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MATHEMATICAL MODEL DEVELOPMENT FOR SWITCH POWER MANAGEMENT IN WIRELESS NETWORKS

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Abstract

Energy consumption consideration is becoming of increasing importance in the daily operation of networking infrastructure, especially in enterprise and data center networks [1]. Several strategies for management of energy of networking devices has been proposed.
Still, an all-inclusive characterization is required of power consumption by a variety of switches and router components to estimate accurately how these elements consume electrical power.
In this paper we develop a mathematical model to accurately quantify the energy consumption of key networking devices; switches s as regards dynamic consumption of energy to enable planning and predicting power needs in the building of network infrastructures. The devices selected were from two vendors (Cisco, Netgear) and this choice was made as they have a large share of the existing market today. Three products were used namely: Cisco 2950, Cisco 3560 and Netgear GS-724T devices.
At the conclusion of this research work a mathematical model was developed consisting of a number of equations that model power consumption of the three switches under review.
The developed model can be used to test for simple networking scenarios and can be extended to more complex scenarios with variable traffic load patterns.

Keywords*:* Wireless Components, energy efficiency, Cisco, Netgear, data center networks, 2.4GHz, 5GHz

I. INTRODUCTION

Today, Telecommunication network services are a part of everyone's life. These services induce an increasing demand for high access rates in the network. This in turn increases the internet traffic rapidly, where the network operator needs to increase their network capacity. To increase network capacity there is need to use a greater number of network component (like switches, routers, hubs, bridges, etc.). 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 [2]. 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 Information Technology (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 [3]. Those data centers are consuming a huge amount of energy each day so as to carry out the needs of its customers and the increase in the information processing requirement of different sectors [4]. 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.

PROBLEM STATEMENT

i. Internal power instrumentation equipment is not shipped with networking devices to provide accurate information on power consumption of these devices. In any case, such addition may incur extra costs.
ii. Most Switches lack comprehensive data about power consumption as their specification data sheets only give information on maximum rated power. Maximum rated power is quite insufficient to model the actual energy consumption of such devices.

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AIM:

i. Development of Mathematical model for power management of wireless network components

OBJECTIVE

i. To ascertain the relationship between electric power and number of active ports.
ii. To ascertain the relationship between the power consumed and traffic through the device.
iii. To determine if the power consumed by the switches are dependent on the firmware version on the switch/router.

II. METHODOLOGY

This paper mainly focuses on the power modelling of the network devices i.e., how power usage of devices varying with the impact of load and also with varying active number of ports of the switch and varying the connection type of the access point. The main focus of this project is on the power usage of switches and wireless routers. 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.

EXPERIMENTAL SETUP FOR DEVICES

Experimental setup for Switches

In this stage of the project the experimental test bed was setup to know the power usage of different network switches of different configurations from different vendors. Mainly from research we considered the switches from two vendors Cisco and Netgear. The reason for using these vendors is 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.

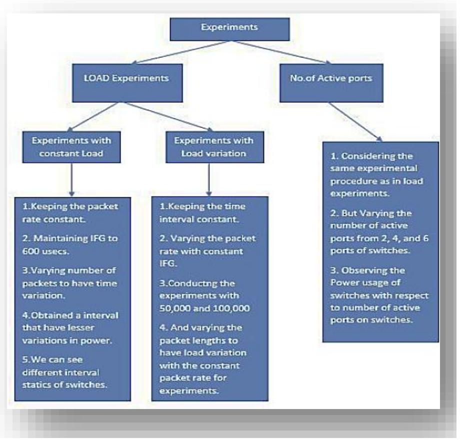

Figure 1: Experimental Procedure steps

In this work the traffic load is produced by considering three parameters.

They are:

i. Number of packets.
ii. Inter frame gap. (IFG)
iii. Packet size.

From the above listed 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.

i. 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.
ii. 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.
iii. Then the latter experiment procedure is followed to reach objective of this research. This has been discussed in the below sections.

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, some traffic load need to be generated which is User Datagram Protocol (UDP) traffic load in our work. The required traffic load generation has been done by udp client which was a shell script. From this shell script the traffic load was generated on the source and it was switched to destination through the Device under test (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.

i. 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.
ii. In this interval of time the generated load for the switches are varied with constant packet rate unit.
iii. Firstly, the experiments are conducted for packet rate of 238 packets per second with the variation of load.
iv. 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.
v. For these experiments, the corresponding energy values are grabbed from the Monitoring tool Emonpi. The energy values are obtained by an approach called watt second approach discussed in the background section.
vi. 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.

The sources and destinations were changed and the same experimental procedure was followed for the other sources and destinations. By following the above procedure, we measured the energy consumed for different DUT's. The energy consumed by DUT's for each iteration was obtained by following the procedure of running the automation Perl script in NTAS. The Perl script first grabs start energy of the DUT before the generation of traffic load. Then after that the UDP traffic load generation was done for the parameters considered like Packet length, Number 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 was grabbed as End energy from EmonCMS. So, in order to know how much energy has been consumed by that DUT, we took the difference between start and end energies in order to provide us the average energy consumed. By this average energy values, we can calculate the average power consumed. These values were then taken in a log file for each iteration. These log files were then subjected to further statistical analysis.

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

i. This section deals with the energy usage of the considered DUT variation in the number of active ports on the DUT
ii. This experimentation includes changing the number of active ports on the switches with different load scenarios
iii. The same experimental procedure was followed to maintain the load on the switches as in. First the Power usage with 2 active number of ports is observed for the packet rate considered.
iv. 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.
v. Then packet rate doubled and the experiments were conducted to observe the power usage of switches with respect to the active number of ports.
vi. These experiments of 2ports, 4ports and 6 ports were conducted for 40 iterations. We observed, how minimum number of ports variation impacts the power usage of the switches and can later relate it to more number of ports.
vii. 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 listed procedure was followed for different DUT's considered this project.

III. RESULTS AND DISCUSSION

Here presented are the results obtained in intervals for varying the load as well as variation in the active number of ports used for each switch. The results obtained in this research were used to provide the power profiling of the switches.

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:

i. For this experiments the traffic load on all three switches considered to be constant.
ii. For that purpose, the considered configurations are keeping the wait time as constant to 600 microseconds.
iii. 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.
iv. The experiments were conducted for the three switches considered in this study.
v. The results obtained for these experiments are shown in the tables below.

Table 1: Statistical analysis of switches for different time intervals

Switch:	Time In-terval (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 2: Statistics of switches with Packet rate 238 packets/sec

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 3: Statistics of switches with Packet rate 576 packets/sec

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

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 5: Power profiles of switches with maximum load with 640 bytes size

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 6: Power profiles of switches with maximum load with 1280 bytes size

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 7: Power profiles of switches with maximum load with 1470 bytes size

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 8: Average Power Consumption with variation of Number of active ports

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

POWER/ENERGY CONSUMPTION MODEL FOR SWITCH

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. The practical insights was combined 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. 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:

$$P_{switch} = P_{base\_components} + P_{active\_ports}$$

$$P_{switch} = P_{base\_components} + \sum_{i}^{n} P_{active\_ports}$$

$$P_{switch} = P_{base\_components} + P_{traffic\_components} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where $P_{base\_components}$ corresponds to power consumed when switch is on but none of its ports are active. And $P_{traffic\_components}$ 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:

$$P_{switch} = P_{base\_components} + P_{active\_ports} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

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

$$P_{switch} = P_{base\_components} + \sum_{i}^{n} P_{active\_ports} \text{ --------------------------- } (4)$$

Table 9: Summary of Active ports Overall Average Power for the three Switches under Review

Switch	Cisco2950	Cisco3560	GS-724T
Ports	Average Power (W)	Average Power (W)	Average Power (W)
2	63.6	61.8	55.6
4	64.1	62.4	56
6	64.6	62.9	56.1

To predict the power consumption of these switches as the number of active ports (P_{active_ports}) increase, we rely on the following obtained experimental models:

For Cisco 2950,

$$P_{Average} = 0.25n_{active\_ports} + 63.1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

For Cisco 3560,

$$P_{Average} = 0.275n_{active\_ports} + 61.7 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

For GS-724T,

$$P_{Average} = 0.125n_{active\_ports} + 55.4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Therefore

For Cisco 2950

$$P_{base_{components}} = 63.1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

For Cisco 3560

$$P_{base_{components}} = 61.7 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

For GS-724T,

$$P_{base_{components}} = 55.4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

V. CONCLUSION

In this paper power usage of network switches was profiled. From the results and analysis of the experiments conducted with different scenarios, a set of simple equations were then derived from the charts. It is observed that the power consumed by the switches are dependent on the firmware version on the switch and its number of active ports This equation can be used to test simple scenarios and can be extended to more complex scenarios with variable traffic patterns.

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