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Power Profiling of Network Switches

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Abstract

Context In the present world, there is an increase in the usage of the telecommunication networking services, as there is a need of efficient networking services in various fields which can be obtained by using the efficient networking components. For that purpose we have to know about the components parameters. One of the most important parameter is the energy usage of networking components. Therefore, there is a need in power profiling of the network switches.

Objectives The objective of this research is to profile the power usage of different network components(Switches) for various load scenarios. Power measurements are done by using the open energy monitoring tool called emonpi.

Methods The research method has been carried out by using an experimental test bed. In this research, we are going to conduct the experiments with different configurations to obtain different load conditions for sources and destinations which will be passed through DUT(Device Under Test). For that DUT's we will measure power usage by monitoring tool called emonpi. Then the experiments are conducted for different load scenarios for different switches and results are discussed.

Conclusion From the results obtained, the Power profiles of different DUT's are tabulated and analysed. These were done under different ports and load scenarios for Cisco2950, Cisco3560 and Netgear GS-724T. From the results and analysis it can be stated that the power usage of Cisco 2950 is having the maximum power usage in all the considered scenarios with respect to packet rate and also number of active ports. The Netgear-GS724T is having the minimum power usage from the three switches as it having the green switch characteristics in all scenarios. And the Cisco 3560 is in between the above two switches as it is having energy efficient management from Cisco. From this we have proposed a simple model for energy/power measurement.

Keywords: Network components, Power profiling, Power usage, Switches.

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List of Abbreviations

ACPI	Advanced Configuration and Power Interface
DUT	Device Under Test
I/O	Input/Output
IT	Information Technology
LAN	Local Area Network
NIC	Network Interface Card
RAM	Random-Access Memory
SDK	Software Development Kit
TWh	TerraWatt Hour(s)
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
WLAN	Wireless Local Area Network

Chapter 1

Introduction

In present world, Telecommunication network services are a part of everyone's life. These services induces an increasing demand for high access rates in the network. This in turn increase the internet traffic rapidly, where the network operators needs to increase their network capacity. To increase network capacity there is need to use more number of network components(like switches). These network components will continuously pass the traffic between the nodes in the Telecommunication network. By using these network components the main concern for networking industry is energy/power management of the networking equipment.

As there is growth in various technologies, it mainly brought growth in need and use of computation resources. The amount of energy consumed during the use of such resources is high. Large Data centers are becoming very common nowadays, with the growth in the IT needs. Multinational companies like Google, Yahoo, Amazon or Microsoft have deployed large data centers with hundreds and thousands of servers integrated with large network components. Those data centers are consuming a huge amount of energy each day so as to carry out the needs of its customers[2] and the increase in the information processing requirement of different sectors. Example includes digital services and functions that are needed by different industries varying from constructions to banking. Such a drastic increase in the computation resource has brought a lot of increase in the growth in the IT infrastructure. Data center are the main strength of the IT industries, which has brought in many applications in to life. So it is very important for improving energy usage in such growing sector [3].

The total energy consumption of the data centers in 2012 was approximately about 270TWh, which is around 2% of the global energy consumption. It has an annual growth of 4.3% in power consumption, which has gained attention of many researches. As per report from New York times on 2012 the total amount of energy consumed by the data centers is around 29.9 Giga watts per hour. That is almost equivalent to power generated by 30 nuclear power plants.

In search of Eco-friendlier solution for a more sustainable information technology IT, a technique called energy profiling is adopted by monitoring the power consumption characteristics of computer resources based on its internal resources. Distributed computers share their jobs in the condition of over load and load balancing and it can be done in both static and dynamic way[4]. Power profiling in this research is performed on system with parallelism, besides multi-core processing there are other way of achieving parallelism by deploying different cores in re configurable-logic [5]. Power profiling is done for various integral elements of a computer like CPU, I/O disk and the NIC (network interface card). Assuming that their power consumption is dependent on workload and the work load is expressed carefully for performing an empirical validation. So profiling is done by inserting various work load on each of the integral part of a heterogeneous computer and then, collecting the required power data with the help of the power monitoring tool and a statistical analysis is being done.

As there been a tremendous growth in the usage of the network services, the network traffic passing through the telecommunication network is more. For this, the network components should handle this network traffic flow efficiently. To provide efficiency in handling the network flow we must consider the energy parameter of the network component into consideration. The energy usage of the network component will play a crucial role for providing the efficient services. For that purpose we have to focus on energy efficiency of the network components as in [6].

The network services provided by the Telecommunication network will impact the growth of energy consumption. This growth is becoming an environmental problem and at the same time, the price of energy also increasing dramatically. Because of the economic and environmental reasons[7], the energy consumption has become a key issue in today's Telecommunication networks especially in data centers. In data center networking, different types of network components can be used to manage the network environment[8] [3]. Each network component present in the communication network will consume energy according to the traffic load on that component. The main network component like switches which are used for switching the packets are focused in this research. Due to an increase in the packets flow, energy consumed by the switch is more and high-speed switches will also consume more energy. So that there is a need for optimization of energy usage of different network components. In order to acquire optimization in the energy usage for providing greening of the networks, we must use energy efficient network components. In order to know power usage of the network components, power profiles of that components with respect to work loads without effecting the quality of service of the end users[9].

The energy usage of a component can be measured as the work done by a system. It can be calculated as work done for a particular time which can be stated as Watt-hour. If a high amount of work has done in a system then the time for that service is more so that the energy used by the components is increased. The service time in that system is based on the speed of the service doing by that particular components. So, that energy usage will be varied according to service time.

The energy consumed by each network component can depend mainly on the traffic load[7] and also on the different types of components used in their manufacture in the communication network. As the network traffic load increases, there is an increase in the energy consumed by a particular component. This consumption also depends on the network line cards and also the configuration of the switches. The network line cards have a more impact in the power usage of the devices used.

There are some monitoring tools that measures the power/energy usage of the network components. The monitoring tools that are used to know the energy usage of components can be software/hardware tools. The software tools will provide the energy usage in a simulation environment but the hardware tools will provides an accurate power usage of devices. By these tools we can present the power profiles of the devices in particular time of intervals. Then we can take the measures to reduce the energy usage of those devices. Reducing the energy consumption may increase the network effectiveness and thus reduce the economic costs. Power monitoring can be done on two levels they are software-level and hardware level. Power monitoring can be done using power monitoring tools to assume the amount of power consumed. The software-level power monitoring tool is used to estimate the amount of energy consumed by the software in a hardware environment. Approaches like BIT WATTS is a power meter which was used to collect process usage and power consumption without any involvement of any hardware[10]. There are other hardware level power monitoring tools which can be used to estimate the amount of energy consumed by system hardware. Tools like monsoon which is a mobile device that is used to monitor the power consumed[10] and others from Schneider electric has brought some power utility meters which are used to monitor the power consumption[8]. So in this research for measuring the energy consumption of the heterogeneous system and switches, an open energy monitoring tool called Emon pi is used. By using this tool we can know energy/power profile[11] of the particular resource which would enable the energy efficient service operations. The efficient operations that are achieved by reducing the energy usage of the resource will lead to the greening of the networks.

This thesis work is to develop the power profiles of the network components like switches and for computer systems. In our consideration this study conducts the in-depth experimental study of the power consumption profiles of network switches and to evaluate its dependence on various traffic characteristics. Our specific contribution for the science are:

1. We use traffic generator and an open source energy monitor tool to measure the power consumption of the network switches from different vendors and characterize their power profile for varying traffic characteristics.

2. We develop a simple model that yields the analytical estimates switches power consumption as a function of traffic characteristics. The model is derived from the practical insights that we will provide in our study.

1.1 Motivation

The main reason for performing this study is because the energy requirements of computing and networking equipment are predicted to grow substantially in the coming years. And there is need to address energy efficiency issues in the networks which is believed to account wire line energy costs. And in providing the efficient services in the communication network. There is a requirement to profile the power usage of the Network switches and end computer systems to provide the energy/power management of the devices and systems. So in this study we have profiled different switches from many vendors and end computer systems under different scenarios. And also we have proposed a theoretical power model to use for further researches.

1.2 Aim and Objectives

The aim of this thesis is to develop the Power profiles of Network switches. The main concern for performing this study is energy/power usage of the networking equipment is the main concern in the recent years for providing services.

The objectives required to reach the aim of this thesis are:

- Study of different network devices and their configurations provided by different vendors.

- To increase the load and number of active ports on the devices and know the power usage.

- To profile the power usage of the switches.

1.3 Scope of Thesis

The main focus of this research is to profile the power consumption of network components like switches in different scenarios. This power consumption estimation can be done by using a open energy monitoring tool called emon-pi. To evaluate the power consumption of switches network traffic load is generated between the sources and destinations by varying different packet rate for particular interval time which has lesser variation between the power values. And also the power consumption by varying the active number of ports. This research does not focus on how the line card speed and also on the port utilization with respect to the power consumption. This research only provides the power foot prints of the systems and doesn't gives the information on how to reduce the power consumption. Profiling on the systems are done based on the power consumed when there is workload on only two elements of the computer that is the CPU, RAM and NIC.

An experiment test bed was framed to perform the experiments. These experiments are conducted to profile the power usage of different components by using the monitoring tool called emon-pi.

1.4 Research Questions

The following research questions are considered:

- What is the impact of the load on the communication network components(Switches) in their usage of energy?
- What is the impact of interfaces (ports) of the components (switches) on the energy usage of the devices?

1.5 Expected Outcomes

- Profiling of the Power values for the different network devices and computer systems considered in our research.
- Average power consumption of the considered devices and computer systems and also statistical analysis that is calculating the Min,Max and Standard deviations.

1.6 Outline of Thesis

The rest of the paper is structured as follows. Chapter 2 deals with the related works for the energy consumption of different network devices and computer systems and how they have presented the energy efficient profiles. Chapter 3 deals with the Methodology that has been implemented in the experimentation. Chapter 4 deals with the results and analysis of the experimentation for the requirements to provide the work defined. Finally, Chapter 5 deals with the conclusion and future work.

1.7 Split of work

This section illustrates the distribution of work among the thesis partners.

SECTION	TOPIC	CONTRIBUTOR
Chapter 1	Introduction	Megh Phani Dutt Chilukuri Prashant Atla
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Chapter 2

Related Work and Background

2.1 Related Work

Relevant related work associated with this study has been introduced in this section.

In [12], the authors presented the different types of Telecommunication networks and estimates the power consumption of those networks on operational phase. In this the authors investigated the energy consumption of residential networks and commercial network, for this the most important parameters for energy consumption forecast are number of connected subscribers and volume of traffic. From this investigation, there is 5% increase in the energy usage of networks operation from 2009 to 2017. To provide energy efficiency, they have considered metrics to know the energy and power consumption in Telecommunication Networks. From this paper we can make reference to know about the energy consumption in home network where number of network components can be considered.

In [7], authors investigated the energy consumption of network access switches to enhance the energy efficiency. The authors considered several switches from several brands to investigate the energy consumption. For this measurement authors considered four cases i.e., devices in active state, point to point communication, communication using broad cast message and communication within Vlans. For energy value measurement the authors used an electronic device called "kill a watt[13]" which measures voltage, power and current parameters that are consumed. The authors have used the switches like Cisco 2950, Cisco3560, 3Com. The authors conducted the experiments on those four cases and compared the switches. From this the authors concluded that the devices which are having the higher processing capacity will have higher power consumption and the energy consumption also influenced by the brands, models and configurations of the devices. For to provide energy efficiency network designers must take a look at the designing issues.

In [14] the authors have measured the energy consumption of the residential and professional switches depending on the traffic flow in network. For the measurement they have considered two extreme cases for study: home and cluster switches. The authors considered the energy consumption relation with network usage. In this paper, the authors conducted experiments considering TCP and UDP traffic to the devices under test and measured the energy consumption using a high precision meter. The measurements can be done by using electronic laboratory power meter which is "HAMEG HM8115-2[15]" offers 0.5% precision. In this paper, the residential switches considered are 8 port Fast Ethernet Netgear switch(FS608v2) and Freebox an ADSL modem/router compared the energy consumption of these two by providing TCP and UDP traffic under various scenarios. In professional context they have considered 48ports Gigabit Ethernet switch(HP Procurve 2810-48G) and a 24 port 3Com switch. From the experiments they have concluded that energy consumption of switches can be approximated at first order by a constant plus a constant increase for each computer plugged.

In paper[9], the authors introduced a sensor network to measure the power consumption of computer networks. In this author had profiled the power consumption with respect to workload, in which workload represents any traffic load or the computational load. The main contributions of this paper was power measurement acquisition tool which was used to observe power usage of network elements for real-time observations. The author have used EPUMS sensor network which was used to measure power consumption along with the bit rate, CPU load of routers. The author has made experiments with various packet sizes, and concluded that the router operating at higher clock rate or with higher number of interfaces would produce a higher power consumption, for to optimize that he had provided power efficient routing.

In reference [16], feasibility of power management schemes in network devices in the LAN is examined. During low traffic activity periods, various components are kept on LAN switches to sleep mode and are investigated. Here, author's examined potential energy savings possible for different times of day for different interfaces. It is concluded that sleeping in order to save energy is a reasonable approach in the LAN. Author's initial idea of using simple sleep for host-to-switches along with extended ACPI resulted in very good energy savings, also there is minimum or no packet lass while using this approach. However, author's also concluded that extent of energy savings for other LAN interfaces can be improved if appropriate hardware support is provided in the form of implementing HABS.

In reference [17], author's proposed various strategies for efficient energy management of networking devices. In this paper, difficulties in network power instrumentation are described and author's presented a power measurement study for various networking devices such as hubs, edge switches, core switches, routers and wireless access points in both stand alone mode and production data center. Here, author's proposed a benchmarking suite which allows users to measure and to compare the power consumption for huge set of common configurations at any switch or router of their own choice. Also author's proposed a network proportionality index, a measurable metric to compare power consumption for various networking devices. After careful observations, author's summarized that power consumption depends on number of active ports, line speed of each configured port and other factors such as firmware version on the switch or router. Also, author's concluded that power consumption is independent of the packet size.

In reference [18], the main aim of author's is to introduce the reader to current green technologies. Author's described the importance of energy efficiency in modern and future telecommunication networks and also suggested directions for optimising network performance in terms of energy needs. In this paper, author's discussed about fixed line networks and cellular networks that suffer from most of the power waste these days. Also, various energy efficient techniques are discussed and proposed for the green operation of telecommunication networks. Finally after careful observations, author's concluded that fixed line and cellular networks are driving to energy efficient directions. Energy efficient data centers and power management of fixed broadband networks are proved to be a solution for fiber optics. Access networks and base station technologies are of utmost importance for mobile operators.

Related work for Prashant work: There are many studies done to estimate the power on computer systems. Energy consumption in various entities of a data center is very important, in[8] the author presents the power profiling on two systems namely Dell PowerEdge1855, Dell PowerEdge1955 which relays on real power measurements. A generic application emulator (gamut) a benchmark tool, matrix multiplication and convolution of two matrix's where used to produce load on the CPU and Disk I/O of the system. And the power is measured using a power meter which is deployed in between the main power supply and the inlet of the system. In[2] the research is done on energy consumption of various servers and in each of them the power consumed by the CPU, network and disk under different operational level is identified and the power is measured using an external power monitoring tool called Voltech PM1000+ power analyzer. A benchmark tool called lookbusy is used to apply load on cpu. A dd linux command is used for reading and writing of data and finally concluded that the CPU has a largest impact compared to the all the three component .

[19] presents a review on all the energy measurement approaches in both software and hardware of a system. Such as Power-Scope which is a digital multimeter which is used to take the values and it uses another system to store and analyze the data. In simple, it uses three software's the first is the system

monitor which helps in storing program counters and program identifier. The other two are the energy monitor and energy analyzer which are used to collect and store the values taken by the meter. Another such kind of tool is the pTop[19] that works similar to top which gives the energy values in joules based on each process. Jalen & PowerAPI[19] which calculate the energy values based on power models for estimating the energy values, it can give the energy values of each CPU and hard disk. There are also some software tool that are been given a brief idea PowerTop[19] a Linux tool which is used to estimate the power consumption of the software, Energy Checkers is an SDK made by Intel which is used to calculate the energy consumed by an application by using its counters. Similarly, joulmeter is other tool that is used to estimate the power consumption of both hardware and software in this way all the measuring tools are been briefly explained. In[11] there is another tool which is been proposed that is the Energy profiler, the main aim of this work is to measure the energy consumed by the software for user in making software more efficient.

[20], developed a middle ware power estimator BITWATTS which gives the power consumed at process level without any hardware investment which can measure the power consumption in VM level and the machine. The proposed solution can calculate the power consumed by software that is been deployed inside a VM with its modular framework.

In [21] a technique is introduced which is a combination of power measurements to the performance counter on each power unit. The tool produces the power measurement for intel Pentium 4 processor and can also provide power break down for 22 of the major CPU subunits over minutes of spec2000 suit. An LKM is used to collect the counter information at run time. And the author does the real measurements using a clamp ammeter[21]. In [22] the research was conducted on a system which was considered as SUT system under test. The systems are Fujitsu RX2540 M1, Dell power edge R730 sun and server x3-2. And for measurement they used yokogawa's WT210 analyzer and ZES Zimmer LMG95 power meter both the tools report the measurements with an uncertainty of less than 1%. The variation in power consumption is done using six different workloads and at 5 different workloads.

2.2 Background

This section provides the description of the underlying technologies used in our research work. The main purpose of this research work is to create the power profile of the network components and computer systems. For that we have to know how do we measure the energy or power and then their tools used to calculate them. For that we have to know about power or energy and their relation:

Power:

Power is defined as the rate at which work is done.
Electrical Power(P) can defined as the product of current(I) in amps and voltage(V) in volts.It can be given as:

$$P = VI \tag{2.1}$$

The units of electrical power is Watt.

Energy:

Energy is defined as the capacity of a physical system to perform work.
The relation between the power and energy can be as shown below:

$$Energy(E) = Power(P)Time(T) \tag{2.2}$$

The units of energy are Joules.

2.2.1 Power Profile

The Power profile of a switch can be stated as, power usage of the switch with respect to load variation. The Power profiles of a switches will provide power values for different load conditions from minimum to maximum load. In this research, we are going to profile the power usage with respect to different traffic load in Mbps. For the Power profiling we have to measure power/energy values with different tools. Tools to measure power/energy values are discussed in the below section.

2.2.2 Tools for Measuring Power/Energy

This section deals with different tools for measuring energy or power usage of the devices. Description of Some of the tools which measures power or energy and also which tool we are going to use is discussed as follows:

Kill A Watt

Kill A Watt[13] is an electricity usage monitor. It measures the energy used by devices plugged directly into the meter. It is device that plugged directly into the outlet and the device which we wants to measure the power consumption is attached to this Kill A Watt inlet. And the power consumption of each device is known. The main features of this device is that it can show volts, Amps, frequency. In this, one of the disadvantage is that it does not used for multiple connections that are going from same outlet.

TED

TED is theenergydetective[23] which is one of the used energy monitoring tool in which electrical energy travels from utility to a buildings meter, where the utility measures the electricity usage. Similar to Emon pi the energy detective can be used to estimate the power consumption of all the electric appliances and one of the disadvantage is that the emonTx will measures the energy of 4 singe phase AC-AC links but this TED will not do that multiple single phase links.

Heat Probe

A prototype called heat probec is been introduced, which is a thermal based power meter. It can be used to sense an individual system power consumption with an average error of 125.03 seconds and with an accuaacy of 80.2%. These readings are taken by the help of the heat pattern that is been generated by the system under test. This is an indirect way of monitoring the system. Instead of calculating the power consumed directly using a probe. The energy values are taken by heat pattern and that can be produced by each application. For this measurement process a thermal camera is been developed, with a thermal imaging algorithm[24].

POWER API

Power API is middle ware tool kit[10] for building software-defined power meters. This is configurable software libraries that can estimate the power consumption of software in real time. The main limitation of this tool kit is that, it only estimates the power consumption for only software and there is no external hardware investment. The power values are never the same or never constant and So they vary but the power values are estimated based on the each internal processes, the real time values cannot be calculated.
Power API can just give an power estimation at process level and is limited to computer processes. The main drawback of Power API is that it can not be used to estimate the power consumed by other electrical appliances or home appliances. Advantages of the power API is that it gives an power estimation of each individual processes that are running inside a system.

Open Energy Monitor

Open Energy Monitor system[25] has the capability to monitor the electrical energy usage/generation. Open energy monitor system is a fully open source, both hardware and software. And hardware is based on Arduino and Raspberry Pi. This Open Energy Monitor consists of different units for monitoring different AC circuits by the use of clip-on CT sensors. This tool can be used to monitor single phase circuits as well as three-phase circuits. It estimates both energy or

power of the devices respect to the requirement. It can store the historic data of the measured units in a local or remote server and used whenever wanted.
From all the above energy/power monitoring tools we have considered the open energy monitor for our research work. As it can be maintained with hardware as well as software to store and reuse the values for measuring the power/energy values. The working of the tool is described in below sections.

2.3 Open Energy Monitor

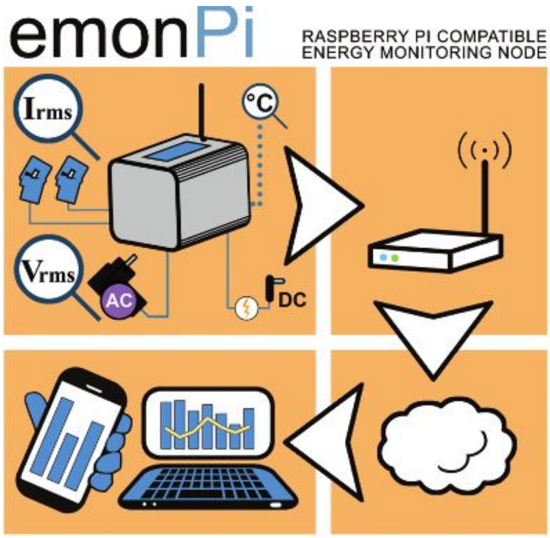

Figure 2.1: Emonpi Working[1]

The main working of the device is that, emonpi is connected to the Clip on current transformer sensors[1] which are connected to the load. From these CT sensors the emonpi will take the current values(Irms). And the voltage values can be provided by using AC-AC adapter which is connected to emonpi. The emon pi has an ADC which is an analog to digital converter which converts analog signal to digital signal. The current from the CT is converted to voltage by using a burden resistor which is present inside the emonpi. In a CT there are 8 loops of wire winding which can be used to measure low amount of current passing through the wire. For emonpi, power supply is provided through a 5V DC supply. As the emonpi is connected to the Ethernet, the data obtained can be now logged to the EmonCMS running on the emonpi local server and the data is saved to the Raspberry Pi's SD card. There are three ways of sensing data in the EmonCMS, instead of saving the data logging of incoming data can be done directly. These options allows the processing of the input data which comes and then the data is logged/stored. We can see the updated input list of connecting feeds and their key ids and their received data on the EmonCMS where the feeds contain the logged data. For that purpose the input data has to be logged to a feed then the power value is logged. If we want to know the amount of KWh's of data consumed we must create a KWh feed. And we have to consider Power to KWh input process. By this feeds we will know the power and KWh values for different nodes where the nodes are the EmonTx's and the Emon Pi. The feed interval logging time should not be less than the default node update. The maximum update rate for emonpi node is 5sec.

2.3.1 Power Measurement Methodology

In emontx 50 measurements are only made for every 20milliseconds which is done at a high frequency.

Real Power: Real power can be defined as power used by a device to produce some useful work.

$$RealPower = ApparentPower \times cos\Phi \tag{2.3}$$

Calculation of real power: Real power is the average of the instantaneous power. First we measure the instantaneous power by multiplying instantaneous voltage by the instantaneous current. Then we sum instantaneous power measurement over a given number of samples and divide by that samples. The calculation is shown below:

$$\left\{\begin{array}{r} Let, n = Number of samples; \\ I\_Power = I\_Voltage * I\_Current; \\ Sum\_I\_Power + = I\_Power; \end{array}\right\} \tag{2.4}$$
$$Therefor, Real\_power = sum\_I\_Power / no.of samples;$$

2.3.2 CT Working methodology

Current Transformers (CTs) are the sensors that measure alternating current. They are particularly useful for measuring whole building electricity consumption. We use split core type CT. The current transformer is similar to other transformer with primary winding, a magnetic core and a secondary winding. The current transformer used are the Non-invasive current sensor. For measurements in the whole building the neutral wire is used as the primary wire which is coming in to the building and is made to pass through opening of CT. And the secondary winding is made up of multiple number of turns with in the transformer.

The current that is flowing in the primary winding produces an magnetic field in the core, which induces a current in the secondary winding circuit.

Burden Resistor : A current output from the CT needs to be used with the burden resistor. With the help of this burden resistor the voltage is calculated and the sampling is done by converting an analog signal to a digital signal by using the ADC which is connected inside the emonTx. The burden value needs to be very low so as to prevent CTs core saturation.

What is Transformer? A current transformer is same as the voltage transformer with two windings, but unlike the voltage transformer it comes only with one winding and on the secondary side. The primary windings are in the form of the cables that passes through the transformer core. And this transformer namely called as the current transformer and provides the current in the secondary windings which is proportional to the current in primary winding.

Working principle of CT: A wire carrying an electric current set up a magnetic field around it, the windings around the CT is the primary winding of the transformer. The iron transformer core concentrates the field and couples it to the secondary windings. The magnetic field continuously changes, that flow the current in the winding. The current that flows in the burden resistor is converted into voltage and can be used by the emonTx. The current Transformer will not measure direct current.

1. Single Phase supply: The CT is clipped around the cable that runs from the meter to the consumer unit. The face with the name SCT-013-000 should be faced towards the meter. If the neutral wire is used then the CT is to be faced in opposite way.
2. Three Phase supply: Plug the lead from each CTs into EmonTx and then CT is clipped around one of the wire three phase wire. And the neutral wire is not used. The marked phase is faced towards the meter and supplied current is measured using a current transformer. The resulting current is converted into voltage by the burden resistor and the analog single is converted to an digital signal using a ADC which is placed in the emonTx.

The CT burden resistor is 120ohms and 22ohms in the emonTx V3. for a meaningful current value it is to be multiplied by a calibration constant.

$$I\_supply = count \times aconstant \tag{2.5}$$

where

$$aconstant = currentconstant \times (3.3 \div 1024) \tag{2.6}$$

And for EmonTx V3

$$currentconstant = (100 \div 0.050) \div 120 = 16.66; \tag{2.7}$$

This is for the CT4 which is sensitivity CT.

$$currentconstant = (100/0.050) \div 22 = 90.9; \tag{2.8}$$

This is for CT's from 1 to 3.
In this study EmonTx v3 is used when one volt is produced across the burden resistor.The calibration of the EmonTx v3 is done by taking the reference with respect to multimeter readings with the multimeter the calibration values are as shown below:

$$\begin{aligned} floatVcal &= 245.0; \\ Ical1 &= 85.6; \\ Ical2 &= 87.3; \\ Ical3 &= 87.3; \\ Ical4 &= 15.90; \end{aligned} \tag{2.9}$$

2.4 Power Estimation Approaches

2.4.1 Watt-Second / Energy Approach

In this energy measurement approach, firstly the start energy(a) values are grabbed by probing the EmonCms at the starting of the job and the time sample value at start of job. And then again the end energy(b) values are probed after the given job has been completed and that instance the time sample value is also taken. So the total energy consumed by that job is taken as the difference between end energy value and start energy value. The Tsample value is also calculated by taking the difference of the time sample values at start and end of the job. By taking the division between the total energy consumed and also the time sample value we obtain the power consumed for that job by that device. A simple model graph is provided below in Fig:2.2.

$$StartEnergy = a[Ws] \tag{2.10}$$

$$EndEnergy = b[Ws] \tag{2.11}$$

$$TotalEnergyConsumed[Ws] = EndEnergy[Ws] - StartEnergy[Ws] \tag{2.12}$$

The obtained total energy value is the average energy value. So that the Total power consumed which is a average power by that device can be shown below:

$$Avg.Power = TotalEnergyConsumed/(Tsampleend - Tsamplestart) \tag{2.13}$$

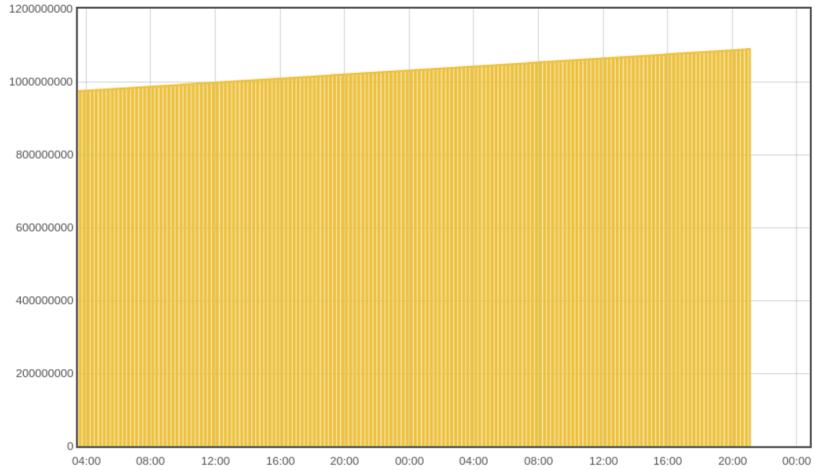

Figure 2.2: sample graph for Watt-sec approach

while doing measurements by using this approach the probed energy values are divided by a 8. As the CT's are having 8 loops which are done for measuring low current values.

2.4.2 Watts Approach

In this power measurement approach, the step by step procedure has been explained below:

- In this approach, to calculate the power consumed by the DUT and SUT first we have to grab the unix time stamp values at the start of the job and at the end of the job. We will grab these values by probing the Feedid's of the EmonTx which is connected to Emonpi.
- By using these unix time stamp values and the id of the feed in Emoncms we grab the power values for the particular interval of time using the unix time stamps. The power values are grabbed from EmonCMS.
- After grabbing the power values in between those time stamps we will calculate the average power value from the sample values obtained. Therefore the average power value can be given as:

$$AveragePowervalue = Sumofallsamplevalues/(Numberofsamples \times 8) \tag{2.14}$$

- From the above average power value we take the 75% power value which is we call it as lowerlimit which is given below:

$$lowerlimt = AveragePowervalue \times 0.75 \tag{2.15}$$

- Then the Power values are compared with this "75% average power value" and then the mean of all the sample values greater than the this average power values are considered and it is defined as the power (Avgpower) in watts consumed by that systems.This can be shown below:

$$\begin{aligned} Samples &= find(samples > lowerlimit) \\ AveragePower &= mean(Samples)[W] \end{aligned} \tag{2.16}$$

  Average power is the power consumed in Watts by DUT and SUT for that particular given job.

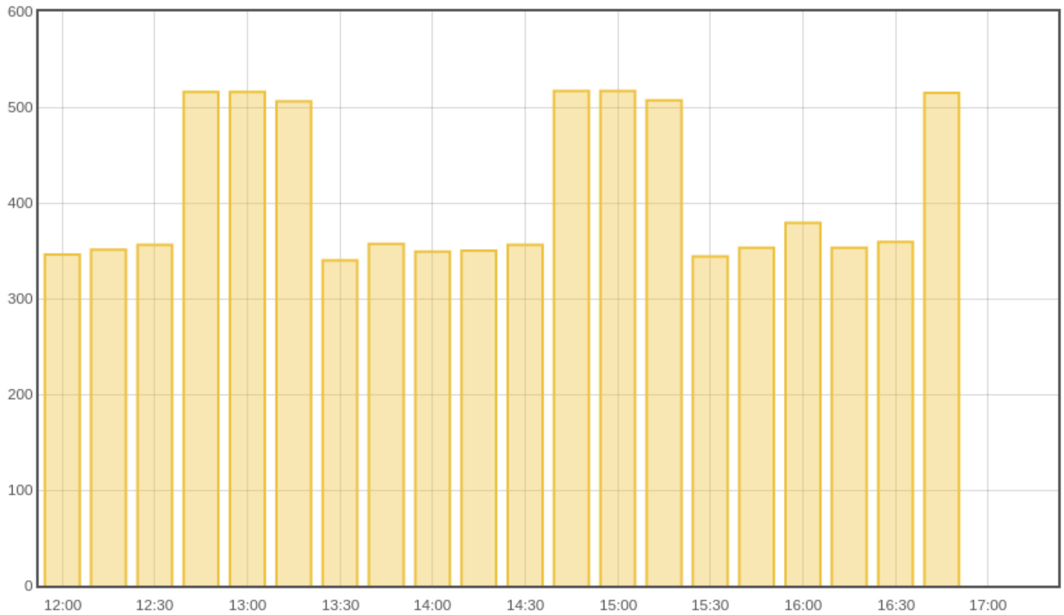

Figure 2.3: sample graph for Watts approach

From the above considered approaches the wattsec/Energy approach is the best to conduct for our study. Because in the watt approach if the load on the devices varying then grabbing the particular power value for particular time interval is difficult. As in the wattsec/Energy approach the energy value has been measured for a interval of time with start and end energy values, which provides the average energy value. From this average energy value we can obtain average power value.

Chapter 3

Methodology

This chapter is going to provide the methodology considered for research work. This work mainly focus on the power profiling of the network devices, that is how power usage of devices varying with the impact of load and also with varying active number of ports of the switch. The main focus of this research on the power usage of switches. Based on the survey of the related work the main characteristics we are going to present in this work is, how the traffic load affects the power usage of the devices. And also impact of the variation of active number of ports of the switches will affect the power usage of the switches.

3.1 Experimental Setup

3.1.1 Experimental setup for Switches

In this stage of research we setup the experimental test bed to know the power usage of different network switches of different configurations from different vendors. Mainly for our research we have considered the switches from two vendors Cisco and Netgear. The reason for using these vendors because of their availability and also because of their constant usage in the networking purposes in colleges and industries. Initially the experiments are conducted to know the interval which has less power variations to take into account to check the approach considered in the background. The experimental setup and experimental procedure is discussed in below sections.

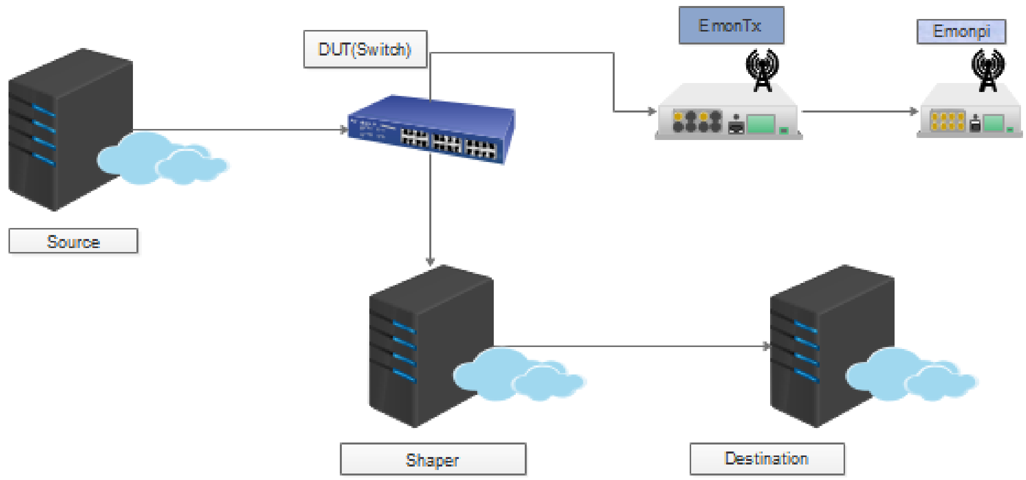

Figure 3.1: Experimental setup

The experimental setup is as follows:

The setup mainly consists of source and a destination which are connected via Shaper in which the shaper will shapes the traffic if required. This shaper acts as bridge between the source and destination. Then the DUT is placed between the source and the destination and it was connected to an energy monitor tool emonTx, which will be used to measure the power usage. This setup has been taken for other three sources and three destinations which are having their each own shaper. The DUT's were placed between the three setups and these were connected to the energy monitor Emonpi via EmonTx. Fig:3.1 shows the experimental setup in which source is connected to private network in lab. Then source is connected to shaper, shaper is connected to the device under test(DUT) example Cisco 2950 switch. And then DUT is connected to the source and that DUT is connected to the EmonTx which is a low power wireless energy monitor node which senses the data from multiple CT sensors, where we were grabbing the energy usage of the DUT. Then it was connected to Emonpi through a wired cable. The grabbed energy has been stored in the SDcard placed in the emonpi. The DUT's considered in our research work are Cisco 2950[26], Cisco3560[27], Netgear GS-724T[28]. The data sheets for these DUT's will provide us the required information from the manufactured vendors.

3.2 Experimental Procedure

The experimental procedure considered for our research study is as shown in the flow chart provided below. And then it can be explained with each of the experiments conducted for our study to reach the aim.

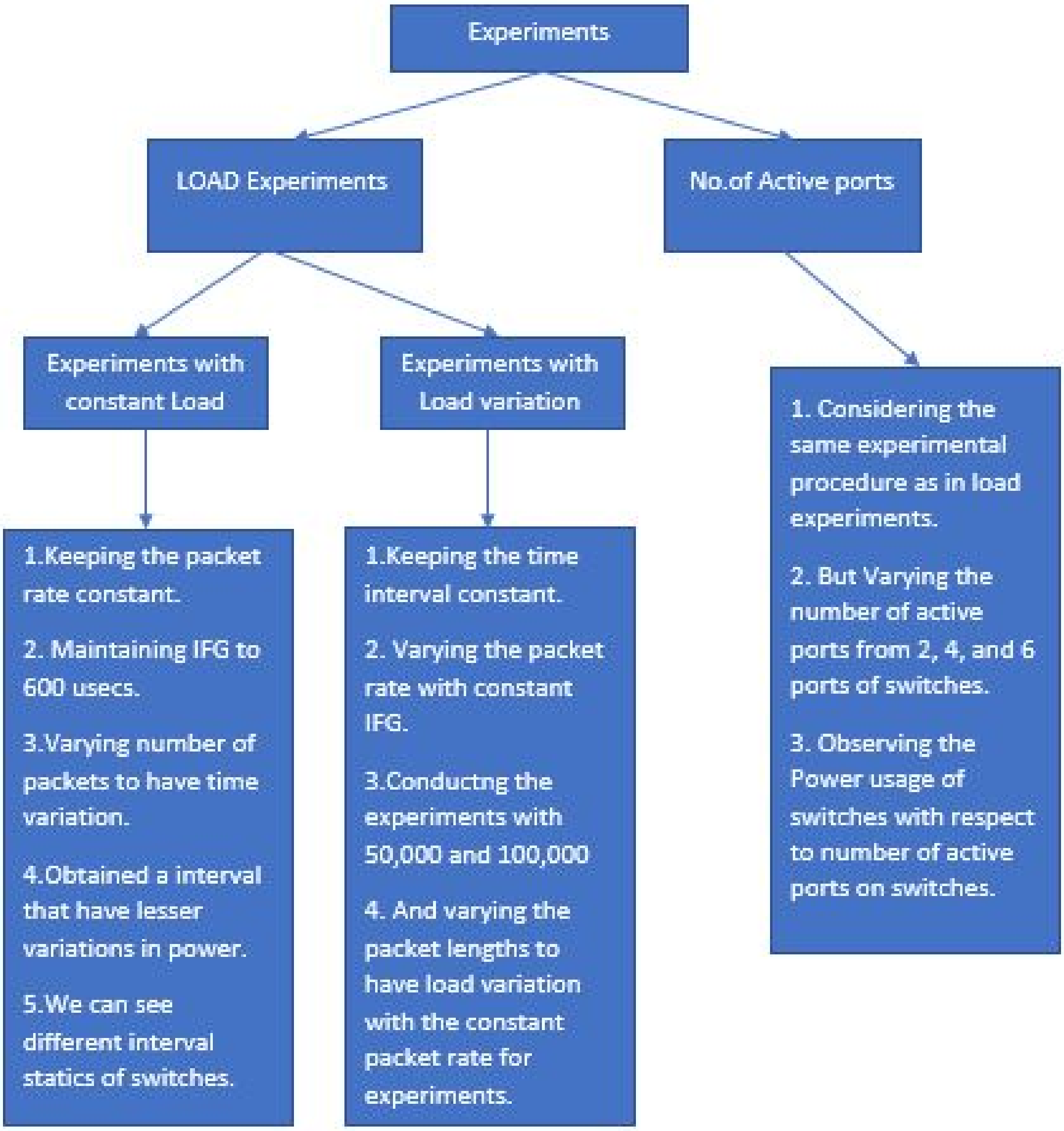

Figure 3.2: Experimental Procedure steps

In this work the traffic load is produced by considering the below three parameters.They are:

- Number of packets.

- Inter frame gap.
- Packet size.

From the above parameters we have a unit called packet rate that is how many packets per second are considered. To profile the power usage of switches, below experimental methodology is followed as the preliminary experiments for the start of the research.

- Initially the experiments on the switches have been conducted for various time intervals that is from 30 to 210 seconds with gap of 30 seconds each.
- From the initial experiments on the switches, we have an interval that has lesser variations in the power values that suits to be the best interval to produce the traffic load and see the power consumption of the devices in that interval itself.
- Then the latter experiment procedure is followed to reach objective of this research. This has been discussed in the below sections.

3.2.1 Power usage of DUT by varying load.

The procedure for the experimentation is as follows, sources and destinations considered here are ubuntu systems and the configurations on these are same. As we have to know the power usage of the device under test, so there is a need of doing some work between these source and destination. For that purpose we have to generate some traffic load which is UDP traffic load in our work. The required traffic load generation has been done by udpclient which was a shell script. From this shell script the traffic load has been generated on the source and it was switched to destination through the DUT. This traffic generator was taken in a perl script which is used to grab the energy values from EmonCMS. From this perl script we send the UDP traffic load to know the power usage of the DUT, as the initial purpose of our DUT is to switch the packets between source and destination. For that purpose, generating and varying load has been done on the DUT's and their corresponding energy values are grabbed from the monitor tool and from the grabbed average energy values average power is calculated.

- The experiments are conducted for a particular interval of time that has been taken from the initial experiments conducted to have lesser power variations of the switches.
- In this interval of time the generated load for the switches are varied with constant packet rate unit.
- Firstly the experiments are conducted for packet rate of 238 packets per second with the variation of load.

- This variation of the load was produced by considering different packet lengths of the load considered in the traffic generator that 128,640,1280 and 1470 bytes.
- For these experiments, the corresponding energy values are grabbed from the Monitoring tool Emonpi. The energy values are obtained by an approach called wattsecond approach discussed in the background section.
- These experiments are conducted for 40 iterations to have the statistical values of the values obtained within that interval for the power values with respect to variation of load on switches. The results and analysis are discussed in next chapter.

In fig:3.1 we will change the sources and destinations and the same experimental procedure has been followed for the other sources and destinations. By following the above procedure we will measure the energy consumed for different DUT's. The energy consumed by DUT's for each iteration can be known by following the procedure by running the automation Perl script in NTAS. The Perl script will first grab start energy of the DUT before the generation of traffic load. Then after that the UDP traffic load generation has been done for the parameters considered like Packetlength, No.of packets and inter frame gap. Then after the generation and switching of the packets from source to destination the energy consumed by that DUT can be grabbed which is End energy from EmonCMS. So we have to know how much energy has been consumed by that DUT, this can be known by taking the difference of above start and end energies provide us the average energy consumed. By this average nergy values we can calculate the average power consumed. These values have been taken in a log file for each iteration. These log files have used for further statistical analysis.

3.2.2 Power usage with respect to variation in number of active ports on DUT

This section deals with the energy usage of the considered DUT variation in the number of active ports on the DUT shown in Fig:3.1.

- This experimentation includes changing the active number of active ports on the switches with the load scenarios considered in the section 3.3.1.
- The same experimental procedure was followed to maintain the load on the switches as in section 3.3.1. First the Power usage with 2 active number of ports is observed for the packet rate considered.
- Then the same load is maintained on the DUT's and by variation in the active number of ports from 4 ports and 6 ports, the power usage is observed.

- Then packet rate doubled and the experiments were conducted to observe the power usage of switches with respect to the active number of ports.
- These experiments of 2ports, 4ports and 6 ports are conducted for 40 iterations. For observing, how minimum number of ports variation impacts the power usage of the switches and can latter relates to more number of ports.
- For this procedure number of experiments have been conducted and the energy consumed by that DUT is noted and the results are discussed.

The above procedure has been followed for different DUT's considered in our research work.

Chapter 4

Results and Analysis

This chapter gives description on the results obtained in the initial experiments conducted to know the best interval to generate the load and observe the power usage of the devices. And latter it will be followed by results obtained in that interval for varying the load as well as variation in the active number of ports used for each switch. The results obtained in this research will provide the power profiling of the switches.

4.1 Different Time interval statistics

The initial experiments to find interval that has lesser power variations between minimum and maximum power consumed were having the configurations as follows:

- For this experiments the traffic load on all three switches considered to be constant.
- For that purpose the considered configurations are keeping the wait time as constant to 600 microseconds.
- Then number of packets are changed from 50000, 100000, 150000, 200000, 250000 300000, 350000 to vary the time interval from 30, 60, 90, 120, 150, 180, 210 seconds intervals.
- The experiments were conducted for the three switches considered in this study.
- The results obtained for these experiments are shown in the table below.

Switch:	Time Interval (sec)	Avg Power (W)	MIN (W)	MAX (W)	VAR	STDEV
Cisco2950	30	63.1	50.02	78	45.33	6.73
	60	63.5	54.67	70.35	16.99	4.12
	90	63.9	59.15	68.50	4.92	2.21
	120	64.1	60.97	67.08	2.75	1.65
	150	63.8	60.53	67.55	3.22	1.79
	180	63.7	60.12	66.8	1.80	1.34
	210	63.5	61.83	66.08	0.98	0.99
Cisco3560	30	61.7	48.88	74.47	37	6.08
	60	62.6	56.13	69.03	13.17	3.62
	90	62.4	57.61	67.48	5.71	2.39
	120	62.3	59.60	64.92	1.86	1.36
	150	62.0	59.64	65.23	1.93	1.39
	180	62.3	59.60	65.41	2.11	1.45
	210	62.2	60.07	64.48	1.14	1.069
Netgear GS-724T	30	54.9	44.8	66.25	29.16	5.477
	60	55.9	46.93	65.58	25.86	5.08
	90	56.0	50.66	62.02	9.93	3.15
	120	55.7	53.52	57.91	1.21	1.10
	150	55.7	52.3	60.33	4.98	2.23
	180	55.6	52.11	58.45	3.50	1.87
	210	56.1	53.99	57.95	0.87	0.93

Table 4.1: Statistics of Switches for different Time intervals

Table 4.1 shows the statistical analysis of switches for different time intervals from 30 to 210 seconds for difference 30 secs interval. Table 4.1 consists of Avg power, MIN, MAX, VAR, STDEV values for different time intervals for Cisco2950, GS-724T and Cisco3560. From this table we conclude that the larger time intervals having the lesser variations in the power values than the smaller intervals. For Switch GS-724T the variance of power is 0.87 for 210 seconds interval and 29.16 for smaller interval that is 30 sec. The same trend was followed for other two switches in this research. From the variance values we can conclude that larger interval of time that is 210 seconds best suits to generate load and observe the power usage of considered devices.

4.2 Average Power Consumption Vs Load

In this section we will discuss the results obtained for the experiments conducted to reach the aim of one of research questions that the impact of load on the power usage. For this the experiments were conducted on the larger interval that is 210 seconds with the iterations of 40 runs each which was observed from the section 4.1.

- In this time interval the experiments were conducted by changing the load on the devices with a unit of packet rate.(i.e.,packets/sec)
- First the experiments were conducted with the packet rate of 238 packets/sec by varying the load on the switches considered in research and power usage was observed.The average power usage was observed by conducting 40 iterations of each experiment considered.
- And then the experiments were conducted by doubling the packet rate unit and the power usage was observed.
- The profiled power usage of switches Cisco 2950, Cisco 3560 and Netgear GS-724T for different packet rate are as follows:

Considered configuration of the traffic generator was number of packets=50000, waittime 4200 microsec and varying the packetlengths from 128, 640, 1280, 1470 bytes. For this configuration it is having packet rate of 238 packets/seconds

Switch	Load (Mbps)	Average (W)	Min (W)	Max (W)	STDEV	VAR	CI(95%)
Cisco2950	0.24	63.6	60.89	66.75	1.33	1.78	0.41
	1.2	63.7	60.82	65.92	1.35	1.84	0.42
	2.4	63.8	61.40	68	1.44	2.07	0.44
	2.8	63.9	61.10	69	1.45	2.12	0.45
Cisco3560	0.24	61.8	60.26	64.12	1.04	1.08	0.32
	1.2	62.0	59.53	64.26	1.12	1.27	0.34
	2.4	62.0	60.24	64.33	1.03	1.06	0.31
	2.8	62.2	60.22	64.55	0.95	0.9	0.29
GS-724T	0.24	55.6	54.36	57.73	0.87	0.76	0.27
	1.2	55.7	53.75	58.13	1.03	1.06	0.32
	2.4	55.7	53.86	57.47	0.78	0.61	0.24
	2.8	55.9	53.35	58.11	1.04	1.08	0.32

Table 4.2: Statistics of switches with Packet rate 238 packets/sec

Table: 4.2 shows the Statistics of the switches with their corresponding Load versus Avg.Power Consumption of the switches in the interval of 210 seconds. From the above results we can say that the average power consumed by the switches slightly increases when there is increase in the load on the switches.

This is because as the load on the switch increasing the switching capacity must be increased as a result the power consumed increases.This behavior seems to be constant for the three switches considered in research.

The Table: 4.2 shows the comparison between the confidence intervals obtained for the varying the load on the switches. For the load scenarios considered, from the three switches, the GS-724T switch having the least confidence intervals as compared to other Cisco switches. And then Cisco 3560 having the better CI(95%) where as Cisco 2950 having higher CI(95%). As a result we can say that the average power consumed by the GS-724T switch is less compared to other Cisco switches in all scenarios. From the above results and analysis Switch GS-724T is having the less power usage when compared to Cisco 2950 and Cisco 3560 with respect to load with a constant packet rate.

Switch	Load (Mbps)	Average (W)	Min (W)	Max (W)	STDEV	VAR	CI(95%)
Cisco2950	0.48	63.57	60.87	66.54	1.51	2.29	0.46
	2.4	64.11	60	66.23	1.56	2.44	0.48
	4.8	64.15	61	66.29	1.62	2.64	0.5
	5.6	64.17	60.53	66.34	1.68	2.83	0.52
Cisco3560	0.48	62.19	60.82	64.35	0.99	0.98	0.3
	2.4	62.08	59.91	64.27	1.11	1.25	0.34
	4.8	62.41	59.86	66	1.22	1.48	0.37
	5.6	62.61	60.42	66	1.26	1.59	0.39
GS-724T	0.48	55.61	53.73	57.12	0.87	0.75	0.27
	2.4	55.94	53.79	58.27	0.97	0.94	0.3
	4.8	55.99	53	58.28	1.068	1.14	0.33
	5.6	56.02	52.58	57.85	1.13	1.28	0.352

Table 4.3: Statistics of switches with Packet rate 476 packets/sec

Table :4.3 shows the statistics of the three switches when the packet rate has been doubled from the table: 4.2 configurations. Table: 4.3 shows the average power consumed and their corresponding Min, Max, STDEV, VAR and CI(95%) for the experiments conducted with 40 iterations. This results shows the behavior of power usage of the devices when doubling the packet rate characteristics. And scenarios for various loads were generated and the power usage was tabulated.

The table :4.3 shows the results for load versus avg.power consumption of switches considered in the research. From the table we can compare the confidence intervals of the switches with respect to the load variations. For Cisco 2950 when the load on the device increased the CI values also higher as a result the power consumed is more. This trend was followed by the other two switches Cisco

3560, Netgear GS-724T. But the average power consumed by the GS-724T switch is lesser compared to other switches Cisco 2950,Cisco 3560. But the Power consumed is slightly changed for the load variation. As a result we can say that the generated traffic load is having slightly lesser impact on the Power consumption of switches. And also doubling of the packet rate that is the load on the device also doubled from the scenario considered in table: 4.2. But it does not have a much impact on the Power usage of Switches.

Below tables shows the Average power consumption of the switches with respect to load variation with the speed on the links of the switches with 100 Mbps. The traffic load on switches calculated on the links is as follows: The traffic load on the Switches was provided by taking the packet rate unit into consideration. The load obtained can be calculated in the following process. First, the packet rate was calculated by performing the Packet inter transmission time which can be shown as:

$$Packetintertransmissiontime(PITT) = (packetsizeatL2*8/capacity)+IFG(usecs). \tag{4.1}$$

In our scenarios considered above the packet size varies from 128, 640, 1280 and 1470 bytes with the capacity on the links of switch is 100Mbps. This configuration was summed to the Interframe gap considered from 0,100,200,400 and 800 usecs. By doing this we obtain packet rate as follows:

$$packetrate = 1/(PITT) \tag{4.2}$$

From the obtained packet rate from equation 4.2, load on the switches calculated as

$$Load = packetrate * packetsize * 8bps. \tag{4.3}$$

Switch	IFG (usecs)	Load (Mbps)	Average (W)	Min (W)	Max (W)	STDEV	CI(95%)
Cisco2950	0	8.4	62.9	21	107.4	21.51	9.42
	100	4.6	61.8	36.37	70.62	11.42	5.00
	200	3.1	61.4	53.03	78.65	6.75	2.96
	400	1.9	61.1	54.5	74.78	5.27	2.31
	800	1.1	61.0	59	70.09	2.43	1.06
Cisco3560	0	8.4	62.9	20.2	106.8	22.57	9.89
	100	4.6	61.4	39.13	89.8	12.27	5.37
	200	3.1	61.3	52.5	70.7	5.50	2.41
	400	1.9	61.0	55.4	70.93	3.82	1.67
	800	1.1	60.7	57.33	66.6	2.23	0.97
GS-724T	0	8.4	56.4	14.8	89.1	23.11	10.12
	100	4.6	55.9	39	88.53	18.72	8.20
	200	3.1	54.3	37.4	78.68	8.37	3.67
	400	1.9	54.1	48.9	60.38	3.43	1.50
	800	1.1	53.8	50.34	59.53	2.40	1.05

Table 4.4: Power profiles of switches with maximum load with 128 bytes size

Table: 4.4 shows the Average Power usage of the switches with respect to load by varying the IFG(usecs) from 0, 100, 200, 400, 800 on the switches with the packet length of 128 bytes. This analysis provides the power profile of the three switches when the link speed on the switch is 100Mbps. As we see from the table that when the load on the switches reaches maximum for the packet length consider the power consumed is increased.

Switch	IFG (usecs)	Load (Mbps)	Average (W)	Min (W)	Max (W)	STDEV	CI(95%)
Cisco2950	0	42.3	64.8	29.3	91.4	20.12	8.82
	100	23.1	64.1	41.6	85.13	11.50	5.04
	200	15.9	63.7	53.88	76.48	6.06	2.65
	400	9.8	63.6	58.86	70.26	3.16	1.38
	800	5.5	63.3	58.53	68.74	2.86	1.25
Cisco3560	0	42.3	63.1	26.72	92	15.03	6.59
	100	23.1	62.7	38.6	86.86	14.99	6.57
	200	15.9	62.6	53.33	74.23	4.64	2.03
	400	9.8	62.4	55.74	73	4.51	1.97
	800	5.5	62.3	59.66	67.56	1.98	0.86
GS-724T	0	42.3	59.6	25.2	98	22.30	9.77
	100	23.1	56.4	21.86	88.33	21.08	9.23
	200	15.9	55.5	35.52	75.32	10.31	4.52
	400	9.8	55.2	48.93	61.68	3.21	1.40
	800	5.5	54.8	51.71	59.01	2.11	0.92

Table 4.5: Power profiles of switches with maximum load with 640 bytes size

Table: 4.5 shows the Average power usage of the switches with respect to varying load with varying IFG(usecs) from 0, 100, 200, 400 and 800 microsecs. This analysis provides the power profile of the three switches when the link speed on the switch is 100Mbps. Table: 4.5 shows the average power for different loads, which is less for GS-724T switch compared to Cisco 2950 and Cisco 3560.

Switch	IFG (usecs)	Load (Mbps)	Average (W)	Min (W)	Max (W)	STDEV	CI(95%)
Cisco2950	0	84.6	68.4	37.73	89.66	14.73	6.45
	100	46.3	63.8	38.46	85.8	11.87	5.20
	200	31.9	62.6	50.83	73.08	5.59	2.45
	400	19.6	62.4	55.66	72.31	3.79	1.66
	800	11.1	62.2	57.75	69.72	3.32	1.45
Cisco3560	0	84.6	68.0	50.15	89.4	11.05	4.84
	100	46.3	67.7	47.68	95.93	11.02	4.83
	200	31.9	63.3	52.76	72.46	6.05	2.65
	400	19.6	61.7	51.15	70.28	5.03	2.20
	800	11.1	61.6	57.04	65.15	2.21	0.97
GS-724T	0	84.6	61.4	15.4	100.2	20.89	9.15
	100	46.3	59.6	26.93	89.53	14.81	6.49
	200	31.9	56.3	43.56	75.44	7.66	3.35
	400	19.6	55.0	49.42	62.33	3.82	1.67
	800	11.1	54.8	50.25	60.31	2.64	1.15

Table 4.6: Power profiles of switches with maximum load with 1280 bytes size

Table: 4.6 shows the Average power usage of the switches with respect to varying load with varying inter frame gaps from 0, 100, 200, 400 and 800 microsecs with the packet length of 1280 bytes. This analysis provides the power profile of the three switches when the link speed on the switch is 100Mbps.

Switch	IFG (usecs)	Load (Mbps)	Average (W)	Min (W)	Max (W)	STDEV	CI(95%)
Cisco2950	0	97.1	68.9	48.8	89.2	10.02	4.39
	100	53.2	67.4	44.73	98.8	11.35	4.97
	200	36.6	62.9	50.76	73.53	6.75	2.96
	400	22.5	62.5	54.28	68.58	4.46	1.95
	800	12.7	62.3	57.64	69.85	3.96	1.73
Cisco3560	0	97.1	68.4	33	89.33	14.09	6.17
	100	53.2	59.5	37.46	89.6	14.07	6.16
	200	36.6	58.5	53.96	73.36	4.03	1.77
	400	22.5	58.5	54.25	68.04	3.25	1.42
	800	12.7	58.4	54	65.84	3.85	1.68
GS-724T	0	97.1	62	18.2	99.2	26.39	11.56
	100	53.2	58.5	33.3	84.66	14.16	6.2
	200	36.6	56.6	29.68	65.56	8.78	3.84
	400	22.5	55.8	50.54	63.65	4.03	1.76
	800	12.7	55.1	51	58.94	2.22	0.97

Table 4.7: Power profiles of switches with maximum load with 1470 bytes size

Table:4.7 shows the Average power usage of the switches with respect to varying load with varying inter frame gaps from 0, 100, 200, 400 and 800 microsecs with the maximum packet length of 1470 bytes considered in this study. This analysis provides the power profile of the three switches when the link speed on the switch is 100Mbps.

4.3 Average Power Consumption with Active Number of Ports of Switches

This section deals with analysis and discussion of results regarding the impact of variation of active number of ports of switches on the Power consumption of devices with the packet rate unit. The active number of ports of the switches are varied from 2 ports, 4 ports and 6 ports on the switches with the load scenarios considered in the section 4.2.

ports	Switch	Average (W)	Min (W)	Max (W)	STDEV	VAR	CI(95%)
2ports	Cisco2950	63.6	60.89	66.75	1.33	1.78	0.41
	Cisco3560	61.8	60.26	64.12	1.04	1.08	0.32
	GS-724T	55.6	54.36	57.73	0.87	0.76	0.27
4ports	Cisco2950	64.1	62.05	66.28	1.32	1.75	0.41
	Cisco3560	62.4	58.95	65.04	1.30	1.70	0.40
	GS-724T	56.0	52.50	58.08	1.08	1.17	0.33
6ports	Cisco2950	64.6	61	65.93	1.11	1.24	0.34
	Cisco3560	62.9	60.93	65.11	1.07	1.14	0.33
	GS-724T	56.1	52.83	57.83	1.11	1.25	0.34

Table 4.8: Avg.Power Consumption with variation of Number of active ports

Table: 4.8 shows the Avg.power Consumption with variation of Active Number of ports on the switches Cisco 2950, Cisco 3560 and GS-724T. This table provides the statistics for the constant packet rate of the scenario considered in section 4.2 having the load on the switches constant with variation in active number of ports.

From Table: 4.8 it can be seen that the average power consumption of the device increases as the number of active ports on the Switches increases. For the same load on the switches with different number of ports the confidence intervals reduces from top to bottom. From this table we can say that increase in the number of active ports is proportional to the power usage of switches. But in all the three cases the Netgear GS-724T consumes less power because Netgear GS-724T switch is a smart switch which has the features of green Ethernet. So the power consumed by GS-724T is less when compared to other Cisco 2950 and Cisco 3560. Coming to the second switch which consumes less power compared to Cisco 2950 is Cisco 3560 which uses the vendors energy management tool to manage the power consumption of the device to be minimum.

4.4 Proposed Power/Energy consumption Theoretical Model

From the results and the analysis on the experiments conducted gives the impact of various parameters such as traffic load and number of active ports on the power consumption of the switches. We combine these practical insights with the operation of the switches to propose a theoretical/analytical model for power consumption of the switches under various scenarios. This model depends on measurements and not on simulation. The proposed model is different from the models proposed in the previous works[29][30]. The Power consumed by switch, P_{switch} can be the sum of the base component sum with the per port of the switch which is given as

$$P_{switch} = P_{base} + P_{parameters} \tag{4.4}$$

Where P_{base} corresponds to power consumed when switch is on but none of its ports are active. And $P_{parameters}$ corresponds to power consumed when different configurations of traffic load considered with the parameters discussed in methodology section. When the traffic load taken into consideration we must include Power consumed by the ports that sends the traffic load. So, the above equation can be written as:

$$P_{switch} = P_{base} + P_{ports} \tag{4.5}$$

Here P_{ports} will include power consumed with static active ports (no traffic but active) and dynamic ports which sends traffic between systems.

$$P_{switch} = P_{base} + \sum_i P^i_{ports} \tag{4.6}$$

But from our experiments it is evident that the power consumption of the switches depends not only on the port utilization but also on packet sizes and packet rate. In our study, we have used packet rate as our unit so focusing on packet rate with the above equation is as follows:

$$\begin{aligned} Let, the Packet transmission time = L/C \\ Therefore, Packetrate = 1/(L/C) \end{aligned} \tag{4.7}$$

The main parameters for the energy/power consumption of the devices taken into consideration and the final proposed value is as follows:

$$P_{switch} = P_{base} + P_{parameters} f(Packetrate * L * 8) \tag{4.8}$$

Here, f(Packet rate*L*8) is function which provides the load with the use of parameters for considering the various scenarios. The model proposed here can further used to measure the power profiles and can match with the measurements provided by the tools. This can be implemented for typical deployment scenarios and for different types of traffic. This can be further used to have energy/power savings models to provide efficient services.

Chapter 5

Conclusion and Future Work

5.1 Conclusion

Results obtained by conducting the different experiments shows the power profiles of the Switches. These profiles are provided for the interval, having lesser power variations to know accurate power usage. The initial experiments provides an interval which has lesser variations in power values that is 210 seconds. From this, we have a statement that the larger intervals will have lesser power variations. In this the power usage for the switches profiled with respect to a unit called packet rate and also by load varying for the considered packet rate within the above interval observed. The power usage also observed with respect to the variation of the active number of ports on the switches. These experimental results provides which interval and what type of load scenarios are considered to have minimum power usage.

The experimentation provides the statistical analysis to have power profiles of the switches Cisco 2950, Cisco 3560 and Netgear GS-724T. From the results and analysis it can be observed that the power usage of switches increase with increase in the packet rate unit and also load variation. But the power usage has a minimum impact with respect to the load variation. But the maximum power usage depends upon how active the switch. So, that the power usage mainly depends upon the number of active ports of the switches used in the scenarios. The switches having increase in power usage with increasing active ports of the switches from 2ports, 4ports and 6ports.

From the results and analysis it can be stated that the power usage of Cisco 2950 is having the maximum power usage in all the considered scenarios that is with respect to packet rate and also number of active ports. The Netgear GS-724T having the minimum power usage from the three switches as it having the green switch characteristics in all scenarios. And the Cisco 3560 is in between the above two switches as it is having energy efficient management from Cisco.

In this study we have profiled the power usage of the network switches. From the results and analysis of the experiments conducted with different scenarios, we have proposed a simple model that suits to know the power/energy consumption of the devices to have energy savings in the networks. This model can be used to test the scenarios and can be extended to more complex scenarios with variable traffic patterns.

5.2 Answers to Research Questions

R.Q1)What is the impact of the load on the communication network components in their usage of power?

Ans. For this study the network components used were Switches. For switches this study measures the power usage for different packet rates and for different load scenarios in packet rate. Experiments were conducted on the interval from initial experiments. For these experiments the UDP traffic load has been generated by a udpclient. The load on the switches varied with varying the packet lengths for one packet rate and then the load has been varied by doubling packet rate. Table: 4.1 provides the interval and Table: 4.2, Table: 4.3 provides the statistical power usage of devices with respect to traffic load in the interval considered. From these tables power increase with increase in the traffic load. Tables: 4.5 to 4.8 provides the power profiles of the switches with the link speed on the switches with 100Mbps, to know the maximum power usage. Netgear GS-724T consumes less power in these scenarios.

R.Q2) What is the impact of interfaces (ports) of the components (switches) on the Power usage of the devices?

Ans. Tables 4.4 statistical analysis on the Power usage of the switches. Based on the values and analysis it was found that the active number of ports of the switches have more impact on the power usage than RQ1 results. From the switches Cisco 2950, Cisco 3560 and Netgear Gs-724T. GS-724T power usage is minimum compared to other two switches when there increase in active number of ports. From these results and analysis switch Netgear GS-724T has minimum power usage in all the scenarios for both RQ1 and RQ2.

5.3 Future Work

This research is concerned with the Power profiling for different Switches. In this simple model was proposed which can be extended for more complex scenarios with variable traffic patterns. By using this model the energy/power efficiency of the higher layer traffic characteristics can be studied further. This has to be done to have an efficient services in the communication environment. And also profiling of the other systems like routers and other computer systems will be a useful aspect for the Data centers to maintain services efficiently.

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