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Application-Energy Prioritized Routing Algorithm for Wireless MANETs and its Experimental Evaluation

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***Abstract*: This paper proposes a routing algorithm based on the application energy prioritization in the Wireless Mobile Adhoc Networks. The proposed work accounts for energy expended due to applications running on the node as a significant contributing factor in the overall energy consumption of the network. A four node experimental test-bed is constructed for evaluating the performance of the proposed routing algorithm. The experimental results have shown that the overall network energy of the MANET is improved by 4.39% with the proposed priority-based routing approach.**

Index Terms: Application; Energy; Priority; SOC;Test-bed.

I. INTRODUCTION

A Wireless Mobile AdHoc Network (MANET) is a self-organizing (adaptive) and infrastructure-less network. The nodes of MANET are autonomous, mobile, and powered by a limited energy source [1]. The technical challenges needs to be addressed across all the layers of Wireless MANET include energy conservation ,Quality of Service (QoS), scalability, and the optimization [2]. Increasing the network lifetime is very important aspect of a battery-powered wireless network including the Wireless MANET. The energy source is the primary concern and constraint in the battery-powered nodes of a wireless network [3]. The overall network lifetime depends on the available energy of each node in the network. Various mechanisms are proposed to address and increase the network lifetime. Researchers have proposed the design of both centralized and distributed protocols [4] for minimum energy routing in ad-hoc networks. Optimization of the energy consumed is a preferred method to increase the network lifetime. This paper proposes a priority algorithm to minimize the energy consumption of a node running multiple applications.This paper is organized into five sections. Section 1 gives the introduction to the need for energy optimization methods for wireless MANETs. Section 2 reviews the related work. The proposed priority based routing algorithm is presented in section 3. Section 4 gives details on the experimental implementation of the proposed algorithm and discusses the outcome of the implementation. Finally, section 5 gives the conclusion and future scope of the proposed work.

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II. REVIEW OF RELATED WORK

This section reviews the related work from an energy optimization perspective. The demand for efficient utilization of the energy available on a node and in a wireless network is intensifying each day. First part of the section lays down the context of the application in the routing and emphasizes on the practical modeling of the remaining energy in terms of State of the Charge (SOC). Second part of this section reviews work carried on the prioritization concept in the routing.

A. *The notion of application and Determination of remaining Energy of a Wireless node in terms of SOC*

In Wireless MANETs, the purpose of communication infrastructure is not only limited to providing routes to a specific mobile node but also to provide specific services. Thus along with reachability to mobile nodes, services (Applications) must also be addressed. An application-oriented routing mechanism for specific ad hoc scenario using the Temporally-Ordered Routing Algorithm (TORA) is implemented [5]. The nodes in a wireless MANETs are in general battery powered. The battery capacity is a major parameter impacting network related parameters namely network lifetime and network stability. For mobility, the battery has to be an integral part of a node in the wireless mobile network. The energy of a node in the wireless mobile network not only depends on the radio transmission hardware but also on the processing and applications running on a node. It is experimentally found that processing and applications [6] such as sensor data sampling are mainly responsible for battery depletion rather than radio transceiver. This experimental work has shown that applications running on the node and processing power are the major contributors toward the battery depletion.The energy remaining on a node can be obtained accurately by determining the State of the Charge (SOC) of a battery. Further, SOC of a battery can be related as a function of battery terminal voltage. There are significant benefits of applying voltage and current integration method at higher SOC [Work Book on Challenges and Solutions in Battery Fuel Gauging, Texas Instruments Incorporated, 2004]. These days combined voltage and current-based fuel gauge ICs are available that can improve SOC characterization of a rechargeable battery.

B. *The Prioritization Effect in MANETs*

The concept of prioritization is very generic and contextual in the application. Prioritization is done to achieve optimized values of interest. The prioritization effect is explored in different ways in the MANET. A stable energy-aware topology management method is proposed [7] considering a minimal dominating set (MDS) of the network. The proposed method involves re-computation of priorities for each node and thereby extending the battery life. Simulation results shown indicate that this methodology gives relatively low energy consumption. A Binary Priority Countdown –BPC approach is proposed [8] for the medium access layer. Simulation results indicate a better use of priority space for new optimization and adaptation in MANETs. An optimized priority based algorithm is proposed [9] for energy efficient routing on existing Dynamic Source Routing for MANETs. Lowering residual energy means lower priority and the nodes with lower priority are less likely to forward packets to other nodes. The algorithm can improve the performance of route discovery, route maintenance, and cache management.A routing method for MANETs based on priority level [10] for users at the source and at the destination nodes was proposed. In this work the routing path is derived on the basis of prioritized battery levels. A priority based route maintenance mechanism called P-AODV [11] has shown improvement in throughput, end-to-end delay, routing overhead reduction and packet delivery ratio in comparison to AODV. A new parameter called as "priority" is introduced in the proposed work. A standalone node with an ART entry gets the high priority, other nodes priority is set to low thus modifying the neighbor table information. The node selection in the routing will be done on the basis of priority to provide a more stable path.

III. PROPOSED ALGORITHM

This section describes the proposed algorithm. The main algorithm is logically categorized into three algorithms for the ease of description. In the paper, the application meaning depends on the context. The energy consumed in running these applications is modeled to simplify the application context. A central node concept is included in the proposed algorithm. For the purpose of experimental verification the central node concept plays key role in collecting information of network related performance parameters. Table I gives notations and their meanings used in describing the proposed algorithm.

Table I: Notations and Meaning

Symbol	Meaning
N	Number of Nodes
A	Number of Applications per node
ta	Application runtime duration
V	Remaining Battery Terminal voltage
Vmin	Minimum Value of the Battery(Threshold)
Va	Battery voltage drop due to a particular application
VavgN	Average Voltage of the network
VthN	The threshold voltage of the network
PriApp	Priority Application
PriTime	Priority application runtime
Start_time	Application start time
End_time	Application end time

A. *Flow chart of the proposed protocol*

Fig. 1 shows the flow chart of the proposed algorithm. The algorithm deploys nodes randomly in the specified area. Each node runs application based on internal random application selection algorithm and for a random duration of time. A query for the battery status of each node is broadcasted in the network usually by cluster head or coordinator. This query may be periodic or can be triggered by an event in the network. Each node will respond with its battery status upon receiving the query. In addition to general battery status query, a network may broadcast a command to activate the minimum energy consumption algorithm in the same step. All nodes run on minimum energy consumption application on this command. In the final step, the network average energy is recomputed by the co-ordinator node and all nodes return to operate on non-priority mode.

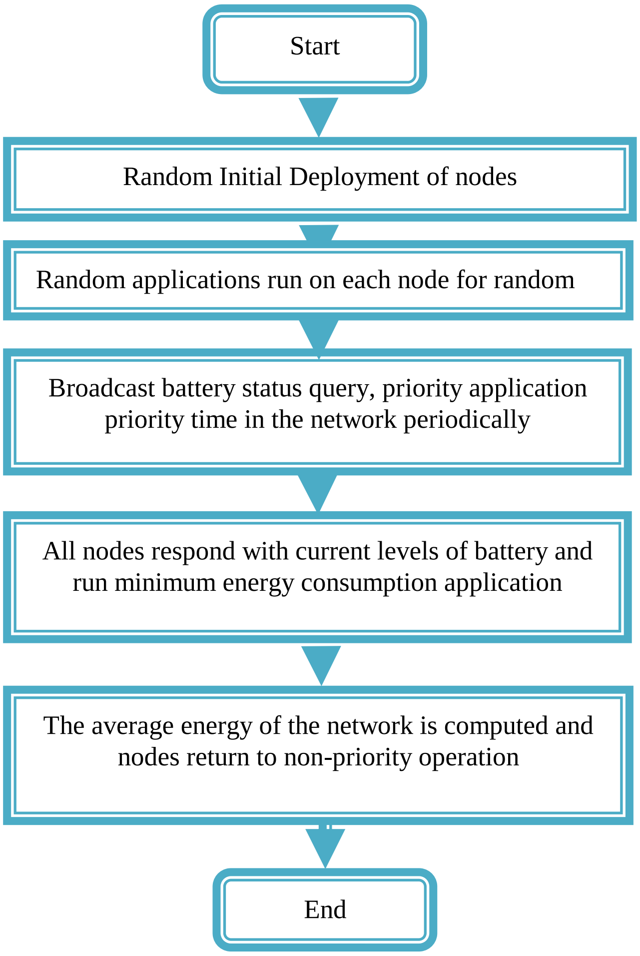

Fig.1: Flow chart of the proposed routing algorithm

B. *Description of the proposed algorithm*

This section describes the priority based energy minimization algorithm for wireless MANETs. It is assumed that a node is capable of running more than one application. Each node runs a random application on the basis of a random selection for a random duration of time. These applications will run until the energy remains above a predefined threshold. Each node starts to run on minimum energy consuming application once commanded by a central coordinator. The coordinator commands the network based on the constraints of the

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wireless network. In this work, the network constraint selected is energy consumption. Thus all the queries and commands will focus on minimizing the energy consumption of the network.Algorithm1 flow is described in Fig. 2. The node has an internal random application selection procedure. In this procedure, applications are allowed to run randomly. The randomness factor is derived from the noise available at the analog pins of the microcontroller. Based on the random selection procedure and runtime of the application, the remaining energy of the node is computed.

Algorithm 1: Compute remaining battery terminal voltage of a node.

for(i<==1 to N)
random(A,ta)
for (ta)
If (V <Vmin)
V=V-(Va)
else
Send status *"critical battery"*
endif
end for
end for

Fig.2: Computation of remaining battery terminal voltage

Each node has a predefined minimum energy level. If the node energy falls below this minimum level, all applications will be stopped. Further, the node sends a critical battery status upon queried by the network.The core concept of the proposed work is to activate the minimum energy consumption application in the network. Algorithm 2 and Algorithm 3 are as shown in Fig. 3 and 4. The priority is activated if the average energy of the network is greater than the threshold value of the network. The network activation is done for a random duration of time. The inclusion of randomness gives a realistic approach to MANETs performance evaluation.

Algorithm2: Network Priority

Random distribution of nodes
random(A,ta)
read the initial battery levels and compute the average energy of the network
if(VavgN>VthN)
Transmit command *"PriorityApp"* randomly for a random duration of time- *"PriTime"*
On receiving from the Network: All nodes switch to minimum energy consumption application and run for the time *"PriTime"*.
endif
Nodes will return to their normal working mode and periodically respond to the coordinator with remaining battery status.

Fig.3: Network Priority Algorithm

Fig. 4 shows the computation of remaining energy in advance for the random priority runtime. In principle, this algorithm estimates the net charge (net energy consumption) required for all applications running on a node and selects the minimum energy consuming application on the node. This ensures that only minimum energy consuming application is allowed to run on the node for the period defined by the PriTime. Thus each node expends minimum energy and as a result overall energy of the network is also increased.

Priority Algorithm 3:For individual node

Random selection of *application* to run on a node.
if(*"PriorityApp"* and *"PriTime")* available
for(t <==current time to *PriTime)*
***start_time*=current_time**
end_time*= current_time+*PriTime
Compute in advance the energy consumption of all applications as
energy consumed(for each application)=
[energy(*@start time*) - energy (*@end_time*)]
run (minimum_energy_application)
end for
end if

Fig.4: Priority Based Energy Estimation Algorithm

C. *Analysis of the algorithm*

Let a network of *'N'* node is randomly distributed in an area in this algorithm. Also, let each node is running *'A'* number of applications and each application has differing energy consumption. Let *'Et'* be the total energy of the network and *'En'* be the individual energy of the node.Also, assume homogenous energy for the network, then the total energy of the network is:

$$Et = \Sigma\ (En1, En2, En3...EnN) \quad (1)$$

$$En = \Sigma\ (Ep, Etx, Erx) \quad (2)$$

Where *Ep*=processing energy, *Etx*=transmission energy,and *Erx*= reception energy.

If *Etx=Erx* then, the variation in the overall energy of a node depends only on processing energy or more pragmatically on the applications running on a particular node. If a network has 'N' nodes with 'A' applications per node then it is possible to increase the lifetime of the wireless MANET or any other wireless network by exploiting variations in the energy consumption.

Corollary

From equations (1), (2) and above-mentioned assumptions: **"If the minimum energy consuming application is allowed to run on a node without affecting the critical requirements of a node then the network lifetime is bound to increase"**

IV. EXPERIMENTAL METHODOLOGY AND RESULTS DISCUSSION

This section briefs the methodology of implementation. The MANET performance validity based on the simulation is debatable and still remains an open issue. Hence, this work presents a novel experimental method for evaluating the wireless network performance. The focus of the work is to minimize the energy consumption of the network through a novel approach and increase the overall lifetime of the network. The network under consideration is a four-node experimental test-bed. This test-bed is an integrated microcontroller and XBee module. The experimental method is described below.

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A. *Experimental Methodology*

This section describes a novel experimental methodology for the proposed algorithm. Fig. 5 shows the major steps involved in the experimental evaluation.

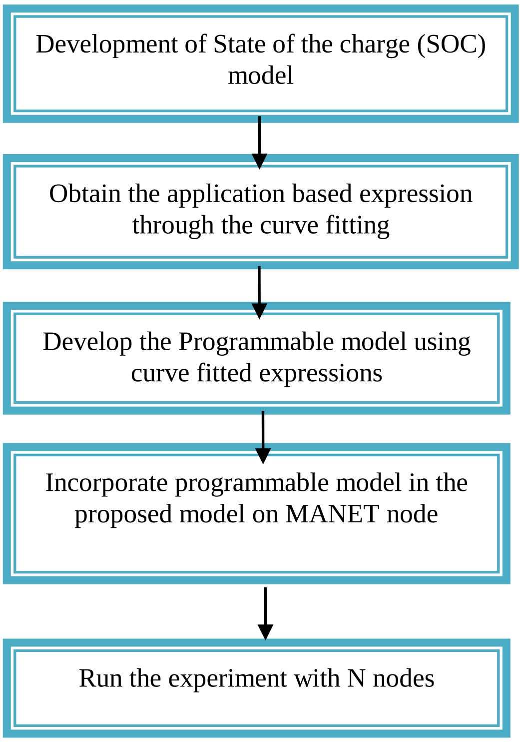

Fig.5: Experiment Methodology

B. *Development of state of the charge (SOC) model for a node*

Table II gives experiment specifications and Fig. 6 shows the block diagram of the SOC modeling of a Ni-MH battery running three different applications. The battery terminal voltage 'Vin' is read directly by the microcontroller.For SOC modeling it is assumed that at any given instant of time only one application will run for the duration decided by the node (Microcontroller). The microcontroller reads instantaneous voltage and current from the INA 219 sensor (Texas Instrument). For developing the empirical model, the application is run till battery drains to a minimum value or until application stops.The INA 219 also reads shunt, bus and load voltages. These parameters are acquired for further analysis and modeling. The SOC due to a particular load can be determined by capturing variations in terminal voltage or instantaneous voltage and current drawn or any of these combinations. The work presented in this paper captures variations in battery terminal voltage for determining SOC of the battery.

Table II: Experiment Specifications

Parameter	Value/specifications
Number of Experimental Nodes	4
Number of applications per node	3
Battery Type	Ni MH, 600mAh, 3.6V.
Applications	1 DC Motor, 2 DC Motor, 2DC Motors +100 K Ohm resistors.
Node –Internal application change time	Randomly(30,60) sec
Priority activation time	Random(180,300)sec
Network priority duration	Randomly (20,40) sec
Threshold voltage	10% of initial voltage

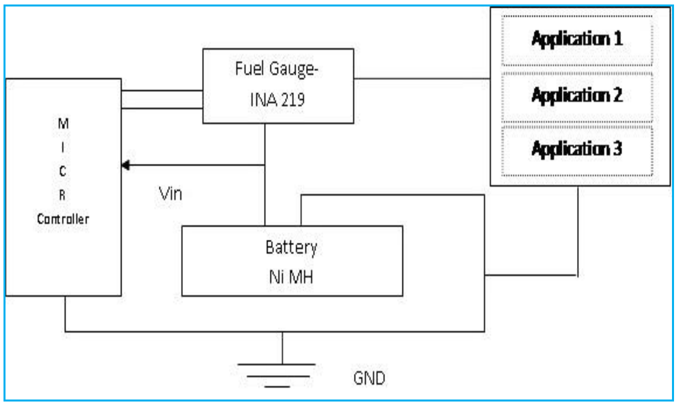

Fig.6:Block diagram for SOC modeling on a node running with multiple applications

C. *Curve Fitting*

The experimental model approach is one type of data modeling technique [12] in which battery characterization is done using equations developed based on the data. Table III gives sample experimental test values for three applications. Following expression (3) to (5) are obtained using curve fitting method after experimental evaluation of three specified applications as shown in Table II. The battery terminal voltage is derived as a function of time for each application. The curve fitted response for three applications is as shown in Fig. 7.

$$Volt\_app1 = (-1.9*10-11 * t^3) + (1.20*10-7 * t^2) - (3.45*10-4 * t) + 3.9 \quad (3)$$

$$Volt\_app2 = (-1.55*10-11 * t^3) - (8.5*10-8 * t^2) + (0.00005 * t) + 3.9 \quad (4)$$

$$Volt\_app3 = (-1.99*10-9 * t^3) + (3.87*10-8 * t^2) - (0.0025 * t) + 3.9 \quad (5)$$

D. *Development of the SOC Programmable Model*

The mathematical expressions obtained above are incorporated as a programmable model in the microcontroller. An algorithm is developed to test the SOC model. Averages of five test runs are considered to ensure the credibility of the experiment. The average battery terminal voltage response of a node is depicted in Fig. 8. From the response, it is observed that the battery terminal voltage (SOC) has nonlinear variations as was expected in the curve fitted response. It is also observed that the end response takes non-linear dip within a short duration of time. This is kind of SOC response is typical for Ni-MH battery chemistry.

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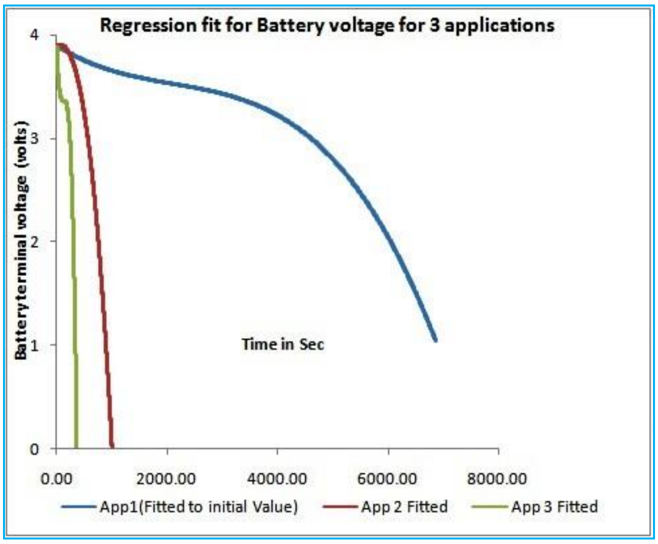

Fig.7:Curve fitted responses for all three applications

Table III:Sample Experimental Results

Time in Sec	App1 (Fitted to initial Value 3.9V)	App 2 (Fitted to initial Value 3.9V)	App 3 (Fitted to initial Value 3.9V)
5.04	3.90	3.90	3.89
10.05	3.90	3.90	3.88
15.06	3.89	3.90	3.86
20.07	3.89	3.90	3.85
25.09	3.89	3.90	3.84
30.10	3.89	3.90	3.83
35.11	3.89	3.90	3.82
40.11	3.89	3.90	3.81
45.12	3.88	3.90	3.79
50.14	3.88	3.90	3.78
55.15	3.88	3.90	3.77
60.16	3.88	3.90	3.76
65.17	3.88	3.90	3.75
70.18	3.88	3.90	3.74
75.19	3.87	3.90	3.73
90.23	3.87	3.90	3.70
95.23	3.87	3.90	3.70
100.24	3.87	3.90	3.69
1708.65	3.57	3.66	1.00
1713.66	3.57	3.66	9.66E-01
1718.68	3.57	3.66	9.32E-01
1723.68	3.56	3.65	8.98E-01
1728.70	3.56	3.65	8.63E-01
1733.71	3.56	3.65	8.28E-01
1738.72	3.56	3.65	7.93E-01
1743.73	3.56	3.65	7.57E-01
1748.73	3.56	3.64	7.21E-01
1753.76	3.56	3.64	6.84E-01
1758.77	3.56	3.64	6.48E-01
1763.76	3.56	3.64	6.11E-01
1768.79	3.56	3.64	5.73E-01
1773.80	3.56	3.63	5.36E-01
1778.80	3.56	3.63	4.98E-01
1783.82	3.56	3.63	4.59E-01
1788.83	3.56	3.63	4.21E-01
1793.84	3.56	3.63	3.82E-01
1798.85	3.56	3.62	3.42E-01
1803.86	3.56	3.62	3.02E-01
1808.87	3.56	3.62	2.62E-01
1813.88	3.56	3.62	2.22E-01
1818.89	3.56	3.62	1.81E-01
1823.90	3.55	3.61	1.40E-01
1828.91	3.55	3.61	9.86E-02
1833.93	3.55	3.61	5.67E-02

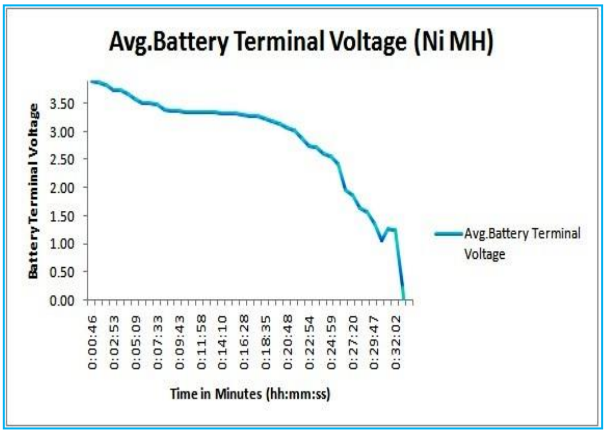

Fig.8: Average battery terminal voltage (Ni-MH)

E. *Construction of the Experimental Test-bed*

The developed programmable SOC model is applied to a test-bed consisting of four nodes. For evaluating the performance of the proposed algorithm, a test-bed is constructed using XBee series 2 modules. A simplified view of the developed node model is as shown in Fig. 9. The choice for constructing the node using ZigBee protocol is judicious. This is hybrid protocol, supporting both reactive (AODVjr-AODV junior) and ZigBee based tree routing (ZTR) [13][14] methods. Hence this Zigbee l has the advantages of both proactive and reactive p [15].

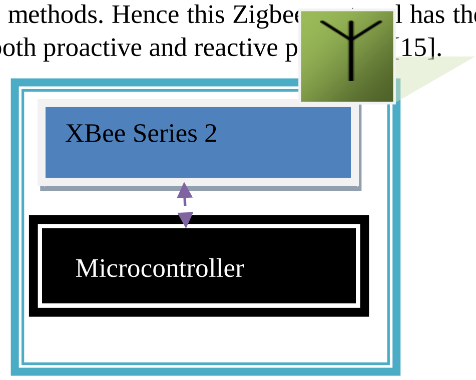

Fig.9:A Simplified view of the test-bed node

Fig. 10 illustrates nodes under experimental trial. All nodes are USB-powered. The experimental data is captured in real-time and for statistical accuracy, five trials are taken. The captured data from all the trials is then analyzed to evaluate the performance of the wireless network. Fig. 10 also shows data acquisition in real-time.The number of applications is restricted to 3; application selection on a node is random and it is selected every (30 to 60) seconds duration of time. Hence, each node remains autonomous in behavior until the network activates the priority algorithm. Network priority activation time is random and is activated for every 180 to 300 sec. This network priority activation duration is varied from 20 to 40 sec. The minimum threshold voltage is fixed at 10% of the initial voltage. It is apparent that variations in Table II values will impact the performance of the network.

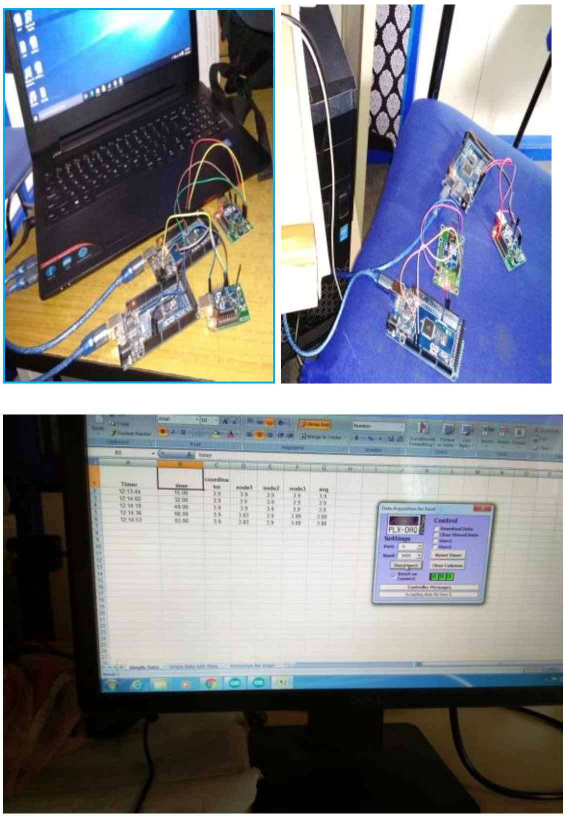

Fig.10:Nodes under experimental trial and real time data acquisition

F. *Results and Discussions*

The average energy consumption of the total wireless MANET test-bed is as shown in Fig.11. Fig. 12 shows the average energy consumption for each of the four nodes with and without priority. The responses shown are obtained after taking the average over five repetitions. The experimental results prove that nodes with routing priority strategy outperform nodes without priority in terms of network stability and network lifetime. The analysis of the acquired real time data shows an improvement of 4.39% with the priority strategy. Also the proposed routing method has shown better network stability compared to network without priority.

IV. CONCLUSION AND FUTURE SCOPE

A novel energy minimization algorithm based on the concept of application prioritization is presented. The algorithm has shown individual node energy stability and overall network energy improvement for the specified values of Table II. It is found that on an average network lifetime is increased by 4.39% for the network nodes with priority. A significant increase in network stability is achieved. The work also presented a novel experimentation methodology. The network test-bed constructed is: economical, scalable and a practical approach toward wireless MANETs performance evaluation. In future wireless MANETs will be made more realistic and heterogeneous by including battery chemistries such as Li-Po and Lithium-ion. In future both heterogeneous and homogenous energy scenarios will be evaluated. Further, the network performance parameters such as packet delivery ratio, energy consumption, the end to end delay and throughput will be analyzed.

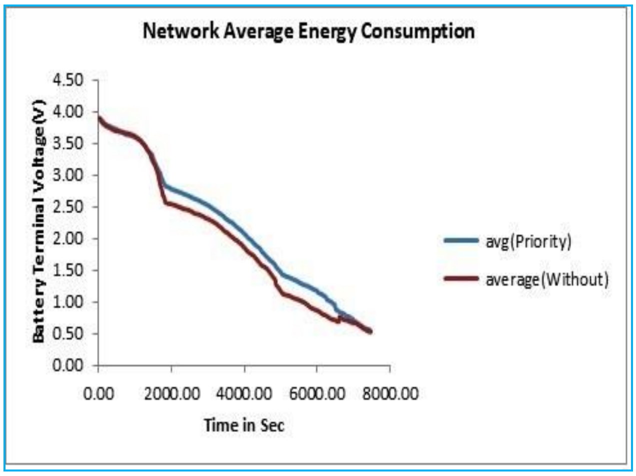

Fig.11:Average Energy consumption of the total network under test with and without priority

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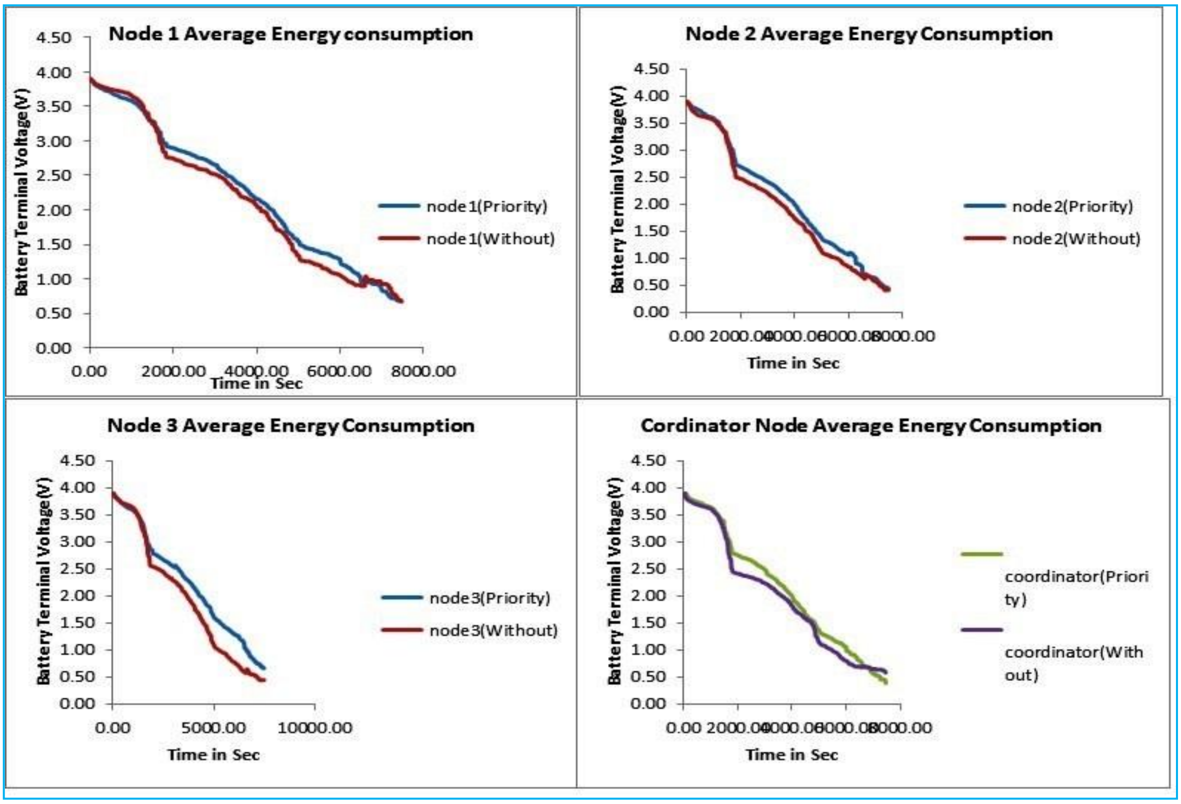

Fig.12:Average energy consumption (battery levels) of each node with prioirty and without priority

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