RPL Optimization for Precise Green House Management using Wireless Sensor Network

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Abstract — **The precision farming techniques provide favorable conditions to grow money crops like capsicum, nursery plants in a temperature and humidity controlled fashion. Wireless sensor networks (WSN) can be used for automatic monitoring and control of soil humidity and temperature inside the green house. The Contiki OS with routing protocol implementation as per IETF specifications, is better choice for precision agriculture. Soil properties can be collected and aggregated over a long distance using ADHOC WSN tree formation. The Routing Protocol for low power and Lossy Network (RPL) parameter decides battery consumption, network efficiency, convergence time of the routing tree, routing table correction and rate of data collection. Battery consumption depends on control overhead packets transmitted over a specific interval. Optimization of network and battery efficiency is the primary concern for deployment of wireless sensor network to any specific case. In the present work, RPL parameter impacts on network efficiency and overheads are simulated in COOJA simulator and MATLAB curve fitting tool is applied to find the optimum RPL parameter value for a particular implementation. The complete architecture required for practical implementation of green house monitoring is proposed and validated using real time simulation.**

Keywords: Green House Monitoring, Wireless Sensor Networks, RPL, Contiki OS.

I. INTRODUCTION

Wireless sensor networks have been applied to myriad of applications due to their simplicity in connectivity, co-operative adhoc networking ability and long battery life in deployed nodes. IETF [2] had standardized the Routing Protocol for Low Power Lossy Networks (RPL) for WSN, considering its proactive nature and constraints like memory and processing capability. RPL has a Directed Acyclic Graph (DAG) formation with root node at apex. The node discovery and routing table repair is done using RPL triple timer mechanism. The DIO Interval minimum, DIO Doubling Rate and DIO Redundancy Rate parameters of RPL plays a critical role in deciding network convergence and control overhead. Optimization involves obtaining the level of above parameters, using real time simulator called Cooja simulator, designed specifically for wireless sensor networks. The Contiki OS [3] is developed specially for networked, memory-constrained and power constrained systems. After inception of the original code in 2002 by Adam Dunkels, enthusiasts all around world joined the rapid developing community. The Routing protocol has to be optimized for any specific deployment. In the current work, an optimum solution is devised to solve the Green house management problem.

Agriculture is the need of day for our economy with vast population. To reduce the import of various grains and to sustain the agricultural practices, automatic green house management is the techno-agriculture solution. The Green house management system architecture is proposed and implemented using zigbee based network and PIC microcontroller [1]. The advantage of the proposed system is its simplistic design and easy management for a single green house system. The current paper proposes IPV6 based connectivity for enhanced monitoring and data aggregation of humidity and temperature data. The RPL performance is estimated through dense deployment in smart grid applications and it is proven that RPL provides ample flexibility in routing packets of embedded wireless sensor networks [4]. The RPL delivers best packet delivery ratio in hostile environment with electromagnetic disturbances. RPL also assures best parent selection using objective function with metrics like RSSI, hop count and battery level of the node. There are currently two objective functions in Contiki OS namely ETX and OF0. The ETX is based on RSSI and other metrics, and OF0 objective function is based on the hop count of the nodes.

II. GREEN HOUSE MONITORING FRAMEWORK USING CONTIKI WSN

A. *Proposed Architecture*

The automatic monitoring and control of green house using Contiki OS with remote management console is shown in figure 1.

The sky mote with TI MSP430 microcontroller is used in the proposed design. The Sky mote has inbuilt temperature sensors and humidity sensors like HSM 20G [1] attached to it. The border router node is an enhanced wireless sensor node with memory capacity more than 20 MB RAM for packet processing. The Raspberry Pi Board can be used as a data aggregator node which has ARM7 architecture. The board provides enough processing power for packet processing and control command generation to maintain soil humidity and temperature.

The calibration and buffer stage amplifier design are vividly explained in related papers [1].The current work is limited to the application of Contiki OS with optimized RPL parameters to enhance data collection and long battery life. The RPL parameters are optimized for precision agriculture area, with reduced node count of 20 and the application packet timing of 2 seconds. The main factors considered in the current work are control packet overhead and convergence time. The Cooja simulator is being used to simulate the field conditions. The practical deployment will be undertaken after obtaining optimum RPL parameters values from real-time simulation.

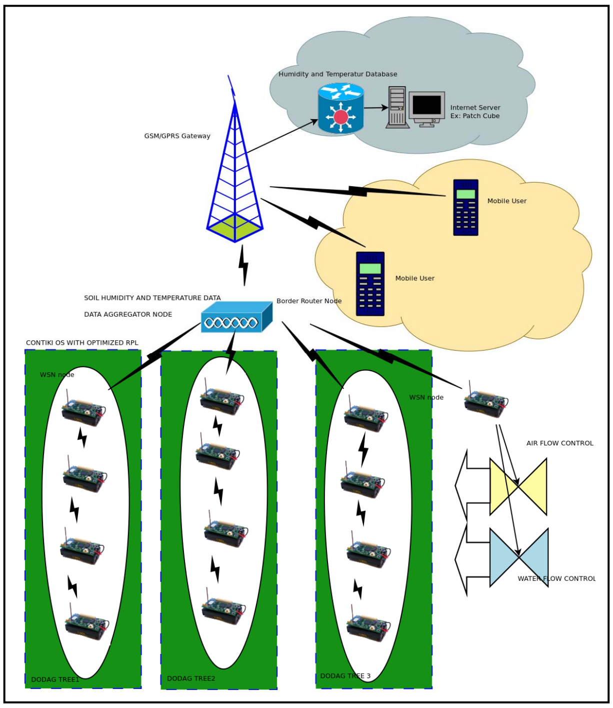

Fig 1: Green House Monitoring Architecture using Wireless Sensor Networks

B. *Choice of Operating System*

The Operating System for WSN is very challenging system, since it demands highly memory constrained and processing power constrained environment with a need for batter conservation. The operating system selection depends on parameters listed in table 1.

TABLE I. COMPARISON OF VARIOUS AVAILABLE WSN OS

Parameters	WSN Operating Systems (OS)			
	Contiki	***Tiny OS***	***MANTIS***	***SOS***
Scheduling	Pre-emptive	Non Pre-emptive	Pre-Emptive	Non Pre-emptive
Dynamic Reprogramming	YES	YES	NO	YES
Thread Stack Memory	Shared Stack	Individual	Individual	Individual
Programming Language	C	NesC	C	C
Active Development	Yes	Partial	No	No

The Contiki OS, with event-driven mechanism, proto-thread execution model and active developers community is will be one of the better choices for WSN. Recently Contiki 2.7 version was released (on Nov 2013) with vast improvement in areas of IPv6 mesh networking and huge bug fixes, with improved code flow. The total supported platforms are TI, Atmel, AVR, ST, Arduino platforms, TI CC2538 802.15.4 System-on-a-Chip, PIC32. The main advantage of Contiki OS is the real time simulation of various hardware platforms using Cooja simulator. Recently regression testing framework was added to Cooja simulator.

The competitor TINY OS with nesc framework having steep learning curve and only provision for static compiled module made it slow performer in competitive WSN market. Most developers in WSN field, switched to Contiki OS due to its structured framework written in C, real-time simulation capability and direct hardware support.

The code once written need not be changed for deployment. The code analyzed and debugged in simulator will work directly in field. Hence it provides reduced development time, marketing time, cost-effective application development. The real hardware is not mandatory during application development phase. Thus analyzing all above parameters Contiki OS is being opted as royalty free low cost, long term development platform for precision agriculture. The custom zigbee application framework is not reliable, since new version may not compatible with older versions like scenario with Microsoft development framework, royalty fee for commercial agricultural deployment.

C. *Routing Protocol for Low Power Lossy Networks (RPL)*

The RPL was drafted by IETF, for low power and Lossy networks such as wireless sensor networks. The various network protocols are of reactive nature namely AODY, DSV etc will determine the route on-demand. The RPL will pro-actively make the routing table ready ahead of data. RPL forms a Destination Oriented Directed Acyclic Graph (DODAG) with root node at apex.

RPL operates in two variations, storing mode with nodes aware of local routes and non-storing mode, with nodes only aware of parent node. The RPL forms route using upward and downward communication, upward communication with DODAG Information Object (DIO), and downward with DODAG Acknowledgment Object (DAO).

The RPL was devised with self-monitoring capability using triple timer mechanisms. Once network become stable, control packets frequency is reduced and thereby control overhead is reduced. The value of these parameters decides the RPL protocol response to adverse environment conditions. The RPL assigns each node with rank value. RANK 0 is assigned to root node, and other ranks to other level nodes in an increasing order. Each network can have several RPL instances, but a node can be part of only one RPL DODAG Instance.

D. *Routing Protocol for Low Power Lossy Networks (RPL)*

The Cooja Simulator is Java framework for Contiki OS wireless sensor nodes simulation. The Cooja Simulator provides debug logs from print statements. Using print statements, radio logs, actual transmission-reception among nodes can be analyzed in real-time. Unlike NS2, which creates routing table rules, wireless environment rules separately will not reflect the real deployment scenario from actual execution perspective. Contiki-Cooja is approximately ideal environment to decipher the magic of wireless sensor network operation in real time.

III. RPL PARAMTERS FOR OPTIMIZATION

The RPL protocol internal operation was analyzed and optimized with respect to following parameters using real-time simulation

A. *RPL parameters selection*

The DODAG Tree is controlled by DIO interval Minimum, DIO Doubling Rate, DIO Redundancy Rate timer mechanisms. RPL Parameters controlling the routing table formation, repair are taken as main criteria in WSN deployment. The node count is also critical parameter in WSN.

The routing table convergence denotes network convergence, inception point at which data packet is delivered to the end server. The network convergence denotes that all nodes are joined in DODAG tree, more optimum parents are selected, no more change in the routing rank.

The control packet overhead denotes ratio of control packets transmitted to data packets transmitted, control packets frequency denotes routing table repairing ability of network for adapting to node failures. The redundant control overhead results in energy dissipation, reduced battery life. Thus control overhead has to be reduced, for optimal field specific deployment of WSN.

IV. SIMULATION RESULTS AND DISCUSSION

A. *Simulation Setup*

The Cooja Simulator screen shot is shown in figure 2. Simulation was carried out in Ubuntu based Host PC with 8GB RAM to meet the simulator load. The simulation environment is standardized with respect to number of WSN motes, Mote Selection, Distribution of Nodes, and Lossy Wireless medium, Simulation time. The border router is configured as serial port server. Tunslip interface is configured to collect data packets at host pc tun0 interface. The Wireshark network analyzer is used for data collection from the tun0 interface, the Wireshark logs saved, with respect to Cooja Log files.

The Log files are analyzed with PERL script for metrics collection and results are tabulated. The formulas to derive convergence time and control packet overhead is shown below,

Convergence Time = LAST DAG JOINED – FIRST DIO SENT
Control Overhead = (CONTROL PACKETS / DATA PACKETS) *100;
Packet Delivery Ratio= (SUCCESSFULL RECEIVED/ TRANSMITTED PACKETS) *100;

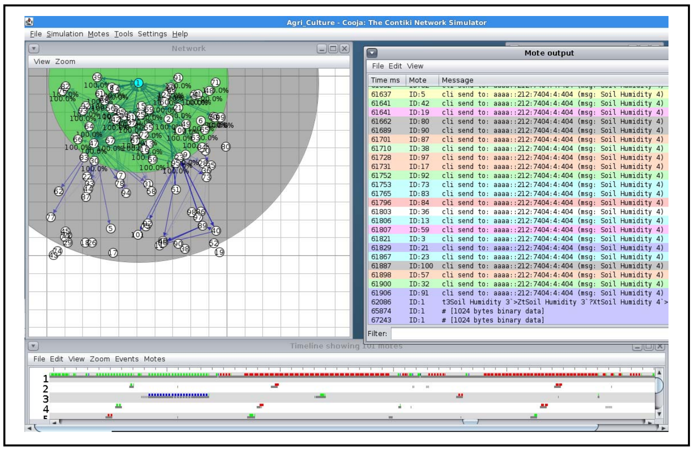

Fig 2: The Cooja Simulator Simulation Screen Shot

B. *DIO Interval Minimum – Optimization*

The DIO interval minimum is a critical parameter for network convergence and overhead, it denotes how frequency information is requested from parent node. Higher control data frequency, routing tree formation will have faster convergence and quick response to adverse environment conditions. The lower value results in slow response to node-path failures. The IETF draft specifies DIO interval minimum value as 3 seconds. Contiki Default value is 12 seconds, but optimal value predicted as per MATLAB mathematical model calculations is 11 seconds. The simulation data is imported to MATLAB curve fitting tool box, polynomial model and Gaussian models are used to find optimal value.

The optimal value obtained with the predicted curve is shown in figure 3. The predicted function can be used to optimize in surface optimization tool box also.

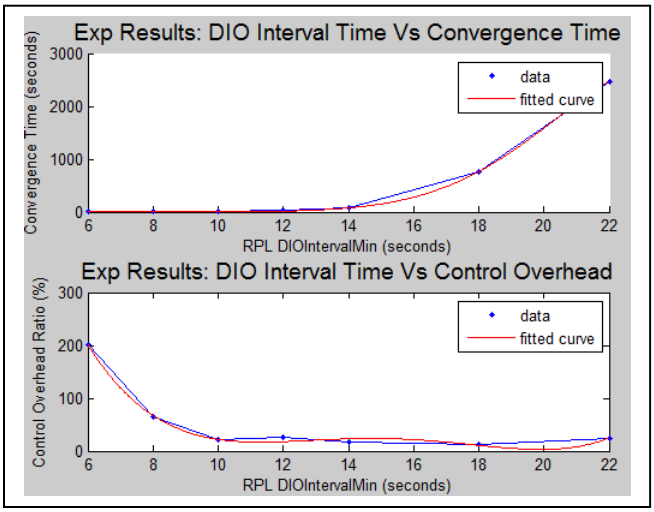

Fig 3: The DIO Interval Minimum Optimization Curves

C. DIO Doubling rate - Optimization

DIO Doubling rate does not affect convergence time, yet it contributes to control overhead. The control overhead is inversely proportional to DIO doubling rate. The Contiki OS default value is 12. The optimum value from MATLAB mathematical modeling is 18 seconds. The fig 4 shows the MATLAB figure with predicted curve and polynomial curve fitting results.

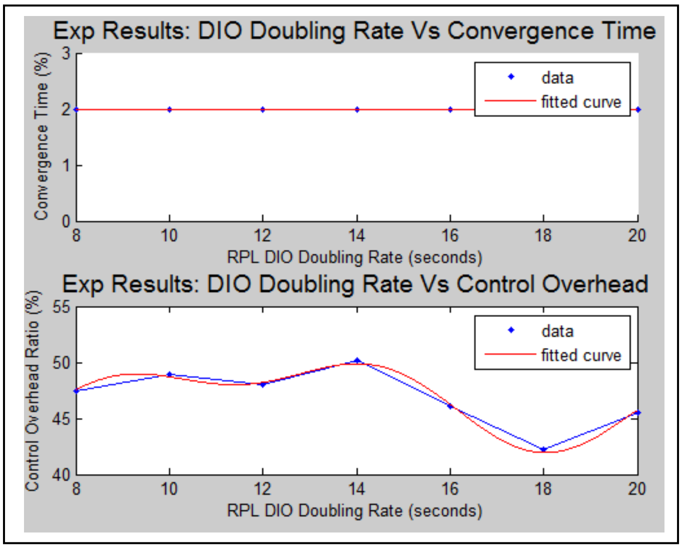

Fig 4: The DIO Doubling Rate - Curve Fitting Results

D. DIO Redundancy Rate - Optimization

DIO Redundancy rate parameter does not affect convergence time, but it has an impact on control overhead. The Exponential and Polynomial model is used to fit the simulation data for finding optimum minimum value. The optimal value of 30 seconds is found from the MATLAB optimization function.

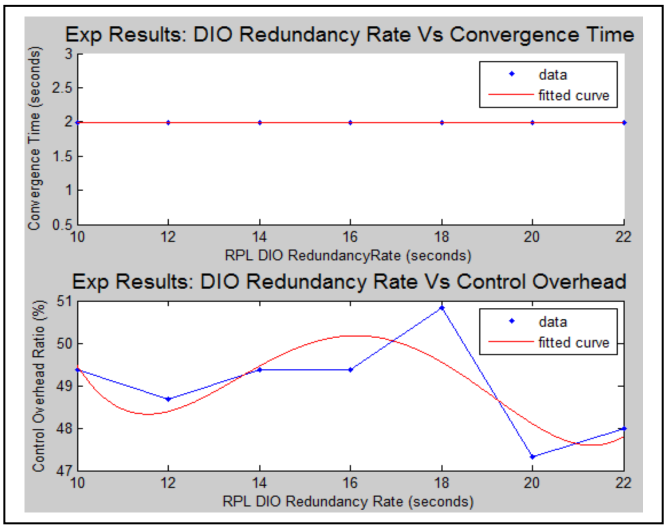

Fig 5: The DIO Redundancy Rate - Curve Fitting Results

E. RPL No Of Nodes - Optimization

The Number of WSN nodes per border router decides convergence time and control packet overhead. In denser network, more interference will occur in wireless channels. Optimal value is 10 nodes per border router. The packet delivery ratio for different nodes is analyzed as shown in figure 7. It is found that some nodes have poor packet delivery ratio as 30 percentage.

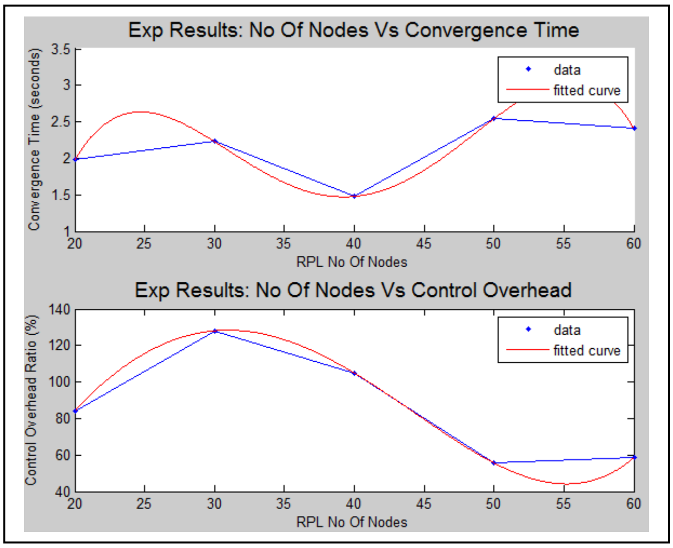

Fig 6: The RPL Number Of Nodes - Curve Fitting with polynomial function

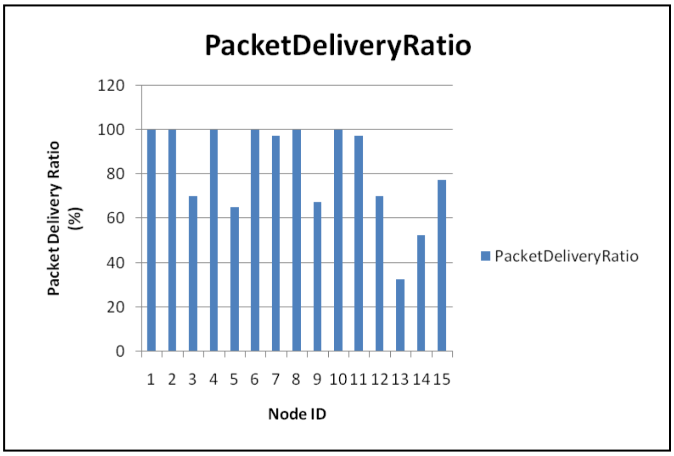

Fig 7: Packet Delivery ratio for Different Nodes

V. MODEL-BASED REGRESSION ANALYSIS

A. Regression Analysis Models Used

In Industrial situation, to predict output with several input parameters, we need to predict mathematical model of system. The mathematical modeling using linear and non linear equations will be predicted using regression analysis. Traditional examples for regression analysis are a) Tar Output from Industry based on input fuel temperature b) Engine Mileage [7][8]. The concept of regression analysis deals with finding the best relationship between y and x quantifying the strength of relationship, and finding best mathematical model. Using models facilitates prediction of future response.

The linear and non-linear models used in regression analysis is shown in table II

TABLE II. COMPARISON OF MATHEMATICAL MODELS

Model Name	Model Equations	Best Usage
Polynomial Model	$y = \sum_{i=1}^{n+1} p_i x^{n+1-i}$	*Simple Empirical Model *Interpolation *Extrapolation
Exponential Model	$y = ae^{bx}$ $y = ae^{bx} + ce^{dx}$	*Rate of change of quantity is proportional to the initial quantity
Fourier Series	$y = a_0 + \sum_{i=1}^{n} a_i \cos(nwx) + b_i \sin(nwx)$	*Periodic Signal analysis
Gaussian Model	$y = \sum_{i=1}^{n} a_i e^{\left[-\left(\frac{x-b_i}{c_i}\right)^2\right]}$	*Peak Fitting Process *Spectral peaks Modeling

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B. Best fit Analysis – RPL Optimization Models

The best model suited for mathematical prediction can be judged from fit parameters namely, SSE, R2, RMSE.

The Sum of Squares SSE value is variation due to error, or variation unexplained. If SSE= 0, all variations are explained.

$$SSE = \sum_{i=1}^{n} (yi - \hat{y}i)^2$$

The total corrected Sum of Squares SST is given by following equation,

$$SST = \sum_{i=1}^{n} (yi - \bar{y}i)^2$$

The SST represents the variation in response that ideally would be explained by the model. The quantity, Coefficient of Determination R^2 is a factor to determine correctness of fit. If fit is correct and all the residuals are zero then R^2 will be = 1. If fit is not proper, worst case R2 will be = 0.So maximum value of Coefficient of Determination states that it is correct fit.

$$R^2 = 1 - \frac{SSE}{SST}$$

The second fit parameter, S^2 term is used to predict lack of fit, lesser value of S^2, means better fitting of model.

$$S^2 = \frac{\sum_{i=1}^{k}(n_i - 1)s_i^2}{(n-k)} = \frac{\sum_{i=1}^{k}}{}$$

The third fit parameter Root-mean-square-error (RMSE) is a measure of differences between values predicted by a model (or an estimator) and the values actually observed. The individual differences are called residuals. From the experimental data, the prediction errors are computed. The RMSE is a good measure of accuracy but useful only to compare various mathematical models. The RMSE is scale dependent, hence not a good tool to forecast error between variables.

The results obtained from real-time simulation can be used to predict mathematical model for routing protocol analysis. The Routing protocol parameter will be optimized based on the predicted mathematical model. The suitable mathematical model for routing parameters is found by goodness of fit. The goodness of fit is analyzed by R2, RMSE values.

C. Optimum Values for enhanced Battery Performance

The optimum values for the effective battery utilization is calculated from mathematical model, using MATLAB optimization tool. The optimum values with bold typeface are listed in Table III below.

TABLE III. OPTIMUM RESULTS FOR MAXIMUM BATTERY LIFE

No	Parameter	Optimization Criteria	Model Used	Value (s)
1	DIO Interval Minimum	Network Convergence Time	Gauss Model Degree 1	3
		Control Data Overhead	Polynomial Degree 4	**11**
2	DIO Doubling Rate	Network Convergence Time	Exponential Model Degree 1	30
		Control Data Overhead	Fourier Series Model Degree 2	**18**
3	DIO Redundancy Rate	Network Convergence Time	Exponential Model Degree 1	22
		Control Data Overhead	Polynomial Degree 4	**30**
4	No Of Nodes	Network Convergence Time	Polynomial Degree 4	39
		Control Data Overhead	Fourier Series Model Degree 1	**10**

VI. FUTURE ENHANCEMENT

The real time simulation results are used to configure hardware implementation for green house management using HSM 20G sensor and Raspberry pi board as border router. The feasibility analysis of low cost Arduino WSN platform is undertaken, to predict cost effective green house monitoring solution. The Wireless Sensor Networks can be applied to various other crops like apple farming [5], and other drip irrigation systems.

VII. CONCLUSION

The Green House Monitoring System is simulated using Contiki OS Cooja Simulator. From the simulation results, the optimal values predicted are 11, 18, 30 seconds for DIO Interval rate, DIO Doubling rate and DIO Redundancy rates respectively. The mathematical regression modeling analysis is done using MATLAB tool. The optimal number of nodes per border router is 10 nodes. The hardware implementation is under progress to validate the above concept.

The current work provides a novel regression analysis method to determine optimum routing parameter values. The WSN is being deployed in smart buildings [9] [10]. The smart energy systems using paper based thin film techniques and RF harvesting techniques are actively studied [11] [12]. In near future, WSN motes will be the trend with myriad of applications. For future smart applications, design of WSN with optimum routing values will be a desirable contribution.

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