# Modeling the power consumption of Ethernet switch

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# MODELING THE POWER CONSUMPTION OF ETHERNET SWITCH

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**Abstract**

*At present, one of the main concerns of green network is to minimize the power consumption of network infrastructure. Surveys show that, the highest amount of power is consumed by the network devices during its runtime. However to control this power consumption it is important to know which factors has highest impact on this matter. This paper is focused on the measurement and modeling of the power consumption of an Ethernet switch during its runtime, considering various types of input parameters with all possible combinations. For the experiment, three input parameters are chosen. They are bandwidth, traffic and number of connections. The output to be measured is the power consumption of the Ethernet switch. Due to the uncertain power consuming pattern of the Ethernet switch a fully-comprehensive experimental evaluation would require an unfeasible and cumbersome experimental phase. Because of that, a design of experiment (DoE) method has been applied to obtain adequate information on the effects of each of the input parameters on the power consumption. The whole work consists of three parts. In the first part a test bed is planned with input parameters and the power consumption of the switch is measured. The second part is about generating a mathematical model with the help of design of experiment tools. This model can be used for measuring precise power consumption in different scenarios and also pinpoint the parameters with higher influence in power consumption. And in the last part, the mathematical model is evaluated by comparison with the experimental values.*

## INTRODUCTION

We are now living in an era of cutting edge technology. Everything is now in the reach of humans, which was beyond imagination, even few decades ago. However this awe-inspiring enhancement in the field of technology has a huge impact on the environment. In coming years, we have the greatest challenge in front of us, which is tackling climate change. Bianzino et al. (2012) mentioned that, power consumption has now become one of the top-most concerns of world industries and the reduction of power consumption has become a primal goal for any industries, because of environmental, economic and ethical reasons. This concern has a strong influence over the field of information and communication technology (ICT). Smart2020 report (2008) published by Global eSustainability Initiative, explains a statistics report on ICT sectors, this report showed that the ICT sector alone was responsible for 2% of global carbon emissions. ICT play a major role in pointing out many environmental problems such as environment pollution, waste management, power and supply management. However, Rondeau et al. (2015) explained that the use of ICT can also have some impact on the environment in terms of ICT footprints such as carbon emission and electronic waste. To minimize the ICT footprint in the environment, there is a need to implement new requirements in order to design a sustainable green network. The number of ICT devices is increasing in an exponential manner. Moreover, Widjaja et al. (2014) mentioned in their article that, currently data centers are growing faster than any other ICT technology, driven by the need for storage, computing and other information technology services. These advancements put lots of concern over the field of electronics designs, ICT, and networking more specifically.

According to Penttinen (2012), in recent years, persistent efforts have been made to reduce unnecessary power consumption, which is usually known as a 'greening' of the networking technologies and protocols. Power-related studies in networks are usually very specific and due to millions of innovations and improvements make it even harder. This work also only focuses on one of the most important devices of wired networks which are the Ethernet switch. Every device has lifelong ICT usage. This starts from manufacturing until dismantling. But here the concern was only during the usage period of the Ethernet switch. The goal is to observe the behavior of the switch with a different variation of a few selected variables and analyze these variations to propose a model which defines the relationship between a few main parameters related to the Ethernet switch and the power consumption. Two models are proposed for measuring the power: one is using full factorial method and another is using linear regression. The first model is based on full factorial which provides a model with fewer experiments and for the more elaborate experimental model, a linear regression model is used. For this work only those parameters are chosen which can be controlled on switch end. That means the plan is to choose only those parameters that network architecture may control during network design. The idea is to get an overall idea about how these parameters affect the power consumption.

## RELATED WORK

Several works have been done for both wired and wireless networks in order to find the power consumption pattern on the network device. However the design of an experiment in the field of networking is comparatively atypical.

### *Related Work in Power Consumption*

Gupta, Grover and Singh (2004) did a feasibility study on power management of Ethernet switches. They provided a fair guideline for running an experiment on switches. Christensen, Nordman and Brown (2004) explained how network devices can have impact on environment pollution. Mahadevan and Shah (2010) claimed that, for an Ethernet switch lifecycle, during the use phase the maximum amount of power is consumed. They did a full life cycle assessment and come to this conclusion. Foll (2008) did a similar kind of experiment to find out the power consumption within the Orange Telecom Company. One of the difficult things for this experiment was to decide the parameter. According to Mayo and Ranganathan (2005) and Rivoire and Shah (2007) from a device manufacturer's point of view one of the challenges is to make sure that networking devices such as switches and routers are power proportional, that means they will consume power proportional to their load and usage like computers and laptops.

### *Related Work Based on DoE*

Zhan and Goulart (2009) used the design of experiment method for analyzing the broadband wireless link for rural areas. On the other hand Totaro (2005) and Gendy and Bose (2003) used the full factorial method for analyzing the mobile ad-hoc network and per hop QoS respectively. Gendy and Bose (2003) examined the per hop quality of service for example throughput, delay, jitter and loss rate by using different input traffic scenario and per hop behavior on routers. Per hop behavior means policy and protocol that have been assigned to a packet during each hop. They used analysis of variance to identify the input which is most significant. These experiments provided a fair idea about how to prepare the test-bed. Mahadevan and Sharma (2009) benchmarked the switch behavior for different parameters. They explained that the switch consumes power proportionately to the load and usage. It differentiated between parameters which have impacts and those which do not have impacts. It helped our work to select the parameter for the experiment.

## METHODOLOGY

This section describes the DOE methods that have been used to model the power consumption pattern of the Ethernet switch. Here statistical analysis methods have been applied to identify the most influential parameters affecting the power consumption of the Ethernet switch within the range and domain of these experiments. Two methods have been used to model the equation. One is full factorial method and another is linear regression analysis.

### *Full Factorial*

A Full Factorial DOE provides responsive information about factor main effects and factor interactions. It also provides the process model's coefficients for all the factors and interaction. A full factorial DOE is a planned set of tests on the response variable or variables with one or more inputs factors, with all possible combinations of levels. If we have n factors, with the i-th factor having $k_i$ levels, and if each experiment is repeated for r times, then the total number of experiments: $\prod_{i=1}^{n} k_i * r$.The main objective of full factorial method is learning the most from as few numbers of experiments as possible. It identifies the factors which affect mean and variation which usually helps to identify if the parameter is necessary for the model or not. And then lastly it produces prediction equations which can be used for validation.

### *Linear Regression Analysis*

Regression analysis is the method of fitting straight lines to set of data. As discussed by Robert (2014) in a linear regression model, the variable of interest in this case is power consumption which is predicted from k other variables using a linear equation. If Y denotes the dependent variable or the response, and $X_1, \dots, X_k$, are the independent variables, then linear regression analysis would be:

$$Y = c + a X_1 + b X_2 + \dots + z X_k$$

However, here linear regression analysis with two way interactions has been used. It considers all the possible interactions between all the parameters. A stepwise regression method has been deployed which is used in the probing stages of model building to find out a useful subset of factors. The process step-by-step adds the most significant variable or the combination of the variables and removes the least significant variable or the combination of the variables.

## RESEARCH METHOD

### *Parameter and Response Selection*

Parameter selection is one of the important issues before starting anything. This work entirely focuses on Ethernet switch behavior and the goal was to include those parameters that can have a major effect. Rondeau and Lepage (2010) did similar experiments with Ethernet switches and mention few parameters. Mahadevan and Sharma (2009) explained that there is no impact of packet size on the power consumption. Because of that packet size is not considered as a parameter. As discussed earlier for conducting the experiment we have initially considered three parameters, bandwidth or link capacity, number of PCs connected to the switch and traffic on the switch. For the full factorial model only two factors, bandwidth and number of connected PCs have been considered. Traffic load has not been considered because initial experiments show that traffic has rather less impact on power consumption compared to other two variables. For a fixed value of bandwidth and number of PCs connected, regardless the load of the traffic, power consumption does not vary much. Therefore, traffic is neglected for reducing the complexity of the model.

On the other hand for linear regression analysis all three variables are used. IEEE introduced IEEE802.3az energy efficiency Ethernet protocol. Christensen et al., (2010) discussed the management parameters for power consumption. Therefore traffic is introduced considering future aspects which are controlling the power consumption of the switch and also checking the effect of idle mode. The target is to review the Ethernet switch as a black box and observe its behavior in different scenarios. Because of that we only consider those parameters which are directly in relation with the Ethernet switch. Now for bandwidth three different values have been used 10Mbps, 100Mbps and 1000Mbps. As an Ethernet switch has 24 link ports, the number of active connections are varied from 2,4,6,8,10,12,14,16,18,20,22,and 24 connections to cover the whole range. The goal of this work is to provide a power consumption model of an Ethernet switch so it can be used to recognize the pattern of consuming power and control the power consumption later on.

For the experiment only one response is measured which is power consumption in Watts. Power consumption is measured for different combinations of bandwidth and number of PC and traffic.

***Experiment Detail***

The experiment was done using the architecture of figure.1. A Cisco Ethernet Switch 2960x is used for the experiment. Architecture was designed in a way as every two PCs are acted as a pair. One PC of the pair is sending data and another one is receiving data. In this experiment, a Powerspy2 sensor is used to measure the power consumption of the monitored switch. The data of power consumption is sent in real-time via Bluetooth (Powerspy2 user manual). The necessary information such as minimum, maximum, standard deviation, and average value of power consumption can be obtained by Powerspy2. It provides a precision of three digits after decimal. All the links used the same configuration for link capacity (Bandwidth). That means for every experiment there was only one kind of link capacity. JPerf is used for the traffic generator. Different variations of traffic are generated by it to observe the Ethernet switch behavior. Variation of traffic is done by changing maximum segment size and window size. Maximum segment size varies between 256,512 and 1518 bytes. Window size varies from 1 to 123 kilobytes. Each experiment is run for 10 minutes in order to observe a stable and steady value.

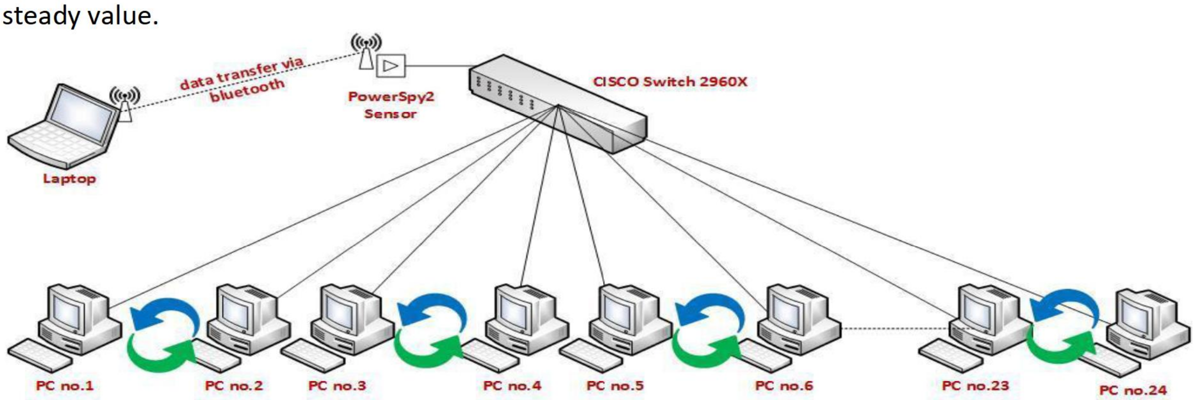


**Figure 80: Network Architecture**

The 0 connection-scenario is omitted because it is practically impossible for a network to have no connections. At least, the network should consist of at least 2 PCs to communicate with each other. Therefore the scenario starts with 2 PCs and then increases up to 24 PCs to occupy all the Ethernet switch ports. The experiment is conducted considering the most common TCP protocol. TCP is the basic communication protocol for the both internet and intranet.

## RESULT AND ANALYSIS

In this section, at first initial insight from the raw data has been discussed. The data pattern is discussed without any model being applied. Then a discussion of the results of our statistical design of experiment, along with an analysis of these results has been made. Visual illustration regarding the impact of the factors on the power consumption is provided.

### *Initial result*

Figure.2 shows the power consumption pattern of the Ethernet switch. To show the combined effect of traffic, bandwidth and number of connected PCs, link load has been used in the x-axis. Link load = Total traffic/ (Number of PC's connected * Bandwidth). For a fixed number of PC and bandwidth, link load is increased by increasing traffic. As we can see without using any analyzing tool, 1000 Mbps bandwidth has a larger impact compared to the other two bandwidths. One more thing is clearly visible is that changing the traffic has clearly very little impact on the power consumption.

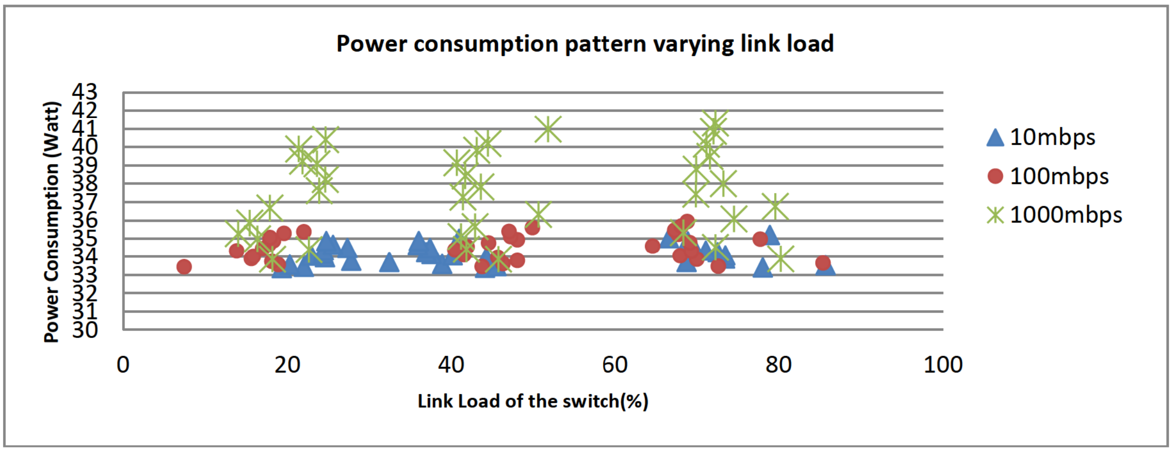


**Figure 81: Power consumption pattern varying link load**

### *Analysis by Modeling*

In this section results analysis is described. For two different methods data is analyzed and model for power consumption is proposed. At first the full factorial model is presented with an explanation of f-value and p-value. Minitab has been used to do the modeling. F-value is a ratio of mean squares. The numerator is the mean square for the parameter. The denominator is chosen in a way that the expected value of the numerator mean square differs from the expected value of the denominator mean square. But this difference is caused only by the effect of the variable. A high f-value indicates a significant effect of that variable on that model. The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low p-value ($< 0.05$) indicates that it can reject the null hypothesis. In other words, a variable that has a low p-value is likely to be an important addition to the model because changes in the variable's value are related to changes in the response variable. Conversely, a larger p-value suggests that that variable is insignificant for the model and changes in the variable values are not related with changes in the response. For all the equation confidence interval was 95%.

**Full Factorial**

A Full factorial method generates a model for power consumption of the Ethernet switch based on the number of PCs connected and bandwidth or link capacity. Figure 3(a) shows the main factors effect on the power consumption. As it can be seen for bandwidth (link capacity) there is a really high impact when the bandwidth is 1000Mbps, however the change of power consumption between 10 Mbps to 100Mbps is not so much. On the other hand, the number of PCs shows a rather linear relation with the power consumption. As the number of connected PCs increases the power consumption is also increases. We include a two-way interaction while modeling. It means all the variables combined effect is also considered. In this case a two-way interaction would be bandwidth*PC. This model includes bandwidth*PC in order to get a more precise result.

Figure 3(b) depicts the two-way interaction of PC and bandwidth. Table.1. shows the f-value and p-value of the variables and shows that bandwidth has highest significance. P-value shows that all variables are significant for calculating power consumption. The model has an R-sq adjusted value of 98.53%. It means 98.53% of the time the variation in response variable is caused by these factors.

| Source | F-Value | P-Value |
|---|---|---|
| **Bandwidth (Mbps)** | 1875.86 | 0.000 |
| **PC** | 215.39 | 0.000 |
| **Bandwidth (Mbps)*PC** | 50.15 | 0.000 |

**Table 47: F-value and P-value of factors (Full factorial method)**

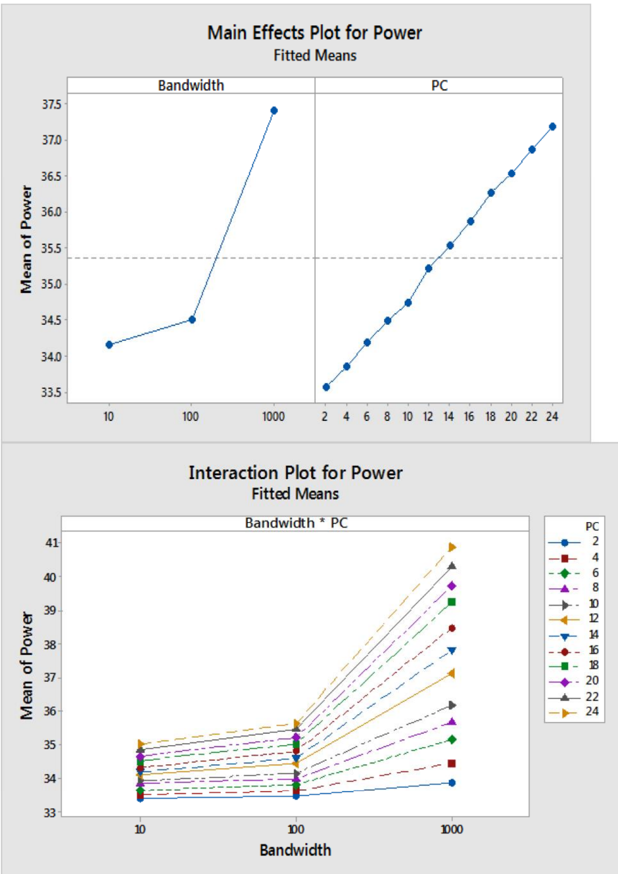


**Figure 3: (a) Main effects plot, (b) Interaction plot**

The model provides a rather long equation which considers all the possible two-way interaction. Considering {x1,x2,x3} are the different link capacities as {10Mbps, 100Mbps and 1000Mbps} and {y1,y2,y3…,y12} are the pairs of connected pc as {2,4,6,…,12} then the equation looks like this:

**Power (watt)** = 35.3642 - 1.2012 x1- 0.8470 x2+ 2.0482 x3- 1.7822 y1 - 1.5109 y2 - 1.1661 y3 - 0.8681 y4 - 0.6156 y5- 0.1439 y6 + 0.1726 y7 + 0.5044 y8 + 0.9022 y9+ 1.1731 y10 + 1.5119 y11+ 1.8226 y12+ 1.017 (x1*y1) + 0.839 (x1*y2)+ 0.638 (x1*y3) + 0.539 (x1*y4) + 0.371 (x1*y5)+ 0.085 (x1*y6) - 0.145 (x1*y7) - 0.347 (x1*y8)- 0.538 (x1*y9) - 0.674 (x1*y10) - 0.821 (x1*y11)- 0.964 (x1*y12) + 0.731 (x2*y1) + 0.615 (x2*y2)+ 0.459 (x2*y3) + 0.335 (x2*y4)+ 0.247 (x2*y5) + 0.061 (x2*y6) - 0.092 (x2*y7) - 0.218 (x2*y8)- 0.394 (x2*y9) - 0.477 (x2*y10) - 0.569 (x2*y11) - 0.698 (x2*y12) - 1.748 (x3*y1) - 1.453 (x3*y2) - 1.098 (x3*y3) - 0.874 (x3*y4)- 0.619 (x3*y5)- 0.146 (x3*y6) + 0.237 (x3*y7) + 0.566 (x3*y8)+ 0.931 (x3*y9) + 1.151 (x3*y10) + 1.390 (x3*y11) + 1.662 (x3*y12)

However, a general formula can be deployed from this formula. As there are only two variables, in general there will be two terms for these two variables and one for interaction of these two variables, there will be also a constant term. Therefore for a simple scenario only four terms from the equation will be used.

$$\text{Power (watt)} = 35.3642 + \alpha X + \beta Y + \gamma(X*Y)$$

Where X is set of bandwidth, Y is set of number of active PCs connected and α, β, γ are the co-efficient of the variables. For a given value of bandwidth and number of active PCs the correspondence value of x and y will be one. The rest of the unused value of x and y will be zero. Allocation of different bandwidth is possible for different ports, then the number of variable will also be increased.

**Linear Regression Analysis**

After doing full factorial, multiple linear regressions analysis is done. As discussed earlier, here traffic is also used as a variable. However, value of traffic depends on bandwidth and number of connected PC. Figure 4 shows the main effects of the variable on the power consumption, which indicates that all three variables have a linear relation. In a linear regression model the whole range of raw value of traffic is considered. This range starts with 3 Mbps where the number of connected PCs is 2 and bandwidth is 10 Mbps and ends with around 17000 Mbps where the number of connected PCs is 24 and bandwidth is 1000 Mbps. Since the range of traffic depends on the number of PCs connected, bandwidth, average segment size and window size. Therefore it is not likely to get the theoretical maximum traffic rate (24000 Mbps). In the graph the effect of traffic is dependent on the PC and bandwidth. Therefore both PC and bandwidth has less individual impact than previous case.
Moreover because of the categorical nature of the bandwidth it shows less impact when it is considered alone. As multiple regressions analysis is used, it also considers the two-way interaction. In the equation only significant variables are shown. Table.2 shows the F-value and P-value which shows that the PC has rather a high F-value compared to bandwidth and traffic. It is due to the nature of the value of the variable.

| Source | F-Value | P-Value |
|---|---|---|
| **Regression** | 4534.57 | 0.000 |
| **Traffic (Mbps)** | 50.57 | 0.000 |
| **Bandwidth (MBPS)** | 5.19 | 0.025 |
| **PC** | 728.07 | 0.000 |
| **Bandwidth (MBPS)*PC** | 1455.69 | 0.000 |

**Table 48: F-value and P-value of factors (linear regression analysis)**

The model has a R-sq adjusted value of 99.61% which indicates that whenever there is a variation in the value of y, 99.61% of it is due to the model (or due to change in x) and only 0.39% is due to error or some unexplained factor.

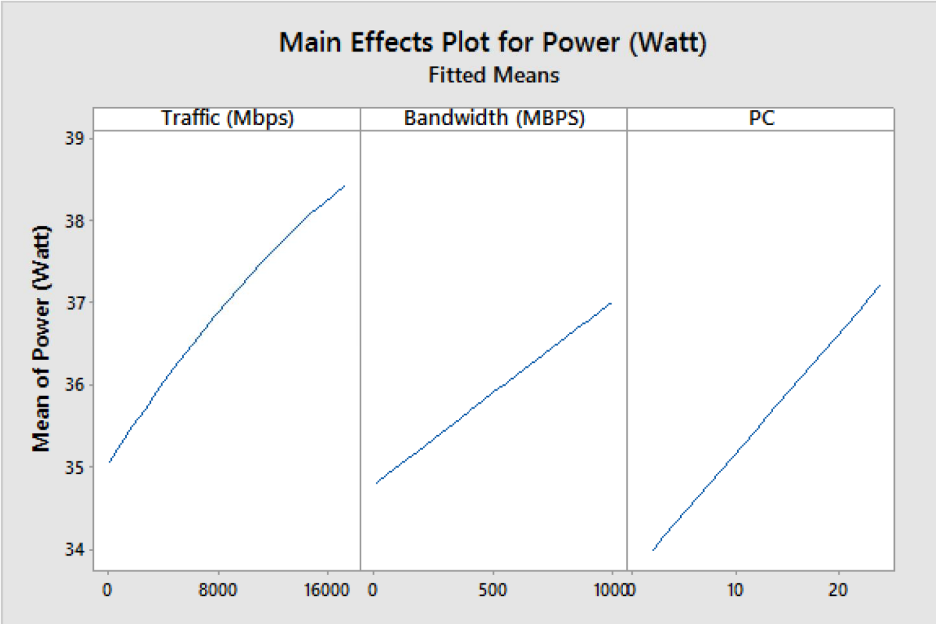


**Figure 4: Main effect plot for regression analysis**

Linear Regression Equation:
**Power (Watt)** = 33.2585 + 0.000389 Traffic (Mbps) - 0.001006 Bandwidth (Mbps) + 0.06646 PC + 0.000213 Bandwidth (Mbps)*PC

From the equation it is noticeable that only the interaction of bandwidth and PC is considered and other interactions are ignored because the effects of other two-way interactions are negligible.

***Validation of Models***

To check the validity of these two different models, predicted values from these models are obtained and then compared with real measured values. A random scenario is chosen in order to validate the model. Figure.5 shows the result of one scenario where bandwidth is fixed with 100 Mbps and a random traffic value is chosen. For a different number of PCs, power consumption value is plotted. As it can be seen, the measured value and the predicted value from the model are close to each other. In this case the mean percentage error of full factorial model and regression analysis model is 0.1% and 0.2% respectively. Mean percentage error is used to find how much the forecasted value differed from the actual value. In the figure.6 a different scenario has been used. Here, the number of connected PC was fixed; for this scenario 10 pc is used. For different bandwidth all the power consumption data is plotted with different traffic. As we can see, the full factorial model provides a straight line for each different bandwidth because traffic is not a parameter for the full factorial. However one important thing to notice is that traffic does not put much impact on the result. Power consumption difference is always less than 1 Watt for maximum and minimum value of traffic in any given scenario. On the other hand regression analysis shows three different plot points for three different values of traffic. In this scenario, the mean percentage error of full factorial model and regression analysis model is 0.5% and 0.34% respectively. In both cases the mean percentage error is very low. This indicates that both models are providing results which are close to the actual value.

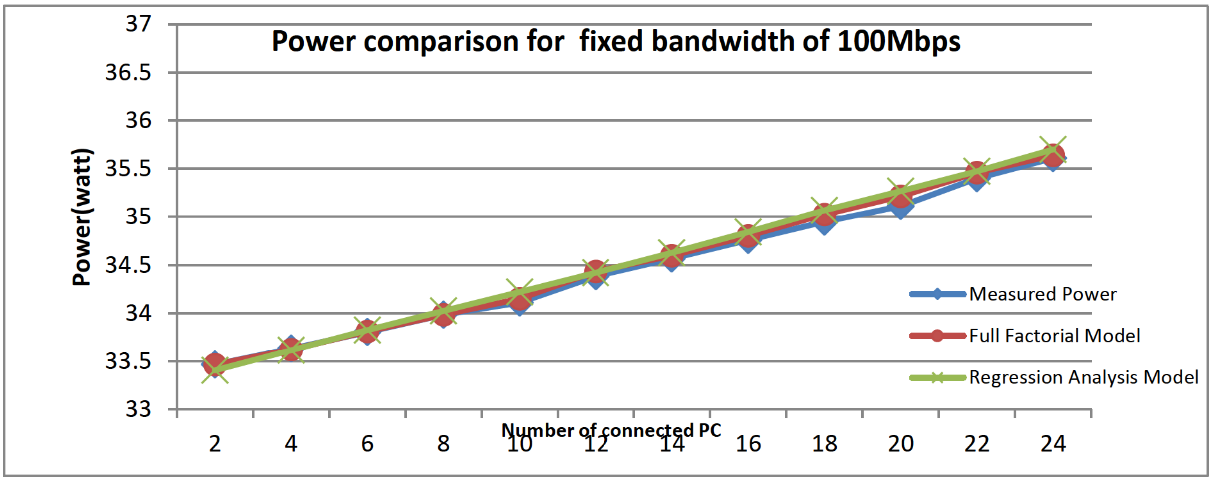


**Figure 5: Power consumption comparison for fixed bandwidth of 100Mbps**

By comparing the two equations provided by two different models, it can be observed that, for full factorial the model is rather complex where each combination has a different co-efficient even though all of them are not used simultaneously. However, in regression analysis model, the equation is rather simple. Furthermore, a full factorial model provides a rather mean value of the power consumption for a given scenario. However, a regression analysis provides different values for different traffic.

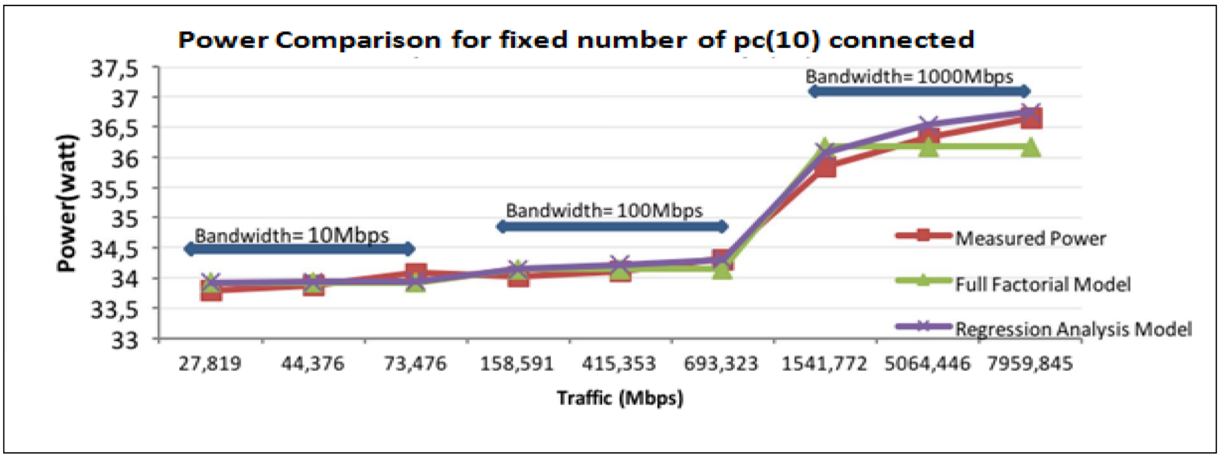


**Figure 6: Power consumption comparison with change of traffic for fixed number of connected PC**

## DISCUSSION

With the advancement of computer networks communication rates have been increased abruptly. This also results in more power consumption. Zouaoui, Labit and Albea (2014) explained some new methods like dynamic adaptation and smart sleeping in order to reduce the power consumption. If the Ethernet switch behavior is explainable then their control will be more efficient. To keep this in mind, this paper's goal was to provide a model that can define power consumption patterns. Here a model for power consumption of the Ethernet switch has been provided based on different parameters.

The Ethernet switch is only a small part of the whole network. The term green networking means greening of the whole network architecture. It focuses on environment as well as methods needed to be cost-efficient. To put an effective impact on the environment through ICT, power consumption of the whole global network architecture needs to be known. This work is another effort towards this target. According to Bianzino et al. (2012) in a year, the maximum amount of power consumed by an Ethernet switch compared to any other networking device. Nevertheless, there are several devices like WIFI hot-spot, and router that needs to be considered in order to get the global architecture.

Moreover, experiments are done in only one Ethernet switch; results may vary for different switches. These things need to be considered for the future. There are also methods like Power efficient Ethernet and Hibernation to be considered. Rondeau et al. (2015) mentioned the correlation between the power consumption and carbon emission on the book. Therefore with the help of these modes another model can be created to calculate the carbon footprint produced by the Ethernet switch. Before controlling power consumption, the first step is to find out the parameters that have impact. The idea is to find out the parameter which has the highest impact and generate a model so that it can be used in future for controlling purpose. With proper development of a global model for overall network architecture of the power consumption it is therefore possible to reduce or at least control the global carbon footprint which is caused by networking devices.

**CONCLUSION**

This paper presents a novel way to study the simultaneous effects of multiple variables on the power consumption of the Ethernet switch using the Design of Experiment (DoE) method. Statistical analysis is conducted only with the test data and data is taken based on one switch. However the work that has been presented is not limited to the measurement of the Ethernet switch. Similar experiments can be done for all the other network devices in order to get a global picture. Two kinds of models are presented here and a comparison of both models is also discussed. Results help to understand the effect of bandwidth or link capacity and number of connected PCs on the Ethernet switch and traffic on the switch over power consumption. Findings from this experiment can be used to find out the power consumption of the Ethernet switch and eventually help to find out a way to reduce the power consumption.

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