An Energy Aware Schedule Based Remote Triggered Wireless Sensor Network Laboratory

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Abstract—**Over the past decade, experimentation for wireless sensor network (WSN) has been widely used to enrich the learning experience of educators and learners. Our remote triggered WSN laboratory is a multi-set, multi-group, WSN experimental setup that provides an intuitive web-based interface to carry out remote experimentation as well as code editing by registered users. This paper presents a multi–level time based scheduling algorithm for our lab which provides optimum utilization, performance and service. Our WSN testbed consists of more than 150 sensor nodes deployed in indoor and outdoor environment. Energy efficiency and delay optimization of WSN testbed are ensured in the design which employs TDMA and state transition schemes. We have implemented and tested two approaches for energy efficiency namely an on demand scheduling and a TDMA based approach which incorporates state transition and CDMA. The performance evaluation result shows that 78% power consumption has been reduced in second approach compared to first. The paper details the implementation of energy efficiency with dynamic scheduling for our real-time remote triggered WSN.**

Keywords— remote triggered lab; energy consumption; scheduling; remote reconfiguration; wireless sensor network

I. Introduction

The Wireless Sensor Network Remote Triggered Laboratory (RT Lab) [1] is an initiative undertaken to support students, faculties and researchers by providing an e-learning web-based platform for learning WSN concepts, sensor node programming etc. by means of eleven implemented remote experiments. This lab provides the provision for users to access the equipments and hardwares remotely. The system offers a code editing platform for the registered users to practice and understand the sensor node programming using nesC in TinyOS. The deployed WSN is managed and maintained by using reconfiguration mechanism.

A sensor node plays a vital role in the WSN testbed. For performing the programming tasks, it uses a power source that supplies the needed power. Generally, each node in the WSN is equipped with a battery which becomes difficult to manage in case of large WSN testbed. As energy is a scarce resource for WSN, the energy consumption of sensor nodes has to manage wisely. Our main challenge is to minimize the energy consumption of sensor nodes in our WSN testbed. Duty cycling approach and energy efficient MAC protocols in WSN helps in achieving the minimization of energy consumption. We proposed a TDMA based algorithm for ensuring the energy efficiency in our system.

The paper is organized as follows: Section II discussed about the related work done in the field of energy efficiency in WSN. Section III describes the scheduling algorithm and Section IV explains the energy efficiency of our system. Section V details the performance evaluation of the system. Section VI describes the conclusion and the future work.

II. Related Work

The literature review on various WSN testbeds has been carried out and found that one of the widely deployed testbed like MoteLab [2], which is capable to access a set of permanently deployed sensor network doesn't consider the energy efficiency and delay optimization. In WSN, to minimize the energy consumption, duty cycling and various MAC protocols can be used. In [3], the authors described various TDMA protocols and duty cycling protocols where major issue with the duty cycling protocols is that the sleep schedules of nodes has to be frequently synchronized, which leads to energy wastage and additional communication delays. The scheduling based TDMA technique offers an inherent collision-free scheme by assigning unique time slot for every node to send or receive data. From the performance evaluation of the centralized and distributed algorithms proposed by Junchao et al. [4], a better energy efficiency can be achieved by reducing the number of state transitions and can reduce the network delay using their distributed scheduling. The authors in [5] discussed about the energy management in battery where the analytical results of their stochastic battery model indicates that there is a significant increase in the performance without introducing any delay in the discharge demand supply. In [6], the experimental results of S-MAC algorithm show that on a source node an 802.11-like MAC consumes 2 to 6 times more energy than S-MAC for traffic load with messages sent every 1 to 10s. In [7], the simulation results show that the proposed TDMA model has the shortest power consumption for a given end-to-end delay followed by adaptive listening, and the S-MAC. Also, as the traffic increases, the power consumption of TDMA scheme increases faster than that of the other two schemes, and eventually surpasses them. In [8], Kulkarni, and Wang explained a multihop network reprogramming approach, which provides a TDMA based sleep-wake

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mechanism which makes it energy efficient and address the hidden terminal problem and reduces message collision in a sensor network.

III. SCHEDULING ALGORITHM OF REMOTE TRIGGERED LAB

Our proposed scheduling algorithm provides optimization of the service availability of remote experiments for the users. The RT scheduling algorithm [9] serves the users with the experiments in an opportunistic manner where the scheduling of users is done automatically. If there are users who are in a waiting queue to access the service, we are providing them a facility to manually schedule an experiment as per their convenience; otherwise a future slot will be automatically assigned by our algorithm.

The two main functionalities in our RT Lab are

- RT Log: This data logger provides all the information regarding the RT experimentation includes the details of the users using the RT experiments, scheduled experiment details, and details of the slots. The details of the user consist of the currently working experiment, and starting time of the experiment. The manual scheduling of the experiment is done using RT experiment scheduler.
- RT Experiment Scheduler: This will provide a future slot to the user according to the experiment. Using this functionality, the user can schedule an experiment as per their choice.

Suppose there are N experiments and n_i number of setups for each experiment i, where i is a positive integer value. For each experiment, the maximum time allocated for a user is 't_i'. Consider UW_{ki} is the users waiting to access the i^{th} experiment where 'k' is the number of users waiting for accessing the experiment.

In the case of users waiting for access, once a current user exits the experiment, the decision on who among the UW_{ki} users is going to get the next time slot will depend on the arrival time (t_{ak}) and request time (t_{rk}) of each user. Arrival time is the time at which a user tries to access a WSN experiment and request time is the time at which the user manually sets for scheduling the experiment. Future time slot is assigned for each of the UW_{ki} based on t_{ak} and t_{rk}. So the next time slot will assigned based on the following two cases.

A. Scheduling based on First Come First Serve

In this case, none of the user uses the manual scheduling facility. i.e. When $t_{rk} = 0$ for all UW_{ki} users. Here the chance will be given based on First Come First Serve basis where the schedule value set will be (t_{ak}, 0) for all the UW_{ki} users. The user having the minimal arrival time will be given the first chance.

There is a maximum duration, t_i minutes, for a user to go through a scheduled experiment. If the current user exits the experiment before t_i, then the next eligible user will be notified on the availability of this experiment. The RT scheduling algorithm checks the RT Log [1] to find whether the user is currently working on any other WSN experiment so that the chance will be given to the next eligible user. Otherwise, if the user is online and not working on any other experiment, then the user will be notified. If the notified user doesn't try to access the experiment within a fixed time, f_t, then the chance will go to the next eligible user in the queue and the process will repeat.

B. Scheduling using RT experiment scheduler

In this case, one or more users schedule an experiment using RT experiment scheduler. i.e. When t_{rk} != 0, one or more user manually select the time slot. Here the scheduling is performed based on a priority scheme developed by considering the manual priority and the priority set by the algorithm. Priority queue provides the list of eligible users based on the arrival time and request time. This process has two phases viz priority queue formation and dynamic scheduling.

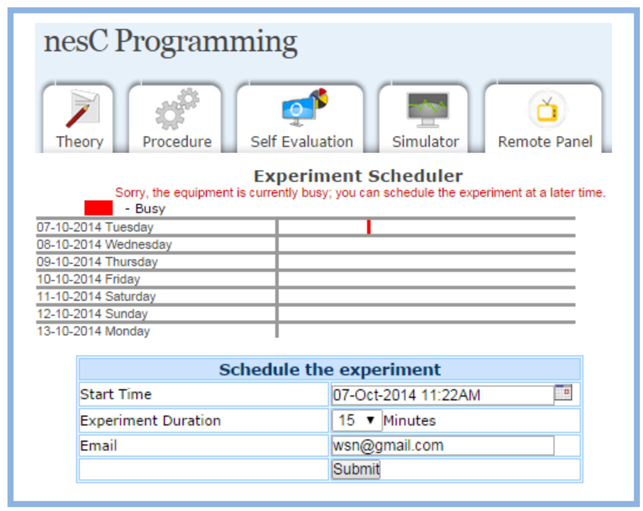

Fig.1. RT Lab experiment scheduler [9]

1) Priority queue formation

Consider UW_{ki} users waiting to access i^{th} experiment and some of the users have scheduled the experiment for a later time slot. For efficient dynamic scheduling of the experiment for these waiting users, we are initially allocating them in to a queue based on their manual priority. The first user to go in to the queue will be the one who having t_{rk}!= 0 and minimal arrival time among UW_{ki}. Thus all the users with t_{rk}!= 0 will occupy its selected slot in the queue. Then the users with t_{rk} = 0, will be arranged in the increasing order of their arrival times and inserted into the free slots of the priority queue in the increasing order of access time.

2) Dynamic Scheduling

When the currently accessing user exits the experiment, the first user in the priority queue will get the first access to the experimental set up after checking the RT experiment scheduler, shown in Fig.1. The algorithm checks the RT Log to find whether this user is currently working on any other WSN experiment. If so, then this chance will be given to the next eligible user in the priority queue after checking the RT scheduler. Otherwise, the algorithm checks the availability of the user and if finds online and not working on any other experiment then notifies the user.

Let T_k be the time at which the current user started using the experiment. Then the experiment can become free in either of the two cases mentioned below:

- If the current user takes the maximum time duration (t_i) set by us to finish the experiment, then the experiment becomes free at a time $T_k + t_i$ minutes.
- If the current user uses the experiment for a duration of '*h*' minutes, where $h < t_i$, then the experiment becomes free at a time $T_k + (t_i - h)$ minutes

In both the cases, once the current user exits the experiment, the chance goes to the first user in the priority queue and he/she gets the access to the next time slot. If the previous user exited before the allotted time for experiment, either we can initiate a reallocation of the time slots or the next user can wait till the next slot begins. Since the first case will consume a lot of energy for reallocation of slots, we use the latter approach.

IV. Energy Efficiency Of Remote Triggered Lab

One of the major challenges to solve for the implementation of RT Lab is optimising the energy consumption, delay, and lifetime of the network. Optimization of energy consumption is achieved by implementing dynamic scheduling, state transitions, low duty cycle protocols and wake up concepts. We are considering an experiment setup of *N* number of experiments, and n_i, number of WSN setups for each of the experiment *i*.

A. Phase 1: On demand scheduling approach

We have used on demand scheduling approach. For any experiment *i*, the first time slot will be allocated on the basis of the first demand. Slot for each experiment will determine as the sum of experiment execution duration, and its guard band allocation time. Once the first slot is allocated, the rest of the next slots are assigned using TDMA for each of the experiment. All the setups have to be always active to avoid missing of a real-time request. This will lead to a high energy consumption and reduction in lifetime of the whole WSN testbed in case we use battery as power source.

In this phase, since all the nodes are active always, the energy consumed by a node at time T_i is,

$$Enode_{ij}\ (T_i) = Es_{ij}+Ep_{ij}+Ec_{ij} \qquad (1)$$

where i =1 to N, and j= 1to n_i for experiment.

If we consider only a limited power source is available for the sensor node then the lifetime, L of this node is,

$$L = Ebat\ /\ Enode_{ij} \qquad (2)$$

The maximum number of time slots that a setup have is,

$$s_{ij}\ (t_{ij}) = h\ /\ t_{ij} \qquad (3)$$

If each experiment i has n_i number of setups, then the total number of available slots for experiment is,

$$S_i\ (t_{ij}) = n_i\ {*}h\ /\ t_{ij} \qquad (4)$$

TABLE I. TABLE FOR PARAMETERS

Notations	Descriptions
N	Number of experiments
n_i	Number of wireless sensor network setups for each of the experiment *i*
$Enode_{ij}$	Energy consumed per second by i[th] experiment and jth setup of experiment *i*
Eslp	Energy consumed per second during the sleep state
Elist	Energy consumed per second during the listen state
Eact	Energy consumed per second during the active state
Es	Energy consumed per second during sensing of a node
Ep	Energy consumed per second during processing of a node
Ec	Energy consumed per second during the communication in a node
Ebat	Initial maximum energy stored in the battery
L	Lifetime
h	Number of hours of operations
s_{ij}	Number of slots that a setup can have for i[th] experiment and j[th] setup of experiment *i*
S_i	Total number of slots for i[th] experiment
n_i	Maximum number of setups for i[th] experiment
$Etot_{ij}$	Total energy consumed per second by i[th] experiment and j[th] setup of experiment *i*
t_i	Total time taken for i[th] experiment
t_s	Percentage of time i[th] experiment in the sleep state
t_l	Percentage of time i[th] experiment in the listen state
t_a	Percentage of time i[th] experiment in the active state

Therefore, the maximum number of concurrent users for experiment *i* at any time period is the number of concurrent users does not exceed n_i any experiment *i*, then the delay experienced by the whole WSN testbed will be minimum and the energy consumed will be maximum.

B. Phase 2: TDMA based State transitions and CDMA approach

We have enhanced this system by integrating TDMA scheme incorporated with state transitions and CDMA. The real-time scheduling among the WSNs for each of the experiment is based on TDMA scheme. The energy utilization is reduced by incorporating state transitions into the TDMA scheme. Fig.2 explains the TDMA scheme used for our RT Lab. The time slots allocated for each experiment will be different with respect to the time duration for the execution of each of the experiment, its listen period, and the guard band.

A state transition implemented in each of the wireless sensor network is shown in Fig.3. The enhancement of TDMA scheme with state transitions assures low energy consumption by tolerating a small amount of delay in data delivery. The collision among the data from the multiple experiments is avoided by implementing CDMA code for the communication between experimentation setups with the WSN gateway. Each experiment set has its own unique code. The entire WSN setup in each of the experiment will utilize the same code. The collision among the multiple experimental setups for each of the experiment is avoided by using TDMA scheme. Setting the threshold for sleep and listen depends on the experiment. The study in [10] shows that we can maximise battery recovery if we carefully adjust the sleep time period before reaching the saturation threshold. The simulation result shows that if the time period for sleep is more than a certain threshold, then there will not be much contribute to battery recovery i.e. saturation threshold.

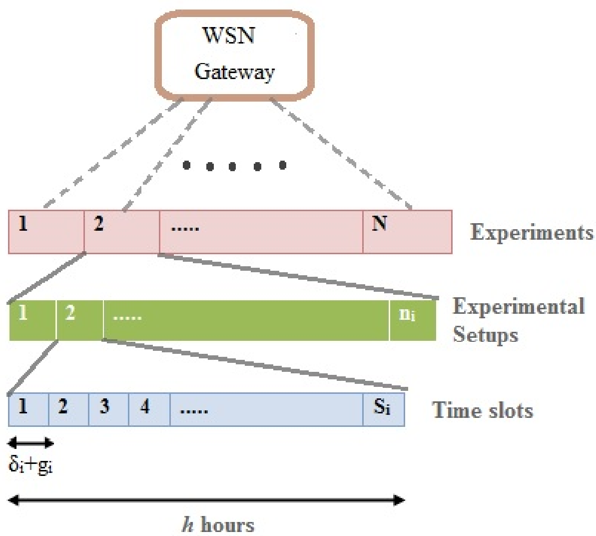

Fig.2.TDMA scheme for RT WSN Testbed

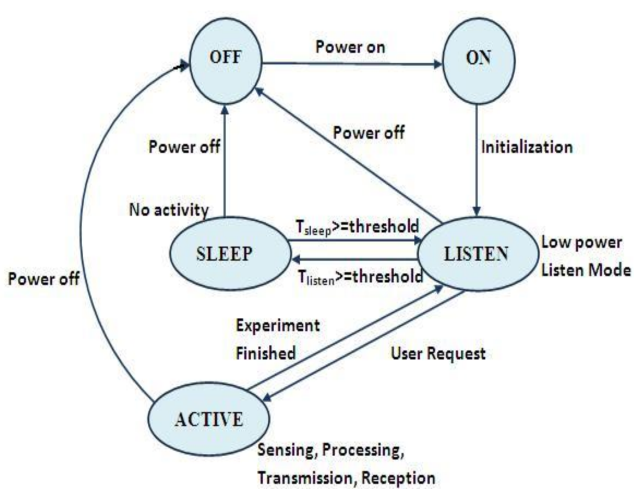

Fig.3.State transition diagram for RT WSN Testbed

Our assumptions are: all nodes are time synchronized, the location of the nodes is known apriori and initially all nodes are having same power consumption. In this phase, since all the nodes are not active always, then energy consumed by a node at time *T* phase, since all the nodes are not active always, then energy consumed by a node at time T_i is,

$$Enode_{ij}\ (T_i) = t_s * Eslp_{ij} + t_l * Elist_{ij} + t_a * Eact_{ij} \quad (5)$$

where

$$t_i = t_s + t_l + t_a \quad (6)$$

$$Ea_{ij}\ (t_i) = Es_{ij} + Ep_{ij} + Ec_{ij} \quad (7)$$

and i =1 to N, and j= 1 to n_i for experiment i.

If we consider battery as the power source for the sensor node, then the lifetime of this node is,

$$L = E_{bat} / Enode_{ij} \quad (8)$$

The maximum number of time slots that a setup i can have is,

$$s_{ij}\ (t_{ij}) = h / t_{ij} \quad (9)$$

If each experiment i has n_i number of setups, then the total number of available slots for experiment is,

$$S_i\ (t_{ij}) = n_i * h / t_{ij} \quad (10)$$

Therefore, the maximum number of concurrent users for experiment i at any time period is n_i, if all of them were able to access the channel during the listen period of the nodes of experiment i. If the user didn't access the channel during the listen period, the particular setup will change its state as sleep and hence the user has to wait for a time period given as,

$$Delay = T_{intial} + t_i - T_{access} \quad (11)$$

where

$T_{initial}$ the starting time of the slot

t_i the slot duration

T_{access} the user access time.

The energy saved by each node will be equal to,

$$ESnode_{ij}\ (T_i) = Enode_{ij}\ of\ phase\ 1 - Enode_{ij}\ of\ phase\ 2$$

$$ESnode_{ij}\ (T_i) = Enode_{ij} - (t_s * Eslp_{ij} + t_l * Elist_{ij} + t_a * Eact_{ij})$$

$$= Eact_{ij} - (t_s * Eslp_{ij} + t_l * Elist_{ij} + t_a * Eact_{ij})$$

$$= (1 - t_a) * Eact_{ij} - t_s * Eslp_{ij} - t_l * Elist_{ij} \quad (12)$$

The total energy saving will increase with respect to the ratio of time the node is in sleep or listen in comparison to active state.

In phase 2, the lifetime extension experienced by each node will be equal to,

$$SaveL = Lifetime\ of\ phase\ 2 - Lifetime\ of\ phase\ 1$$

$$SaveL = L\ (phase\ 2) - L\ (phase\ 1) \qquad (13)$$

V. PERFORMANCE EVALUATION

The RT Lab is equipped with memsic micaz motes, dielectric moisture sensors, rain gauge, on-board sensors, data acquisition boards, multimeters, cameras, computers and servers. The Fig.4 shows a WSN experimental setup in our RT Lab.

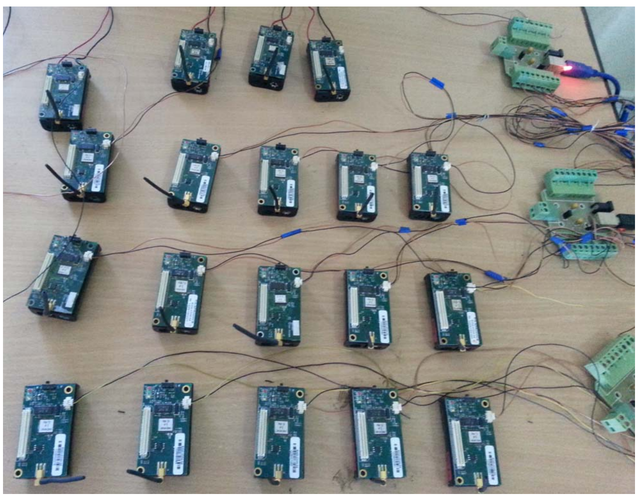

Fig.4. RT Lab WSN testbed

We have done the analysis of phase 1 and phase 2 by collecting the values for (1) and (5). From the testing, we found that the energy saved by each node for a unit time is 0.080739mW from (12). After analysing the power consumption data for different duration in (12), we got the evaluation result. The performance evaluation result, in Fig.5, shows that 78% power consumption has been reduced in phase 2 compared to that of phase 1.

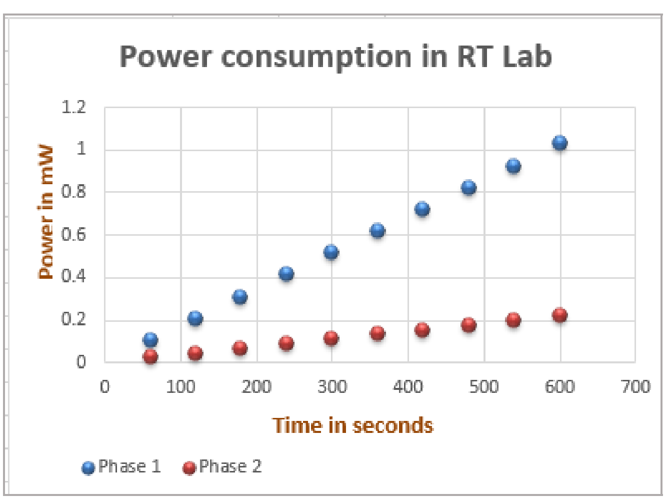

Fig.5. Power consumption per duration in Phase 1 & Phase 2

VI. CONCLUSION

One of the major challenges we faced during the testbed implementation is optimizing energy usage and delay in the network. The optimization of the energy consumption is achieved by the integration of an enhanced TDMA scheme incorporated with state transition and CDMA. This assures low energy consumption by tolerating a small amount of delay in data delivery. Another challenge is to manage the multiple WSN setups which can be solved using RT scheduling algorithm. 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. In future, we will look into the low power listening technique for our system.

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