11b)
Battery Life (in days)	100 – 1000+	1 - 7	1 - 5
Nodes per Network	255/65+	7	30
Range of coverage(in Meters)	1 – 75+	1 - 10	1 - 100
Bandwidth (in kbps)	20 - 250	720	11000+
System Resources (KB)	4 - 32	250+	1024+
Key features	Reliable, low power & cost effective	Speed, Flexibility	High speed and High data rates

Fig1. Different Wireless technologies and their comparison

The interest in wireless sensor networks research has been increasing exponentially over the last few years.In this section, we briefly discuss the existing systems. Han *et al* [8] proposed a home energy management system (HEMS) using a ZigBee technology and Infrared remote controls to reduce the standby power. The configured ZigBee network is composed of the home server (central control unit), the ZigBee hub, and the power outlets. The connected device to power outlet with a Zigbee module cuts off the AC power when the energy consumption when it is below the threshold value. Thus the HEMS user interface is used to control/monitor the energy saving system via server. Gaddam *et al* [9] designed a novel home monitoring system which is based on cognitive sensor network and is intended for elder-care application. Depends on the elders movement the cognitive sensor network collect and transmit the information to the central server. In this instead of webcam based, by using selective activity monitoring network, the system can alert the elder persons when they meet the abnormal situations such as excessive usage of power/water usage and also intimate to caretaker by send the SMS (short message service).Gill *et al* [10] proposed ZigBee based home automation system that can control and monitor home appliances. The home gateway provides network interoperability to the zigbee controlled system, a simple and flexible remote access user interface. By this Academic research we can conclude the Objectives and Challenges

A. Easy Deployment and Self Configuration of Wireless Nodes:

Frequently wireless network topologies changes, as nodes are scalable and flexibility in dynamic environment. The presence of human may be restricted or inappropriate in some real time monitoring like disaster sites ,dense forests, nuclear plants etc., So in this type of situation , node failure affects the system throughput with static routing techniques. It is tedious task to set up a network topology and find the system working parameters whenever the sensor node is deployed or removed (due to improper functioning). Thus it should autonomously reconfigure the system, according to dynamic environmental situation.

B. Effective Energy Management:

The network lifetime is the most critical issue because sensors operate using a limited power resource which is greatly influenced by the battery lifetime. An efficient energy management technique is required to sustain the wireless network communication for a long time.

C. Quality of Service (QoS):

There are multiple applications with different requirements in the same WSN. Latency tolerant, prioritize the different applications and effective usage of the bandwidth guarantees a certain level of performance. Low-contention and low-delay communication protocols which ensure contention-less communication makes the system so flexible. So, QoS management is considered as one of the primary requirements in implementation of WSNs.

By considering the design objectives, we have designed and implemented a ZigBee based a Smart Self Adjusting Sensor (SSAS) network by using Dynamic Ad hoc network protocol, where the sensor nodes can adapt dynamically to communicate in a new environmental situations. We used the ZigBee technology (IEEE 802.15.4 standard) which effectively deliver the solutions for a variety of areas including energy management and efficiency, home automation because of its Low-Power and Low-Cost characteristics.

III. SELF ADJUSTING SENSOR ARCHITECTURE

A. Network Deployment

The proposed system uses heterogeneous wireless nodes to form a distributed and control network as shown in the fig 2. In this we are going to see the three different functional nodes. They are coordinator node, monitor node and sensor node. In this network topology, there is only one PAN coordinator which forms this mesh type personal area network. Here the entire communication among the coordinator and the monitor nodes is via Zigbee wireless technology (IEEE 802.15.4).

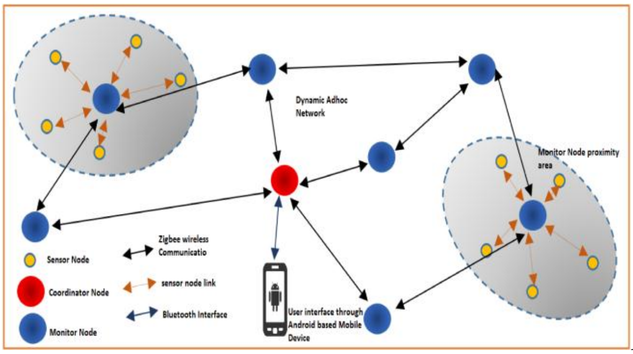


Fig2 . Node Deployment Prototype Overview

1. Coordinator Node :

The Coordinator node plays a major role in the SSAS network. The primary function of the coordinator node is to monitor and control the entire network. In established Personal Area Network (PAN) only one Coordinator node should be present. Thus the coordinator starts a network by new PAN ID (an un allocated PAN ID) and channel for communication through energy scan. Once it starts a PAN, the coordinator can allow monitor nodes to join the network. Performing an energy scan allows the coordinator to have a unique PAN ID and free communication to avoid contention on channels and PAN ID's selected by other PAN network coordinators.

2. Monitor Node :

Monitor nodes are responsible for collecting and analysing the situational information with respect to predefined instructions, and also by providing the required services to actuator circuits with respect to sensor nodes information. The nodes are self manageable and controlled by coordinator node. No monitor node can communicate simultaneously with two or more coordinator nodes.

3. Sensor Node :

The sensor nodes are transducers which provide the environmental changes by converting the sensed information (Analog form) to the electrical pulses (Digital form).

B. Self-Adjusting sensor network

The smartness comes to the system is by combining a new emerging wireless ZigBee technology and a dynamic Adhoc network protocol. Here the nodes are scalable and flexibility in environment. To maintain a stable connectivity and maximizing the network communication throughput through wireless, with effective and reliable delivery is difficult to handle and thus become a real challenge. The main key behind this challenge is the effective routing within the dynamic environment. So, by the dynamic ad-hoc network protocol makes the system more adaptable. The monitor nodes are used to collect and analyze the situational information and able to provide respective services with respect to predefined instructions. However, simply gathering and transmitting the data from all sensor nodes is not suitable for an efficient system, which makes bandwidth wastage. So, the monitor node will sit idle until an event to happen. Then it comes to a active mode to communicate in the network. It has to respond and configure itself by sending the gathered environmental information to destination node.

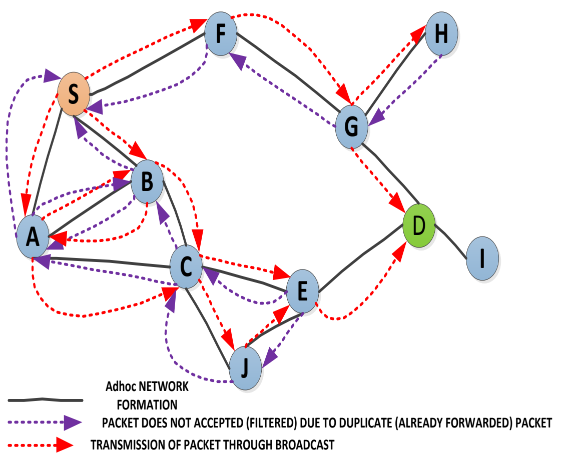


Fig 3. Route Discovery Process To Get Unknown Address

As this is wireless network, frequently changes in the sensor nodes can be observed. So in the ad-hoc network formation, identifying the unknown destination node address is done by broadcasting the control packet (REQ_PACKET). This process is called Route Discovery. It can be observed diagrammatically in fig 3.

The control request packet contains the source network address, the destination network address and a path cost field (a metric for measuring route quality). Every zigbee device has two types of addresses. One is 16 bit network address and other is permanent device 64 bit address. The 16 bit is a network address which is unique and dynamic address assigned when it joins the network where the 64 bit address is given by manufacturer which is unique, static and permanent .Always, a routing is done through a network address (dynamic address) to decrease the latency and in the packet load in the communication network. In the route discovery process the destination 16 bit network address is not known, for first time it will send the static address. The source node will flood the packet through the method broadcasting, in this control packet are broadcasted to its adjacent nodes, those nodes will broad cast to their adjacent nodes, thus this process will continue until it find a destination node.

While responding to the source request, the destination will send the dynamic network address along with the response packet (RSP_PACKET). Thus destination node will respond via shortest route through unicast, depends on path cost field metric. In this the duplicate packets are filtered out. For example, the S node wants to communicate with D node as shown in fig3. So it has to find its destination address by route discovery. The duplicate messages are filtered out when it reach to the broadcasted/source node. Thus a communication link is formed between the S and D for Data transmission.

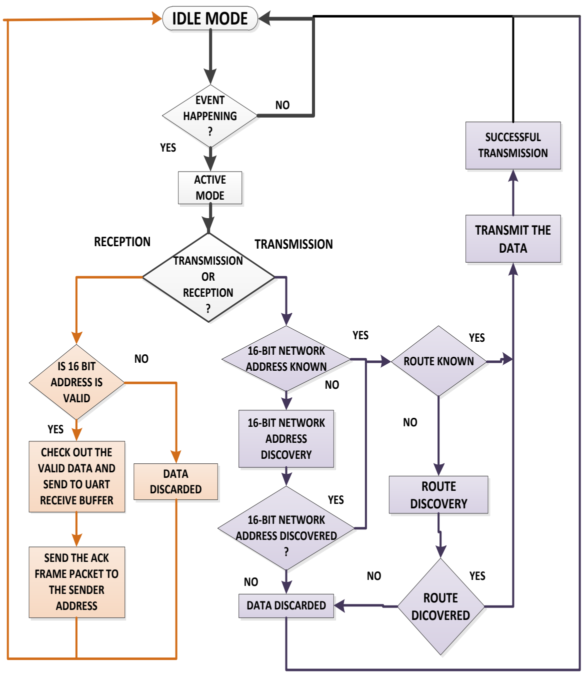
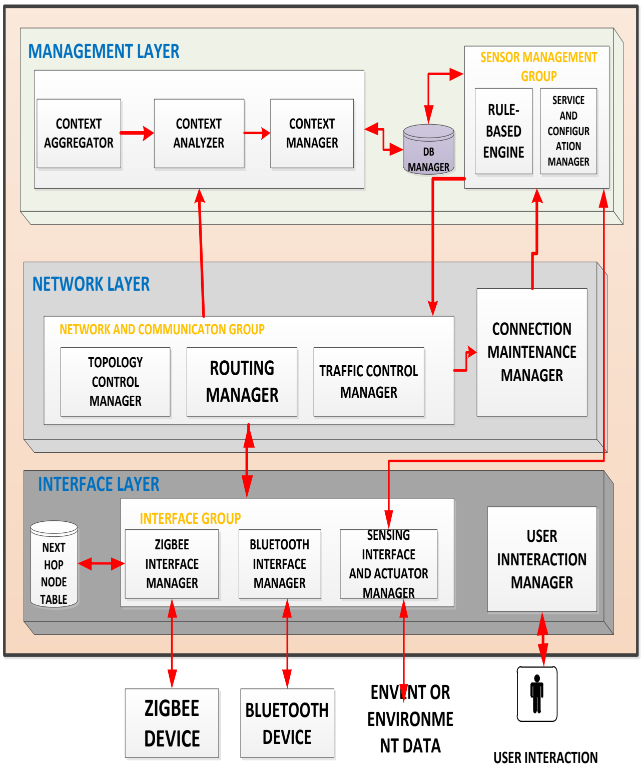


Fig 4. Algorithm For Transmitting / Receiving On Event Happening

The algorithm flow is show in the fig. 4, how the idle monitor node will change to active mode to initiate the



communication when an event has happened, to transmit or receive the data.

Frame format structure of packet which is shown in fig 5 consists of a preamble, pan identifier (address), source identifier, destination identifier, control or data information, End frame delimiter

PREAMBLE	PAN ID	SOURCE ID	DESTINATION ID	CONTROL OR DATA	END FRAME DELIMITER

Fig 5.Frame format of the Data/Control packet

1. Preamble:

   At the beginning of each frame (packet), there will be a start of the header called the Preamble. The Preamble is used to do the following:
   - Inform the receiving station that a new packet is arriving
   - For synchronization purpose

2. Address Field(s):

   Source, Destination and PAN identifier uses network 16 – bit addresses which are used to authenticate themselves in respective PAN network.

3. Control or Data :

   This field is used to indicate the Type of Information that is being sent as Data. The Type of Information can be Control information used when establishing a connection (i.e. handshaking), or it can be Data such as file transfers between two nodes.

4. End Frame Delimiter:

The End Frame Delimiter has a specific bit pattern which is identified as the end of the packet by the destination node.

C. Node Failure With Message Indication

After monitor nodes paired with coordinator node, the coordinator node will assign the 16-bit network address. We are going to activate a timer in each monitor node, where it is going to send the beacon signal frequently to coordinator node. The coordinator is monitoring these beacon signals. Due to failure or out of coverage within the network, the coordinator will observe the updated flag with previous flag status. If those values are matched, it is going to conclude that the node is failure or it may out of network coverage. This node failure is intimated immediately with proper error message to respective user.

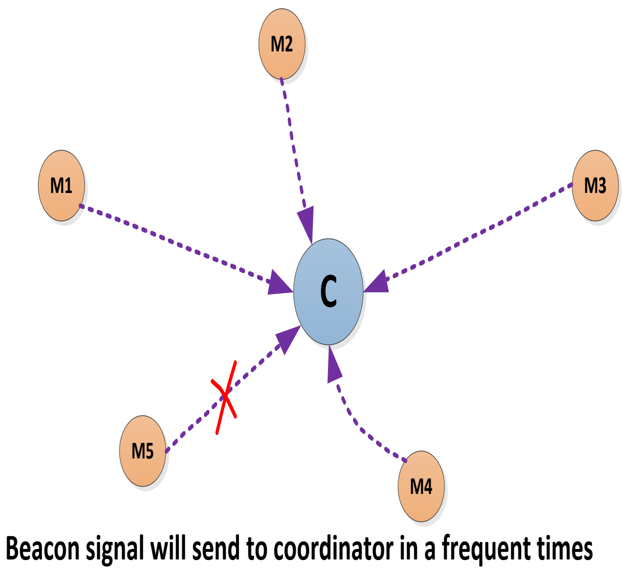


Fig 6. Failure of the Node and it's identification

D. The Layered Architecture Of The System

To provide the modularity and also making it much easier to change the implementation of services, we made the system into the layered architecture.

This layered architecture has been divided into three main layers. They are: Management layer, Network layer and Interface layer.

1. Management layer:

This layer consists of sub layers, a context management group and a sensor management group. **A context management group** is composed of a context aggregator (CAG), a context analyzer (CA), and a context manager (CM). CAG gathers the sensor data and categorizes the situational events. CA assorts the valid meaning events . It sends the meaning event to CM otherwise the data will be discarded. CM then infers and predicts the service required in the given situation. **A sensor management group** is composed of a rule based engine, a service and configuration manager (SCM). This group has a role in sensor management. With the predefined instructions and depends on the events and situations happening through sensing elements, the system send the control signals to reconfigure the system according to environmental changes.

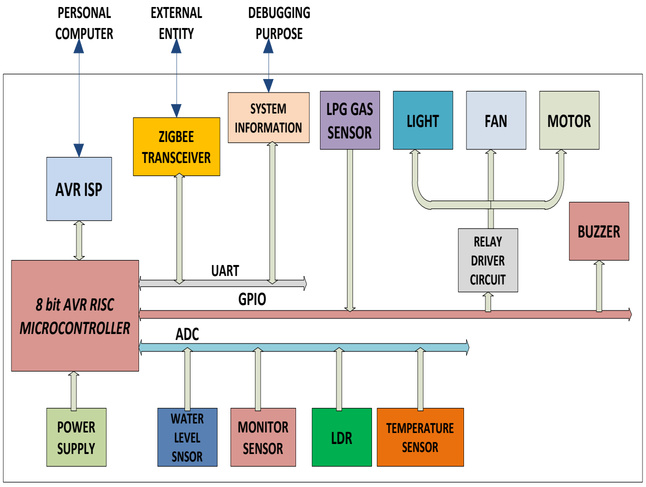


Fig 7. Layered Architecture Of The Proposed System

2. Network Layer:

This layer plays a major role in communication management, routing, topology control, traffic control, etc. **A Networking and communication group** consists of a topology control manager (TCM), a routing manager (TM), and a traffic control manager (TRCM). This group is a core component of network layer; it provides and controls the network and communication services, such as MAC, routing, topology, transmission and synchronization, etc.

3. Interface layer:

This layer provides the interface to interact with the networked devices or Physical Environments. This layer includes an interface group, and a user interaction manager, and a next hop node table. **An interface group** plays a role in providing a point of interaction with external component (networked device or user). This group is composed of a network interface manager (NIM), an Bluetooth interface manager (BIM), and a sensor interface and actuator manager (SIAM). We use IEEE 802.15.4 standard (ZigBee) for communication with other SASs or ZigBee enabled device and use an Bluetooth signal to control by the user. In addition, event and environment data sensed by various sensor modules are gathered through SIAM.

IV. IMPLEMENTATION AND TEST BED

A. Hardware Implementation

For experimental and practical purpose, we implemented the proposed system using two monitor nodes and one coordinator node deployed in the home through some smart home services. Fig 8. shows the block diagram and the prototype. In this system , we present the hardware implementation of the system. SSAS monitor node is based on

1. *Main part:* A 8-bit AVR RISC architecture microcontroller and has an internal flash memory and RAM, which acts as a main part for processing and computations.

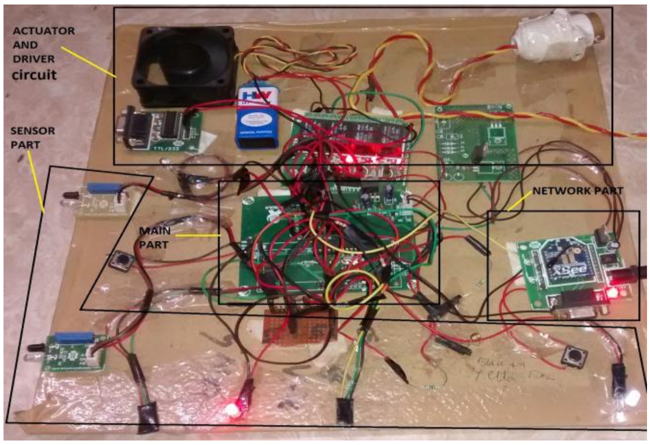


Fig 8. Monitor Node With Prototype And Hardware

2. *Network part:* Zigbee (IEEE 802.15.4 standard) acts as a transceiver/radio to establish a wireless link in a network connection.

3. *Sensor Part:* There are different sensors to sense the environmental changes. All these are connected to ADC port pins because the sensed information is in analog form. The SSAS has various environmental monitoring sensor modules. Different types of sensor modules – temperature, water level sensor, gas sensor, motion detection sensor and Light detecting sensor – are basically installed. So by our system we are going to monitor the status and routing of the information dynamically through adhoc manner irrespective of the topology. In the case of more complex services, other sensor modules can be installed through a user connector.

4. *Actuator and Driver part:* These parts are the appliances which are controlled and maintained to save the power consumption. Driver circuits drives the components according to microcontroller instructions.

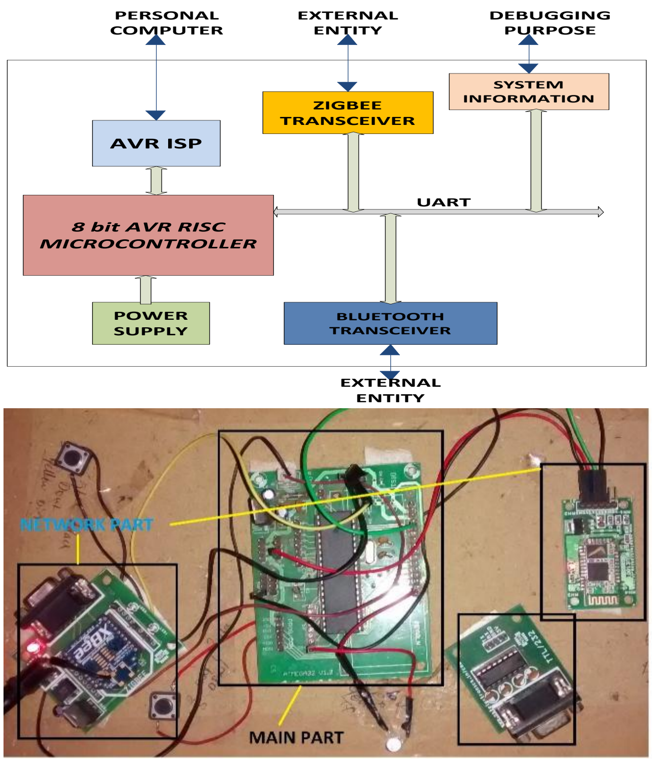


Fig 9. Coordinatior Node With Prototype And Hardware

SSAS coordinator node is bit different. It is mainly controls and act as a medium between user and the network. For this we are choosing a Dual-UART 8-bit AVR RISC architecture microcontroller and has an internal flash memory and RAM to simultaneously communicate. Zigbee is mainly intended to communicate within the PAN network whereas the Bluetooth transceiver establishes a communication channel between the user and the controller.

B. Software Tools

1. *Code Vision AVR*:

Code Vision AVR is a C cross compiler, Integrated Develop Environment designed for Atmel AVR family microcontrollers. The entire code is written in the embedded-c which is compiled by code vision and dumped in to the microcontroller through AVR ISP (AVR In-System Programming)

2. *Real Term*:

Real term is a terminal program with extensive features which is specially designed for capturing, controlling and debugging binary and other difficult data streams.

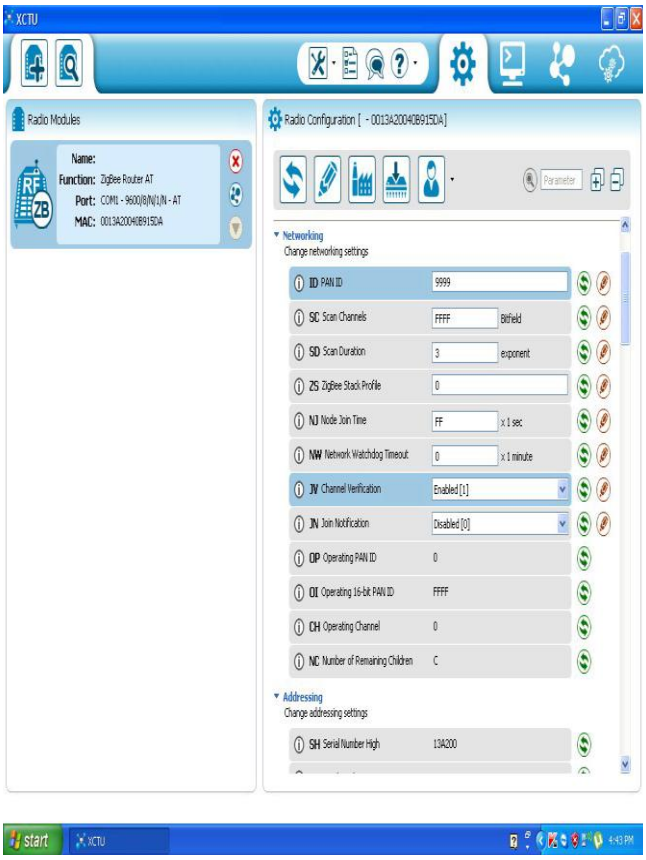


Fig 10. A Snapshot Of the X-CTU Tool

3. *X-CTU:*

We configured the zigbee modules by using **X-CTU (Xbee Configuration & Test Utility Software).** With AT commands we configure like modes, baud rates, maximum hops, power level modes etc., We can update the firmware to the zigbee modules. The snapshot of the tool is shown in the fig. 10

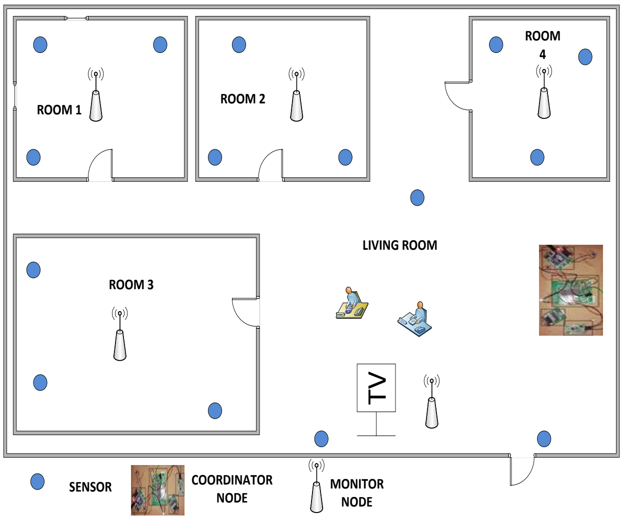


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Fig 11. Floor Plan Of The Test Bed

Fig 11, illustrates the floor plan of the test bed . We deployed the SSAS in the different rooms. The coordinator node is responsibility for controlling the monitor nodes. Each monitor node is responsible for gathering information from the sensor nodes. We have flexiblility of changing the SSAS monitor node places without loss of information due to dynamic routing protocol. Android based mobile through Bluetooth user interface is used to control and get notifications from the sensor network through the coordinator node. A snapshot of the smart self adjusting interface is used to control and monitor.

The snapshot shown in the fig 12, is a graph of temperature versus time . In this application we have two

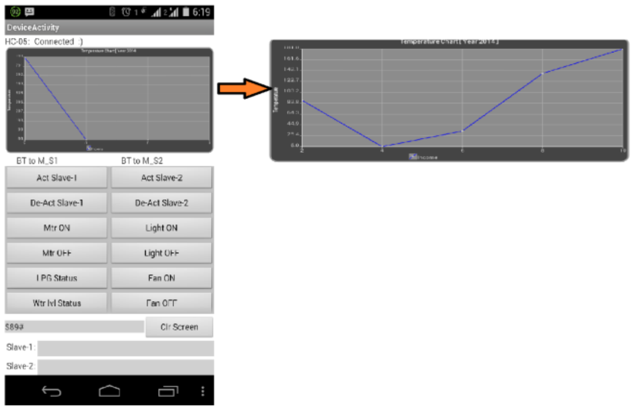

Fig 12. A Snapshot Of The A User Interface Andriod Application

working modes, they are Auto and Manual. In Auto mode the monitoring of the information is autonomously configured to predefined instructions. Through manual mode the users can control themselves. This application can be easily shared among multiple users. Thus these users can simultaneously monitor their appliances through android based mobile device.

V. Experimental Results

In the experiment, we have reduced the consumption of the battery energy through some smart network and a flexible way of deploying the sensor nodes to monitor with dynamic adhoc network protocol. We maintain a stable connectivity in sparsely deployed network which tends to ensure a correct packet delivery. Due to the cooperation of the devices with this protocol in dynamic network infrastructure, we can decrease the total battery consumption and without loss of information and connectivity. This shows, safety and energy efficiency can be achieved.

VI. CONCLUSION AND FUTURE WORK

We studied the challenges and constraints for both densely deployed and scatter wireless sensor network. However, due to the fixed architecture, existing conventional routing schemes are not well suited for dynamic environments. We then introduced the emerging wireless communication technology, namely ZigBee, which supports low-power, low-cost, short-range communication. To address these constraints we have proposed a smart self-adjusting sensor(SSAS) network based on zigbee through dynamic adhoc network protocol. By this protocol we are going to maintain a stable connectivity in sparsely deployed network. For experimental purpose, we designed and implemented the system through the smart home services in a real test bed. The proposed system shows an efficient delivery of the packets with effective routing and new emerging Zigbee technology. This shows, safety and energy efficiency can be achieved.

As a part of our future works, we are doing more research to develop a highly efficient routing protocol which provides high quality of service and high sensing capability in dynamic adverse environmental conditions.

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