

A Remote Triggered Wireless Sensor Network Testbed

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Abstract—This paper presents a remote triggered wireless sensor network (WSN) testbed used to facilitate multi-user remote access to the WSN experiments for virtual learning of wireless sensor network concepts. This testbed provides multi-set, multi-group of WSN experimental setup that is capable to provide opportunity to perform remote code editing using over the air programming mechanism. This testbed also provides an intuitive web-based interface to the registered users for running the experiments, accessing and editing the source code of the experiment from anywhere in the world by means of internet. This remote triggering mechanism offers the user a flexible environment for the experimentation. An experimentation setup of 150 wireless sensor nodes are developed to suit the design of both indoor and outdoor experiments. The outdoor lab setup allows the users to learn the wireless propagational effects in the real environment. The WSN indoor lab setup comprises of nine sensor network experiments which allows the users to learn the WSN concepts such as configuring a WSN, clustering mechanisms, time synchronization mechanisms and experience the practical implementation in real time. This test bed offers the researchers and students an opportunity to trigger their inquisitiveness by providing the access to remote equipments and materials needed for the experimentation, shared via virtual manner wherein the experiment conduction and output observation can be performed online through an effective visualization tool.

Keywords—WSN testbed, E-learning, Remote triggered lab; Remote code editing; Remote panel

I. INTRODUCTION

Wireless sensor network (WSN) is one of the tremendous technologies which use sensors for tracking, locating and monitoring various environmental as well as health parameters. In many universities, there is a lack of e-learning facilities which degrades the availability and usage of WSN applications. Most of the universities are not afford to procure the WSN equipments because of its high cost. The concept of virtual laboratories integrated with enhanced computer simulation, animation etc., are used to enhance the learning capability of the students and to improve the learning facilities in the remote areas. However hands on experiments will provide better learning capability. Hence a virtual laboratory integrated with real-time experimentation is necessary to enhance the learning capability [8].

Our main aim is to enhance the learning capability by providing equipments and materials to researchers and students which helps them to do real time hands on experiments remotely. Our testbed allows the users to access the remote

equipments and perform real-time experimentation by means of the intuitive web-based interface.

The paper is organized as follows: Section II discusses about the related work done in the field of WSN testbeds. Section III describes the remote triggered lab framework. Section IV explains the remote experiments provided by this laboratory. Section V explains the WSN outdoor RT lab, Section VI explains the WSN indoor RT lab, Section VII deals with RT scheduling algorithm, Section VIII shows the implementation details and results of the system and Section IX concludes the paper.

II. RELATED WORK

The research work [1] presents a survey of a set of performance evaluation tools for WSNs which will aid the researchers or tool developers to select an appropriate tool for their implementation. The results obtained from emulators are more accurate than simulators and the only drawback is it can simulate code for specific platforms and the Physical test beds are developed in a controlled, real-like environment so that the results obtained are more accurate than software based tools. The inaccuracy of simulators and the significance of testbeds in WSN networks are highlighted in [2, 3, 4, 5]. In the case of large WSN networks, the testbed development is an important factor. The basic requirements of the users and operators perspective such as transparent access, heterogeneity, reproducibility, user interaction, mobility, robustness etc are considered in the research work [3] to develop a testbed based on WISEBED technology. The architecture designed in this work allows the operators of WSN testbeds to offer the access to the testbeds for numerous users even with heterogeneous sensor node hardware. Similarly a scalable and flexible WSN testbed called TWIST, mainly for the indoor deployment purpose are discussed in [4]. The experiments are performed on a three floor office building by using more than one hundred sensors and the experiments with heterogeneous node platforms, the active power supply control of the nodes and the creation of both flat and hierarchical networks described in this work. The basic services such as node configuration, network-wide programming, out-of-band extraction of debug data and gathering of application etc., are the unique features of this testbed. A 3D Wireless sensor network testbed called Indriya [5], mainly designed to reduce the cost of both deployment and maintenance of a large- scale testbed. The different types of sensor boards equipped in it and the 3D wireless connectivity among nodes on the different floors made Indriya different from other testbeds. Also an extensive study of all 16 channels of IEEE 802.15.4 are included in this paper to understand the

performance difference and correlations exists among different channels which will helps in the selection of an appropriate channel when there is a need. The development of an energy efficient WSN by incorporating the power management techniques are discussed in [6,7]. Two Transmission Power Control techniques has been discussed in the research work [6]. The system is capable of conducting experiments in both indoor and outdoor scenarios by varying parameters such as the environmental type, the distance among the nodes, multi-hop transmissions and mobility. The results show that, the energy consumption decreased up to 57% and the throughput increased under low mobility scenario over B-MAC protocol. The research work [7] mainly deals with the design and implementation of RPM algorithm for radio power management in the existing WSN networks and the energy consumption model. The RPM algorithm optimizes the sleep transitions decisions based upon the power and response characteristics of the sensor platform's transceiver and the energy consumption model provides increased simulation accuracy by incorporating the average radio energy consumption costs and transition times.

III. AMRITA REMOTE TRIGGERED WIRELESS LABORATORY SETUP

A remote triggered Wireless Sensor Network testbed [9] consists of more than 150 sensor nodes, on-board sensors, data acquisition boards; digital multimeters etc., has been developed. This framework allows remote users to configure the nodes and study various WSN concepts in both indoor and outdoor scenarios. Fig1 shows the architecture of the framework.

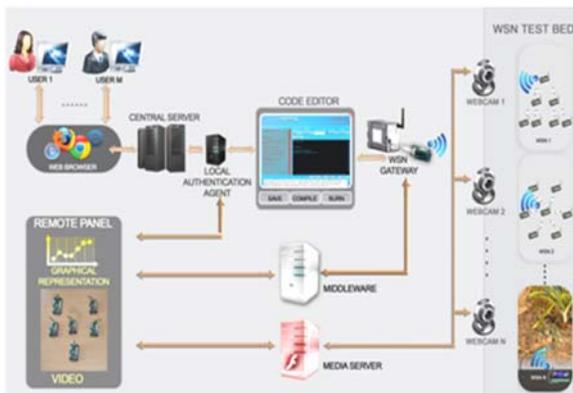


Figure 1: RT Lab Architecture with code editing [9]

A. RTLab Web Layer

The RT lab web layer provides the opportunity of real-time access by remote users. The Web layer in the Remote Backend Server provides all the needed data and visualization of data to the user through real-time communication with the Middleware and WSN Gateway. The Web layer of our RT Lab includes the following tabs:

Theory: The theory incorporates the study materials for each experiment

Procedure: This explains the procedure to be followed for performing the experimentation

Self-Evaluation: After learning the concepts, the user can use Self-Evaluation method to evaluate their depth of learning

Animation: Animation is the imitation of the real world WSN experiment

Simulation: Simulation is the imitation of the real world WSN experiment with the capability of varying parameters for better understanding of the concept

Remote Panel: The remote panel includes the following components

- **User Input:** This user interface allows the user to input different parameters for each experiment.
- **Physical Representation:** It demonstrates the graphical representation or the topology of motes deployed in the WSN Testbed.
- **Chart:** It shows the real time data plotting for each experiment.
- **Video:** For each experiment, there should be a live streaming video which shows the deployed sensor nodes in real time.
- **Code editing:** A platform that allows users to edit the programming codes of each experiment.

Assignment: After doing complete experimentation, the user can use assignment section to evaluate their knowledge.

Feedback: This is used for collecting the feedback from each user

B. Remote Code Editing

Our system offers a remote code editing mechanism, for registered users, which allows them to have hands on experience with programming the sensor nodes. The central aim is to provide an efficient and effective high level interaction between users and wireless sensor nodes with the help of a code editing panel which includes options for editing, saving, compilation and burning of the source code. After finishing the code editing, the user can burn the new binary file in to the sensor nodes using our provided reprogramming facility. The user can experience the rebooting of the motes by watching the real time video of the setup which is streamed using Media Server and also verify the result from the chart which shows the plotted data from the sensor node.

Our system offers three ways of code editing mechanisms.

- **Parameter Configuration:** In this method, the user is permitted to change the parameters of an already existing wireless sensor network program. Here, the user is not allowed to upload a new program code or modify an existing program code. However the user will be able to vary the parameter that will provide the opportunity to learn about different configurations and its impact on the wireless sensor network.
- **Restricted Code Editing:** The code editor window controls the code editing from user by restricting the modification

of an already existing program. Here the user can act according to the instruction provided by the system.

- Full Code Editing: The code editor window permits the user to add or modify the sensor network program code. Here a user can rewrite the program code of an experiment without any restrictions.

The system uses over-the-air programming mechanism, to manage the large WSN. However this remote code editing setup allows the users to experience all the changes happened to WSN in real time.

IV. REMOTE EXPERIMENTS

The remote triggered wireless sensor network testbed provides 11 wireless sensor networks, of which 9 indoor sensor networks with more than 100 sensor nodes and 2 outdoor sensor networks with more than 15 nodes. This testbed used Memsic micaz nodes, implemented several experiments that can be remotely triggered using the wireless sensor nodes and the relevant equipments available in our laboratory. The main experiments implemented are described below:

- nesC Programming: Basic experiment for learning the nesC programming through “Blink” program.
- Send and Receive: An experiment for learning how to transmit a packet and receive it wirelessly.
- Range & Connectivity vs. Antenna Power: This experiment shows how we can select different transmission ranges with respect to the available RF power levels. To configure a wireless sensor node in a particular RF power level, have the transmission and analyze signal strength by different nodes at different physical locations.
- Duty Cycle vs. Power Consumption: An experiment to show the implementation of duty cycle in wireless sensor networks and the analysis of power consumption in different states viz. sleep, sensing, transmission and processing.
- Sensor Data Acquisition: Helps the user to learn how to interface external sensors such as dielectric moisture sensor, rain gauge, temperature sensor, humidity sensor etc using data acquisition board. Allows the user to configure various analog and digital channels in the DAQ board to collect the sensor readings.
- Data Collection Frequency and Transmission vs. Power Consumption: The experiment is used to analyze the power consumption of wireless sensor node under different sampling intervals of sensing and different transmission rates. It helps the user to understand how the variation in sensing rate and transmission rate of the sensed data affects the power consumption of a node.
- Wireless Propagation: To provide an overview of real time exposure on the wireless propagation effects. This experiment is used to implement wireless sensor network at different environmental, terrain, and vegetation conditions.
- Wireless Sensor Network: The experiment allows the user to remotely design wireless sensor network and

experiment data transmission and reception at various power levels and it will also calculate the life time of the network for given scenarios. This helps the user to understand the design of different wireless sensor network topologies, the data communication at various power levels in the different WSN topologies and the network lifetime variation in different topologies.

- Wireless Sensor Network Data Acquisition, Transmission, and Aggregation: This experiment is used to implement wireless sensor network (WSN) to acquire sensor data from on-board sensors, transmit it to the destination node and aggregate the data at the intermediate nodes. This helps the user to understand the effect of data acquisition, transmission and aggregation duration in the energy consumption of wireless sensor nodes in the network.
- Clustering Algorithms: Design, develop and implement different wireless sensor network algorithms for grouping the sensor nodes.
- Time Synchronization: The experiment is used to design, develop and implement different time synchronization algorithms for wireless sensor networks and study its real world characteristics. This helps the user to understand the importance of time synchronization in wireless sensor networks, different time synchronization algorithms for wireless sensor networks and the real world characteristics of the time synchronization algorithms for wireless sensor networks.

A student/researcher/faculty that completes this experimentation will be able to develop and implement a wireless sensor network for real-time continuous monitoring for different applications.

V. WSN OUTDOOR RT LAB

Wireless propagation effect is the sum total of impairments that happens to an EM wave when it propagate from one point to another through different mediums. The transmission path between the sender node and the receiver node could be of either Line-Of-sight (LOS) or obstructed by buildings, mountains and foliage. Attenuation, Free Space loss, Noise, Atmospheric absorption, Multi path, Reflection, Refraction, Scattering etc., are the different types of transmission impairments that can happen to a propagating signals. There are various indoor and outdoor path loss models available that allow us to analyze the loss affected to the received signals at these different mediums. Wireless Sensor Networks Labs are mainly intended to study all the transmission impairments and the Path loss models to effectively deploy the sensor nodes as well as to choose Path loss models according to the different applications. This lab enables the user to learn how link quality and received signal strength varies due to the dynamic propagational effects.

In this lab, the Outdoor wireless propagation experiments are performed at 2.4 GHz using MicaZ Nodes. The Coconut tree in front of the Amrita WNA building was one of the test fields selected to determine the effect of foliage in wireless propagation. In this experiment, the sender and receiver node was at Line-Of-Sight communication (LOS) and the Receiver

mote was kept at a fixed distance of 1m from the sender node. Even though the communication used here is LOS, the propagating signals are affected by the obstruction presented in between the Sender and the Receiver node. Here the experiment was generally conducted to calculate the Received Signal Strength Interference(RSSI) value and the Link Quality (LQ) of the input message to study the effect of foliage in the signal. The Sender node kept at the test field is triggered by the Sink node placed at the Remote triggering Lab through the relay nodes placed in between. The input message from the Sink node is carried to the Sender node through the Relay nodes and it then transmitted to the Receiver node. The Receiver node calculates the RSSI and LQ of the input message and sends back to the Sink node kept at the RT Lab along with the timestamp via Relay nodes. That is, the Sink will receive a string in the format of {Node ID, RSSI, LQ, Time}. The corresponding graphs such as RSSI Vs Time and LQ Vs Time can be viewed from the Web layer. Thus the effect of foliage can be analyzed by comparing the results obtained with the results of the experiment conducted in the Free Space where there was no obstructions in between the communicating nodes.

VI. WSN INDOOR RT LAB

The remote triggered indoor setup consists of 9 sensor networks that mainly allow learning concepts such as configuring a WSN, clustering mechanisms, time synchronization mechanisms etc. This section will give the detailed architecture set up for the experiment to configure a wireless sensor network, collecting data at different intervals and transmit to the sink node. This set up also gives the details of the power consumption by sensor nodes. This set up can be configured either as a centralized network or a 3-level hierarchical network. In the centralized network, all sensor nodes are able to communicate with sink node through single hop communication. But in hierarchical network, multihop communication is required to access the sink node. In this case, the sensor nodes communicate with the sink node through an intermediate node known as cluster head. Fig.2 shows the network topology of both these models.

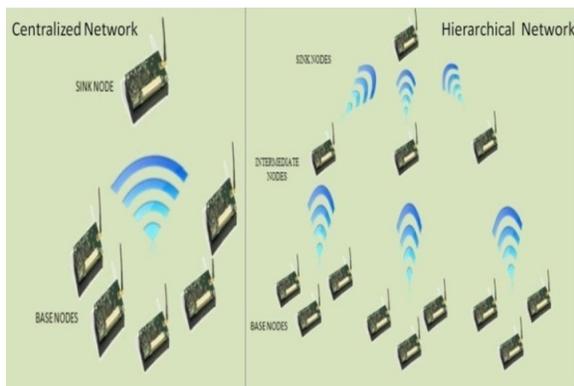


Figure 2: Network topology

In hierarchical topology, the cluster head receives the data from sensor nodes, aggregate it and sent to the sink node. This aggregation allows reducing redundant information in the

network and also reducing the network traffic. This experiment setup allows the user to remotely configure the network topology, sampling interval, aggregation mechanisms etc. The experiment set up consists of lower level nodes that are attached to on-board sensors. These nodes read the current temperature and broadcasts. In hierarchical network, these readings are being aggregated at the cluster head and are being broadcasted to the sink. Each of these nodes is interfaced with a digital multimeter to analyze the power consumption by the nodes. Fig. 3 shows the experimental set up for this sensor network. The various input and output parameters of this experiment are given below.



Figure 3: Experimental Setup

- Input Parameters
 - Network type: This allows the user to configure the network topology i.e centralized or hierarchical
 - Sampling rate: The rate at which the lower level nodes perform data acquisition
 - Transmission rate: The rate at which the cluster head performs data aggregation and broadcast to the sink node
 - Aggregation type: The aggregation operation to be performed on the sensor readings
- Output Parameters
 - Physical representation: The physical layout of the real experimental set up will be displayed on the webpage. The real-time data transfer among nodes will be highlighted by circles of different colours. This will give the remote user a real time experience of the WSN setup and will understand the data transfer among sensor nodes.
 - Charts shows power consumption: Three charts to display the power consumption by the different type of nodes such as lower level node, cluster head and sink node.

VII. RT SCHEDULING ALGORITHM

This algorithm is used to schedule the multiset experiments available in the lab among simultaneous users who tries to access the experiments. If there are multiple users waiting in a queue to access the service, the users can either manually

schedule a slot to access the experiment or they can just avail a future slot that is determined by the scheduling algorithm. If there are multiple users waiting to access the experiment and the current user exits the experiment, the algorithm chooses the next user based on the arrival time and request time of each user. Here, arrival time is the time at which a user tries to access a WSN experiment and request time is the time which the user manually sets for scheduling the experiment. The RT log produced by the scheduling algorithm has been shown in Fig 4.



Figure 4: RT Log[9]

VIII. IMPLEMENTATION AND RESULTS

This section deals with the results from the major WSN experiments implemented in RT Lab.

A. Sensor Data Acquisition

In this experiment, the simulation allows the user to practice the connection of external sensors to the WSN node using an acquisition board. This is an interactive section, and if the user make mistake the system will display error messages as pop up. The sensor readings are displayed in the chart. Fig 5 shows the output screen of this experiment.

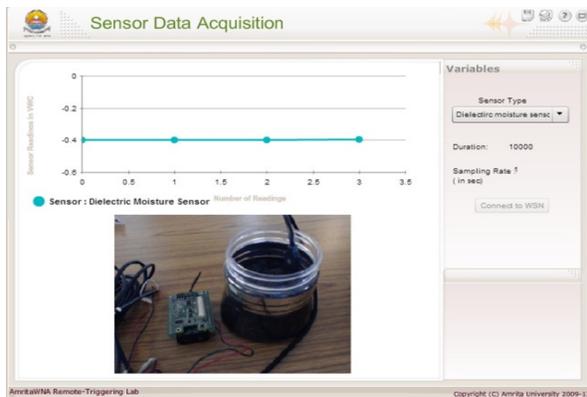


Figure 5: Sensor Data Acquisition

B. Wireless Sensor Network Data Collection, Aggregation and Data Transmission

Section VI gives the detailed architecture of this experiment. In this experiment, the physical representation of the experimental set up, charts displaying the power consumption by different sensor nodes are given as the output to the remote user. Fig 6 shows the remote panel tab of the experiment.

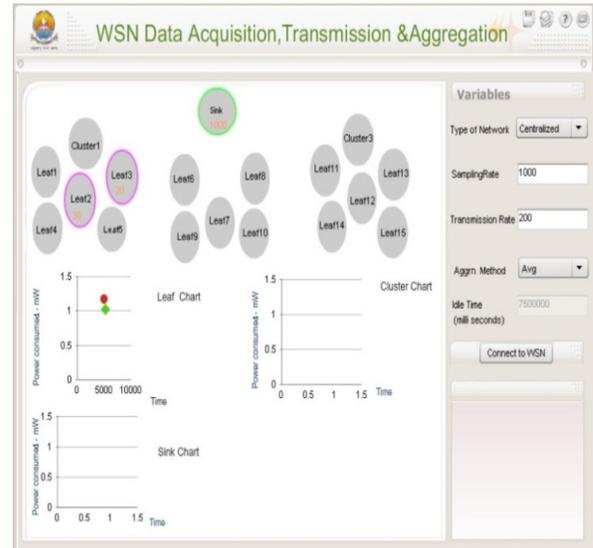


Figure 6: WSN Data Acquisition

C. Wireless Propagation

Section V gives the detailed architecture of this experiment. In this experiment, the link quality and received signal strength of the nodes at different environmental scenarios have been plotted as output. Fig7 shows the Remote panel tab of the experiment.

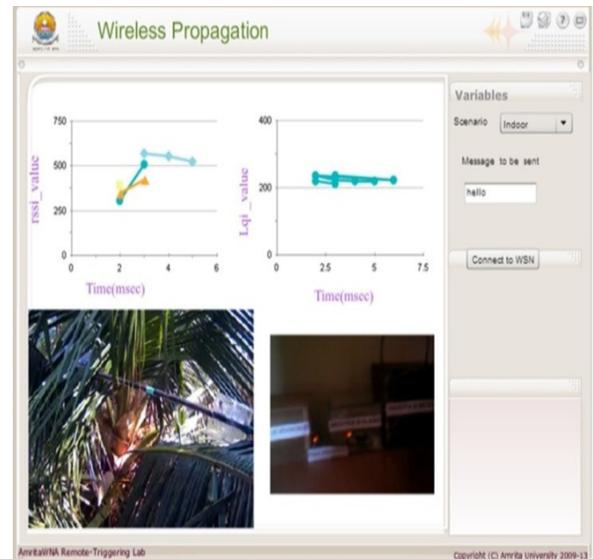


Figure7: Outdoor Lab



Figure 8: RT Simulation

The simulation and output screen of another experimental setup has been depicted in Fig 8 and Fig 9.

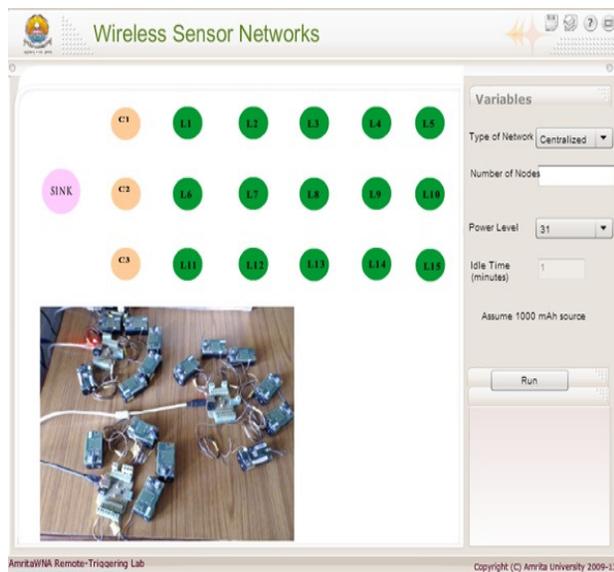


Figure 9: RT Output Panel

IX. CONCLUSIONS

In this paper we describe the design and implementation of an energy efficient remote triggered wireless sensor network laboratory. This testbed consists of 150 wireless sensor nodes, arranged as 11 wireless sensor networks. The testbed provides the opportunity for dynamic scheduling, indoor and outdoor experimentation facility etc. Throughout the research work, we faced operational, managerial, and technical challenges. The main challenge for the implementation of remote triggered laboratory is development and implementation of remote editing, and reprogramming for single and multiple setups of wireless sensor nodes. Configuring an outdoor set up also paused many operational and security challenges. The current

set up provides the opportunity to remote users to study WSN concepts and perform options like parameter configuration, restricted code editing and full code editing, which offers a better learning experience. Another major challenge was interfacing digital multimeters and invoking different output URLs for the same experiment at different instances of time. In general, our complete system incorporates the concepts of virtual laboratory and remote triggered laboratory, thus providing an effective and efficient learning experience to remote users.

As future work we will focus on enhancing this test bed by adding more experiments, optimizing the network based on bandwidth utilization, and developing better medium access protocol to enhance the scalability of the complete system.

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