I J C T A, 9(14) 2016, pp. 6593-6603

Power Law Model Validation for Average Power Consumption of nodes in WSN with Increasing Scale

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ABSTRACT

Power Consumption (PC) of all individual nodes in a Wireless Sensor Network (WSN) collectively form Total Power Consumption (TPC) which is the prime parameter to analyze and to estimate total network lifetime. So it has been another prime area in a wireless network to study the Average Power Consumption (APC) of nodes with different size of the network to estimate the total power consumption of the network, which will decide the span of the network. In this paper, we have studied the characteristics of different WSNs models with different scale and size to figure out whether the total power consumption is following the Power Law Model (PLM) or it is fitting to the Exponential Law Model (ELM). For validating our hypothesis we have simulated the models for different validating methods in Matlab software to choose the best model that will fit our data, which will bitterly describe and characterize the average power consumption in node level. The methods we have use to validate our models are, first, curve fitting method, the second one is residual plot analysis method, the third one is r^2 method and finally the best validating method which is statistically better by doing the null hypothesis for F- test has been simulated and analysed. We have done validation for all the method mentioned above to find out which model is best fitting with the nonlinear total power consumption of wireless sensor networks.

Keywords: *ELM, PLM, TPC, PC, APC.*

I. INTRODUCTION

Wireless sensor network is now becoming a great research area in terms of its power management techniques and power aware routing models designing. To better analysis of any system, we must need to know about its different characteristics and the characteristic of any system is depends upon the system associated parameter. Authors have been trying to figure out the best law model equation that will bitterly explain the characteristically behavior of the system. Here we have taken the system as wireless sensor network and the total power consumption in wireless sensor network is depend upon the á power of the distance between the nodes and it is also depending upon the rate of transmission between the nodes deployed in the network [11] [12] [13].

The total power of the sensor network has been studied by many researchers and they have found out that it basically follow a power model, i.e. the PC of the WSN is directly proportional to [11] [12] [13] [14] [22], where á is depend upon the environment factor and the range of á is from two-to-six but for computational purpose generally the value is set to four. In much research paper the total power has been shown with proof that the network is following a Power law model in context to the total power consumption. From the above it is been a topic of discussion that whether the PLM will following for all the scale of the network model or node or it will deviating from PLM to ELM with an increase in the size of the network. In this paper, our prime goal is to show and to proof the total power consumption in a wireless sensor network with increasing [22].

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To validate the model and to elucidate the problem statement we have sectioned our paper into many parts. In the introduction, we have given a basic idea about the node architecture design to understand the wireless sensor network, and we have discussed some energy issue related to WSNs. After that, we have written little literature survey related to the total power consumption and node power consumption in the second section. In next section, we have mentioned the model's validation analysis and the idea of how F-test analysis is validating the model for any hypothesis.

In next section, we have formulated the model of different scale and of different size for analyzing the model validation. In last we have stated our result after simulating all networks model using curve fitting method, r^2 method, residual plot analysis and F-test null hypothesis analysis.

(A) Nodes Architecture Design

In next section, we have formulated the model of different scale and of different size for analyzing the model validation. In last we have stated our result after simulating all networks model using curve fitting method, r^2 method, residual plot analysis and F-test null hypothesis analysis.

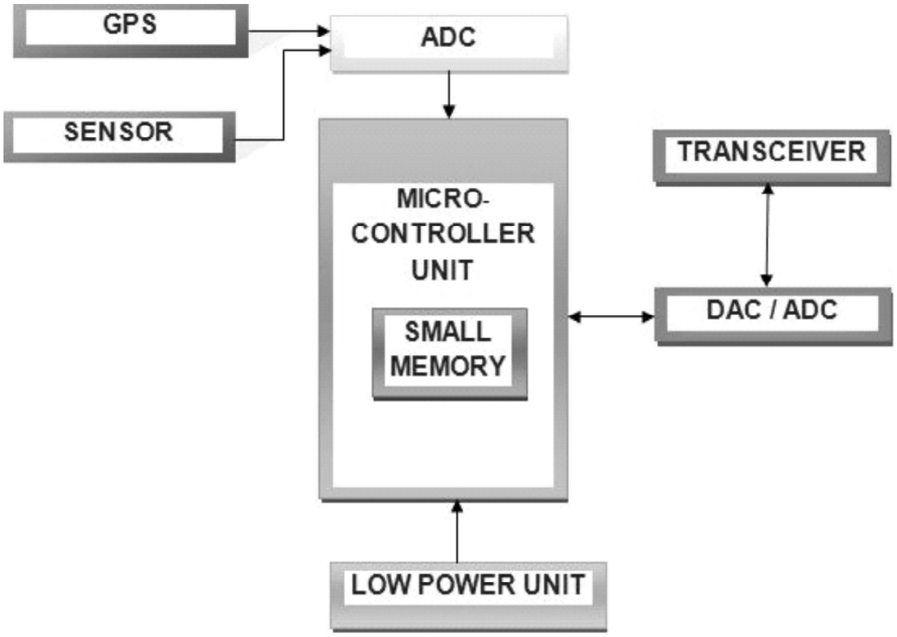

Figure 1: Architecture design of a wireless sensor network

Each sensor node of the WSNs is nothing but of integrated embedded system which consists of the low power unit, micro-controller unit, small memory, transmitter, receiver, sensor, ADC, DCA, global position system in fig. 1. In the real world, the sensor sense the environment phenomena in the analog form which is Analog to Digital converter converts digital from and the microcontroller process the digital platform and store it to transmit from the transmitter to the other node in analog from which is Digital to Analog converter converts on the same network [11] [21].

(B) Energy Consumption Issues in WSN

In the network lifetime, energy consumption is an important factor because sensor node is supplied from the battery which is not possible in to replace the battery from sensor field. The energy optimization can be done by energy awareness is design and operation of the network. A sensor node consists of four sub-systems [21].

(a) Computing Subsystem

A computing subsystem is consists of a microprocessor or micro-controller unit (MCU). It is responsible for the control the sensor and implementation of communication protocols. MUC propose is operating power management. This operating mode is engaged for the consumption of power of each sensor.

(b) Communication Subsystem

A communication sub-system is consists of a short range radio which is communicated to the other neighboring sensor node in the same network. It is the important factor for saving power that radio is putting in the idle mode when it is not transmitting or receiving.

(c) Sensing Subsystem

A sensing subsystem is nothing but it consists of a large number of a group of the sensor, which is communicated with all node of the same network. Energy consumption can be reducing by using the low-power component.

(d) Power Supply Subsystem

A power supply subsystem is consists of a battery which is supply power to the sensor node. It is not possible to replace the battery in sensor field when it is deployed. The lifetime of a battery can be increased by using low power components and power management operation mode [3][9].

The different type of protocols and algorithm can be used to minimize the all over energy consumption of the network lifetime of the each sensor network. The network lifetime of a sensor network can be increased using the operating system, the application layer and network protocols are designed to energy awareness [18]. These protocols and algorithm can be used for the specific hardware like the special feature of the microcontroller and transceiver to minimize the energy consumption. Different type of sensor node is design for different specification in a different type of sensor network.

II. LITERATURE SURVEY

Sumon Mor et al.[1], in their paper they have stated that the network performance and lifetime of the network can be increased by spreading the load on every sensor point of the network and they also have given the notion of balancing the node and the formation of holes in network creations by improper node distribution. Dipak Wajgi et al. [2] have proposed an algorithm based on cluster algorithm where they have used some backup nodes which backs the system when the cluster get out of its threshold, the result of which a high throughput they have attained from the network. Chor Ping Low et al. [3], this group has also used clustering algorithm to balance the node of wireless sensor network where they have assigned some gateway nodes that they have chosen from the network which act as cluster heads of respective chosen cluster to balance the node, they have named this as load balanced clustering problem. Mina Mahdavi et al. [4] have studied the coverage and connectivity problem associated with a wireless sensor network and also stated that for any sensor network to be successful two prime dimensions should be met, where one is sensing coverage and another is network connectivity. Yaping Deng et al. [5] have proposed a strategy to meet the load balancing in a wireless sensor network which is heterogeneous by Load Balancing Group Clustering (LBGC), where the protocol selects cluster head periodically and implementation is done dynamically in according to the condition of distributed energy over the network. M. A. Matin and M.M Islam [6], in this paper they have to elucidate the network theory and the working principle of a sensor node, apart from that they have sighted on the architecture of sensor node and different pros and cons of the network. Swati Sarma and Pradeep Mittal [7] have surveyed the different parameters associated with wireless sensor network like the architecture design, the area of coverage, power consumption, and communication capabilities. M. R. Mallick et al. [8], in this paper they have proposed complementary form of grouping to the network, such that the total power consumption will come with a minimal value. Maximization of network life time has been attained by Kemal Bicakci and team [9] in context to event – unobservable WSNs. In his paper they have analysed WSNs life time limit preserving event unobservability with variety of proxy assignment methodologies using linear programming framework. Fabian Castano et al. [10] have came up with an approach to maximise network life time ina wireless multi-role sensor based network up to five hundred number of sensor where connectivity is a constrain. In his paper they have tested instances which were generated randomly and maximum life time obtained by optimal cover identification and by operational time allocation, then which is solved through a column generation approach decomposition. K. Das et al. [11], in this paper they design a network model by taking 25 nodes based on the shortest path algorithm, in which they have succeed in minimizing the total network lifetime of their proposed model.

III. F-TEST COMPARISION BETWEEN TWO MODELS

We have two expected model that may fit the output data of average power consumption and we have intended to fit the data using nonlinear regression there we may have to choose one model over other to characterize the output. So to test that we need to plot the residuals of the PLM and ELM and from that, we will get r^2 value for both PLM and ELM. After getting r^2, we may conclude about the model fitting to our output data. For this type of situation, the F – test has to be conducted to know t which is statistically better. The result of F- the test will provide a converged answer which is free from the arbitrary interpretation value as coming out from r^2 and residual plot. The physical significance of any model cannot be decided by F-test. Here in this paper, we assume readers about the knowing of physical laws that governing the nonlinear increase of average power of nodes with increasing the size of the network [21].

In this paper we have simulated the average power consumption value for r2 value analysis, residual plot analysis, fitting the curve method analysis and at the end we got our definitive answer from the F- test.

(A) F-Statistic analysis

One of the two equations is taken to calculate F- statistic based on the number of parameters in the models. The F-test formula for having two parameters in both models to be validated can be given as

$$F = \frac{SS_1}{SS_2} \tag{1}$$

Where SS_1 and SS_2 are the residual sum of square for two models respectively.

Degree of freedom is the difference between the total numbers of Observation to the total number of parameters to be evaluated which is mathematically expressed as

$$Df = N - n \tag{2}$$

$P - value$ can be extracted by comparing F statistic with F-table, here in this paper we have use Matlab built in function ‘fcdf’ taking F and Df for both the models as input parameter i.e. $P = 1 - fdcf\,(F, Df1, Df2)$

If there are more than one parameters in models, the formula for F now can be written as,

$$F = \frac{(SS_1 - SS_2)/(df_1 - df_2)}{SS_2/df_2} \tag{3}$$

If P – value > $\propto$

Larger value of P, First model is statistically better

If P – value < 1 – $\propto$

Smaller value of P, First model is statistically better

The p-value can be estimated from the F-statistics and the degree of freedom. Use $df_1 - df_2$ and df_2 degree of freedom for P-value estimation. For this type of cases $P - value < \propto$ indicates model to be more complex (having more parameters) fits the data significantly better then the model having fewer parameter (simple model)[20][21].

IV. MATHEMATICAL POWER MODEL FOR WSN

(A) Power Model

Wireless sensor network has always been a power-aware system since the initial days because the battery associated with any sensor node having a fixed value Electro-Motive Force (EMF) which can drive the circuit for a certain period, which limits the lifetime of the network.

The Total power Consumption (TPC) of a wireless sensor network is a function of individual *PC* which is directly proportional to the power of 'α' to the distance 'd', mathematically TPC can be expressed as

$$TPC = \sum_{1}^{N} PC_i \tag{4}$$

Where *pc* is the individual node power consumption And $i = 1, 2 \ldots ..N$, N is the total number of nodes deployed in the network. And the can be expressed as [11] [12] [13] [14] [21]

$$PC = k \times r \times d^{\alpha} \tag{5}$$

Where k is constant whose value is taken as 1, the r = rate of sending traffic from one node to another, the d = distance between the two nodes, d = distance from the source node traffic to receiving node [11] [12] [13] [14][21]

$$\begin{aligned} \text{Unit of PC} &= (\mu\text{W/M bit} \times \text{m4}) \times (\text{Mbps}) \times (\text{m4}) \\ &= \mu\text{W/sec} \end{aligned}$$

The Average Power Consumption (APC) is the mean of PC

$$APC = TPC/N$$

By using equation (4) APC can be represented in terms of node power consumption [10],

$$APC = \frac{\sum_{1}^{N} PC_i}{N} \tag{6}$$

(B) Network Model for analysis

In Fig. 2 we have 25 nodes deployed having scale 5X5, where the origin is at node number 13 and the inter-distance among node' is having value unity. Our connected graph of network G (v, s) where, "v" is the vertices which nothing but the node point of the WSN and the side "s" of the graph G. Each nodes in the network having a finite range of transmission and each nodes should obey flow balance condition to transmission data where, Rate of Outgoing Traffics = Rate of Income Traffics + Rate of Origination Traffics [11] [12] [13] [6] [16] [22].

In this paper, we have designed different network models of different scale for checking the average power of node in any WSN with increase scale follow which model. For that, we have assumed that every node generates 1Mbps to traffic. The value of α is from 2 to 6 which is depending on the environmental factor. For shadow field α is having value two and for free space, the value of á is six. For our calculation purpose, we have taken the value of á as 4 and the value of K as 1. The trafficking in the model is based on the Dijkstra algorithm that follows the shortest path to route the traffic. Here we have allowed both orthogonal and diagonal for sending traffic. For the orthogonal path, the PC will be 1 by taking á as 2, 4 and 6. And for diagonal path PC will be 2, 4 and 8 by taking á as 2, 4 and 6 respectively by evaluating PC using equation (5).

For Scale 3, the total node is 9 (including the sink node, node number 5), using the equation (5) we can calculate the power consumption of each node shown in Fig. 2.

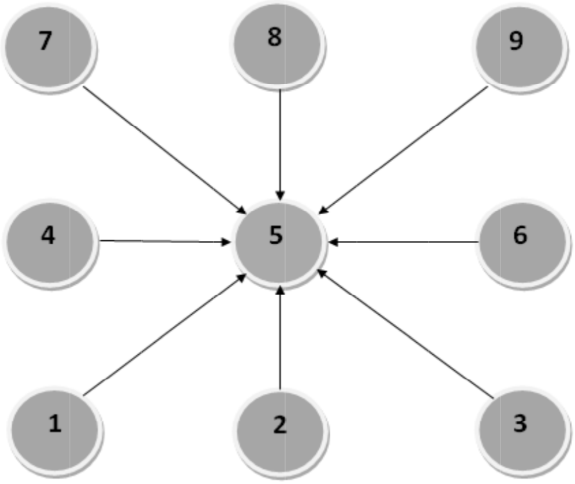

Figure 2: A 3 X 3 scale (3) showing traffice and node distribution with extra distance unity node 5 is the sink node

The 1 node PC = 4 µW/Sec, 2 node PC = 1 µW/Sec, 3 node PC = 4µW/Sec, 4 node PC = 1 µW/Sec, 5 node PC = 0 µW/Sec (center), 6 node PC = 1µW/Sec, 7 node PC = 4 µW/Sec, 8 node PC = 1µW/Sec, 9 node PC = 4 µW/Sec. The total power consumption (TPC) by applying equation number (4), the output value is 20µW/Sec.

For Scale 5, the total node is 25 (including the sink node, node number 13), using the equation (5) we can calculate the power consumption of each node shown in Fig. 3.

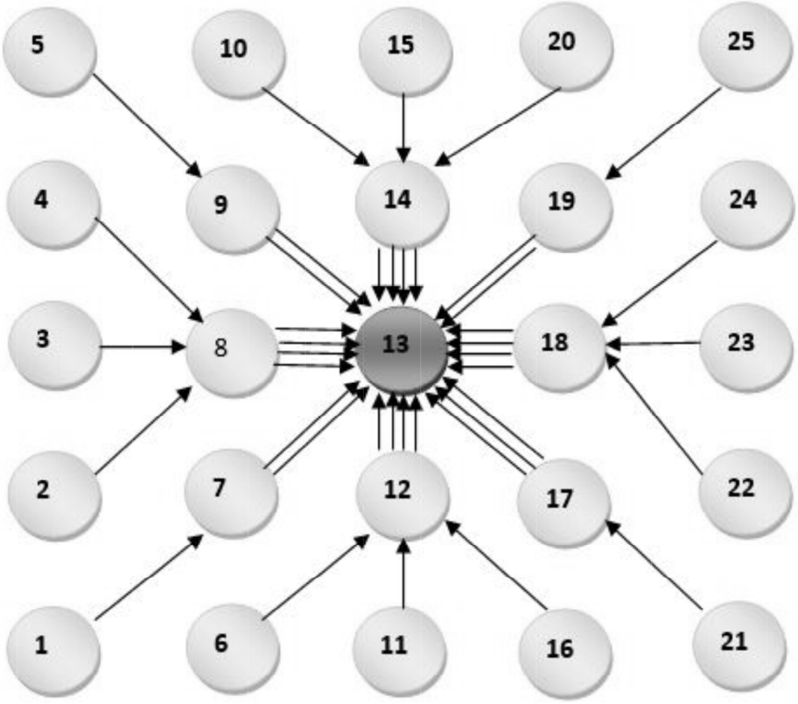

Figure 3: A 5 X 5 scale (5) showing traffic and node distribution with intra distance unity where node 13 is the sink node.

The 1 node PC = 4 µW/Sec, 2 node PC = 4 µW/Sec, 3 node PC = 1, 4 node PC = 4, 5 node PC = 4, 6 node PC = 4, 7 node PC = 8, 8 node PC = 4, 9 node PC = 8, 10 node PC = 4, 11 node PC = 1, 12 node PC = 4, 14 node PC = 4 , 15 node PC = 1, 16 node PC = 4,17 node PC = 8, 18 node PC = 4, 19 node PC = 8, 20 node PC = 4, 21 node PC = 4, 22 node PC = 4, 23 node PC = 1, 24 node PC = 4, 25 node = PC 4. The total power consumption is.

Likewise, we have calculated the PC, TPC and APC for up to scale 15 (15X15 nodes).from the table 1 it is clearly visible that the APC of each node is increasing with increase in the node number in the network, it is not remaining scalar with the increasing scale, giving a nonlinear value which we will try to validate with the model that the APC is fitting best.

Table I

The tables is having thr simulated date of tpc and apc for different scale and for different cluster size.

Sl. No	*Scale*	*Total Node*	*Total Power*	*Power Consumed Per Node()*
1	3	9	20	2.2
2	5	25	100	4
3	7	49	280	5.7
4	9	81	600	7.4
5	11	121	1100	9.0
6	13	169	1820	10.7
7	15	225	2800	12.4

V. SIMULATION FOR VALIDATING MODELS

We have simulated taking the data of the APC, tabulated in the table. I in both MATLAB and in C programming language to check the increasing APC is best fitting to which model. We have taken two general models to check our simulated output data fitting.

Power Law Model (PLM), this is one of our expected model that we want to determine whether the growth of average node power growth is best modeled or not. The general form of the model is as[21],

$$K = Ae^{\alpha\delta} \tag{7}$$

Exponential Law Model (ELM), another well-known model is ELM which can be written in the form,

$$K = B\delta^{b} \tag{8}$$

Where A, B, a, b are parameters to be estimated and is the scale, which determine the size and number of nodes present in a cluster

(A) Fitting the Curve Method

The different scale holding a different number of the nodes in the cluster. The cluster size is depending on the scale value. The higher the scale the higher will be the per node power consumption. And it almost following a non-linear curve which is shown in fig. 3.

From the fig. 4, we can conclude that the power model is appearing to fit the simulated data better. The blue line is the power law model which holds all the APC point where as the red dashed line is not holding the complete point of the data. But this is not much statistically significant, shown in fig. 4.

(B) Residual Plot Analysis Method

Fig. 5 is the residual plot for PLM which is coming within a range, i.e. the residuals for the model are having a smaller magnitude than that of the residual magnitude coming from the ELM as shown in the fig. 6.

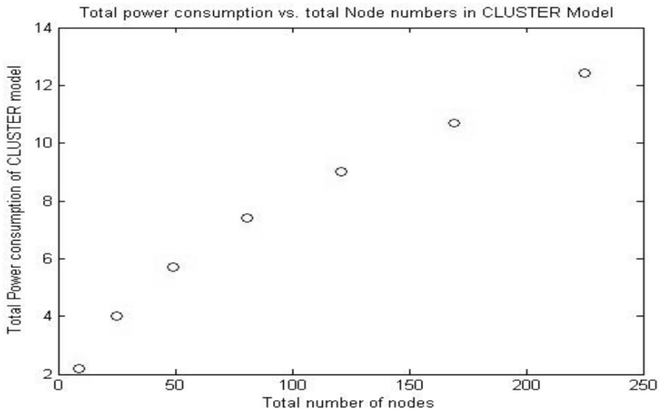

Figure 4: The APC of nodesin the tabulated cluster for different nodes number of different scale

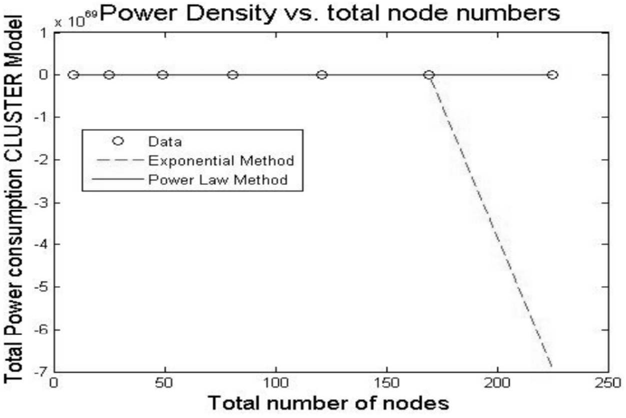

Figure 5: Power density with non-linear modes

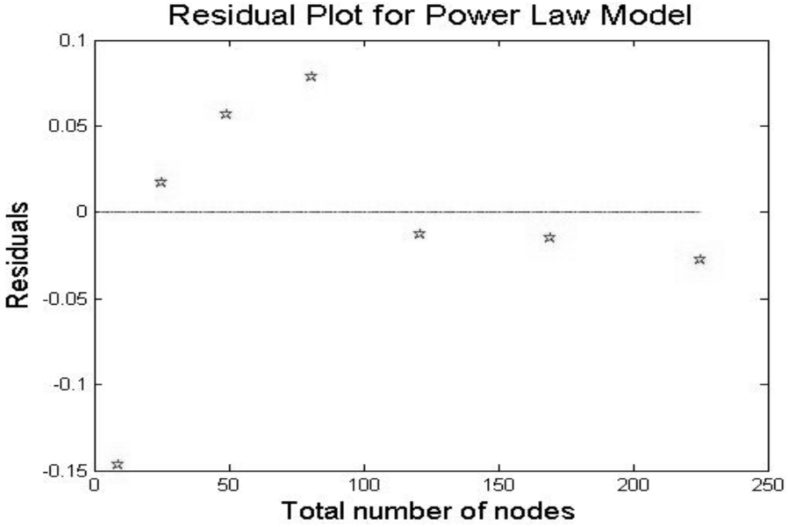

Figure 6: Residual plot for PLM

The residual value magnitude for ELM is too high, is coming of order 69, which is too high and are showing that the said model is not fitting to the simulated data. From these two residual plots, the PLM is showing of best fit to our cluster network. This is been calculated in Matlab by using nlinfit() function, non-linear regression function. And the output of which is been tabulated in Table II. With á equal to [-0.0000 0.9289] for PLM and β equal to [0.7520 0.5179] for ELM.

Table II
The residual value and jacobian value for the two model 1 is for PLM and 2 be for ELM

Residual value		*Jacobian value for both PLM & ELM*	
*R1=1**	*R2= 1.0e+069**	*J1= 1**	*J2= 1.0e+090**
-0.1464	0.0000	3.1202 5.1556	0.0000 0.0000
0.0172	0.0000	5.2963 12.8203	0.0000 0.0000
0.0565	0.0000	7.5045 21.9635	0.0000 0.0000
0.0786	0.0000	9.7358 32.1737	0.0000 0.0000
-0.0128	0.0000	11.9850 43.2239	0.0000 0.0000
-0.0154	0.0000	14.2490 54.9691	0.0000 0.0000
-0.0273	6.9235	16.5256 67.3081	5.9336 0.0000

The tabulated value has been plotted for both the model with Covariance matrix for PLM is 1.0e-003 * [0.4955 -0.1325; -0.1325 0.0360] and for ELM it is 1.0e+018 [0 -0; -0 2.4198]

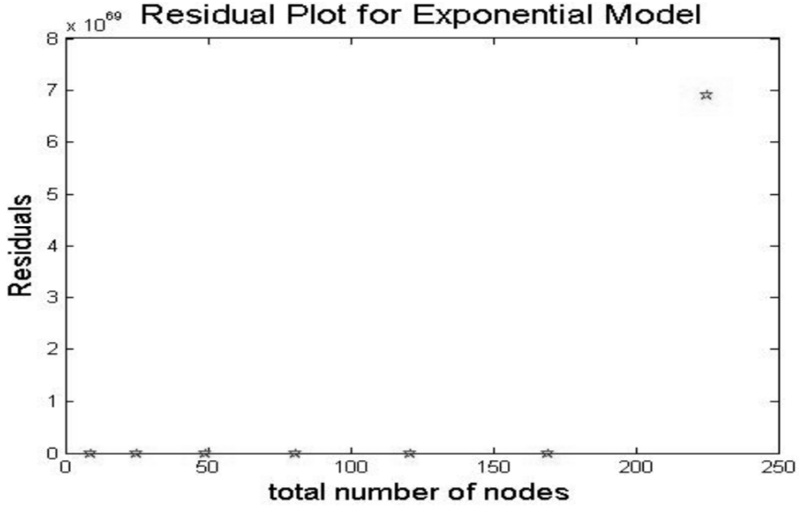

Figure 7: Residual plot for ELM

(C) r^2 Analysis Method

For the fitting the curves to simulated output data using nonlinear regression the value is been calculated from the equation 9.

$$r^2 = 1 - \left(\frac{SS_{residual}}{SS_{total}}\right) \tag{9}$$

Where,

$$SS_{total} = \sum_{1}^{N}(APC(i) - mean(APC))^2$$

And,

$$SS_{residual} = \sum_{1}^{N}(APC(i) - mean(APC))^2$$

by putting all the values in eq. 9. $SS_{residual}$ for both PLM and ELM are 0.0323 and 4.7935e+139 respectively, and the value of SS_{total} is 79.9171. and the r^2 value for PLM is calculated, is equal to 0.9996 and the r^2 value for ELM is equal to -5.9981e+137.

From the above result, it is clear that the PLM has been fitting best to out simulated data, as we know high value signifies the better fit.

(D) F –statistic analysis method

In our case, the both model equation has the same number of parameter, so the equation number (1) is acting over here for calculation of F-statistic

Here the data having 5 degrees of freedom, total data number –no of parameters (7-2=5). We have computed the value of F- statistic by using the Matlab function called fcdf.

The output value is F= 1.4860e+141 and Df=5 and by doing null hypothesis, we have found the value negligible small, tending to zero. Which implies that that the first model i.e. PLM is undoubtedly best fit for our data. That means the wireless network per node power consumption with increasing size and number of nodes in cluster/network can batter explain through and characterized with the Power Law Model.

VI. CONCLUSION

By simulated all the above methods and by doing all the mathematics we come to this conclusion that the APC of nodes in WSN along with TPC of cluster increases with increase in the size of the cluster and node numbers of the network and which is proof to be the best fit in Power Law Model (PLM). Among all the methods the F-statistic method explained that PLM is statistically better then ELM in context to our simulated network data.

In future different statistical analysis should be done in WSB to have better analysis and understanding of network, so that the network lifetime and efficiency could have been increased.

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