Master Thesis Presentation

Modeling the power consumption of switch using Design of Experiment

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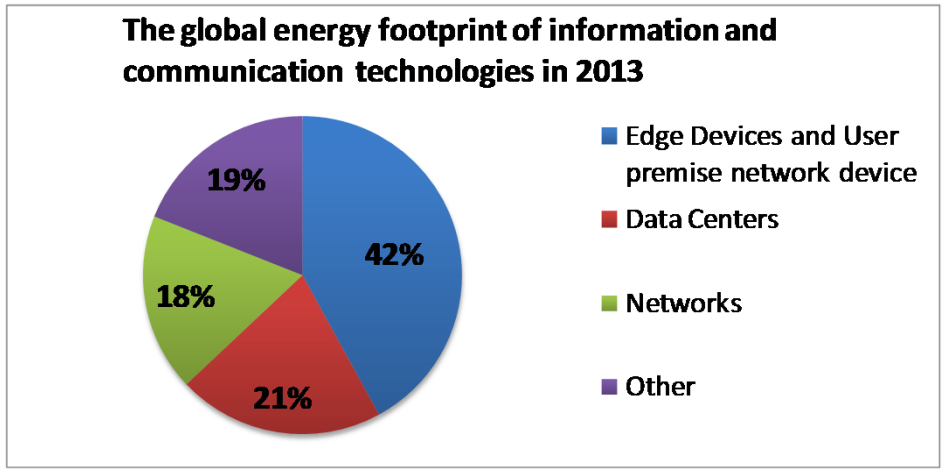
Introduction

- Shifting of business sectors and consumers towards smarter, more connected lifestyles
- With this growth in capacity comes a potential for unsustainable power consumption growth
- ICT industry must address power consumption in order to increase energy efficiency of networking equipment and connected devices.

Motivation and Focus area

- Power greedy network devices



- Energy consumption phases for network devices :
  - Manufacturing
  - **Usage**
  - Dismantling
- Network Devices :
  - Router
  - **Switch**
  - Access Point

Source: Global energy footprint of ICT
(data based on International Energy Agency 2014)

Objectives

- Find the parameter with highest impact on power consumption from the selected parameters.
- Provide an equation for measuring the power consumption.
- Validate the equation.
- Explore hibernation characteristics and analyze its behavior.

Related Work

- Gupta, Grover and Singh (2004)
  - feasibility study on power management of Ethernet switches.
  - Discuss sleep mode
- Mahadevan et. al (2010)
  - Provide a general model for power consumption where every variables power is needed to measure
  - Discuss about parameters
- Zhan and Goulart (2009)
  - Uses design of experiment to analyze the broadband wireless link for rural areas

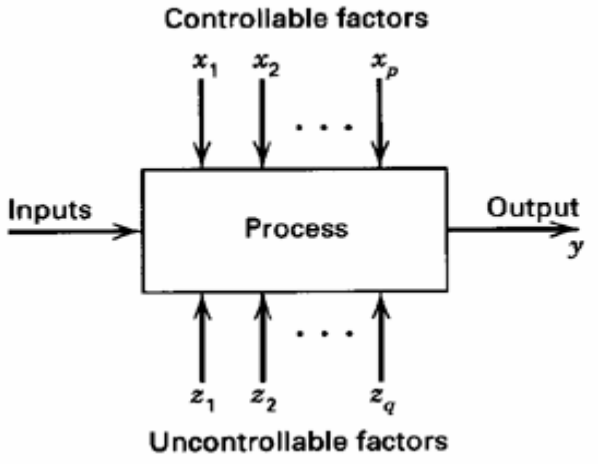
[1]Gupta, M., Grover, S. and Singh, S. (2004). A Feasibility Study for Power Management in LAN Switches. *ICNP '04 Proceedings of the 12th IEEE International Conference on Network Protocols*, pp.361-371.

[2]Mahadevan, P., Sharma, P., Banerjee, S. and Ranganathan, P. (2009). A Power Benchmarking Framework for Network Devices. *NETWORKING 2009*, pp.795-808.

[3]Zhan, W. and Goulart, A. (2009). Statistical Analysis of Broadband Wireless Links in Rural Areas. *JCM*, 4(5).

Research Methodology

- Design of Experiment
  - Design of experiments helps to understand the **inner structure** of the experiment and the **relation** between the input variables and response variables
  - It is a black-box approach in order to solve a problem
  - Reason
    - Precision
    - Factor Interaction
    - Balanced Design



Leopoldo Angrisani, Rosario Schiano Lo Moriello , Massimo D'Apuzzo, Mauro D'Arco "Design of experiments for power measurement method in wireless communications systems", 2011

Design of Experiment

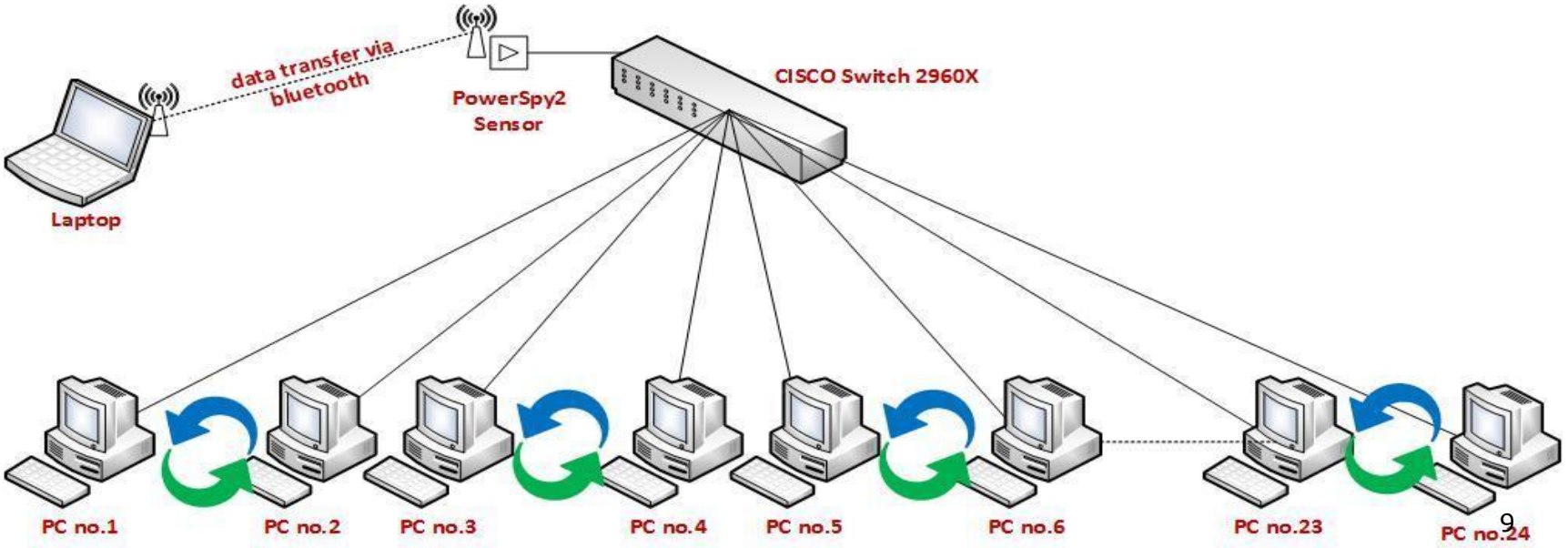
- Full Factorial:
  - A planned set of tests on the response variable with one or more inputs factors with all possible combinations of levels.
  - provides information about factor **main effects** and **factor interactions**
  - Better for less number of factor
- Linear Regression Analysis:
  - Simple analysis technique of experimented data
  - method of fitting straight lines to set of data.
  - Two-way interaction

Selected input parameters

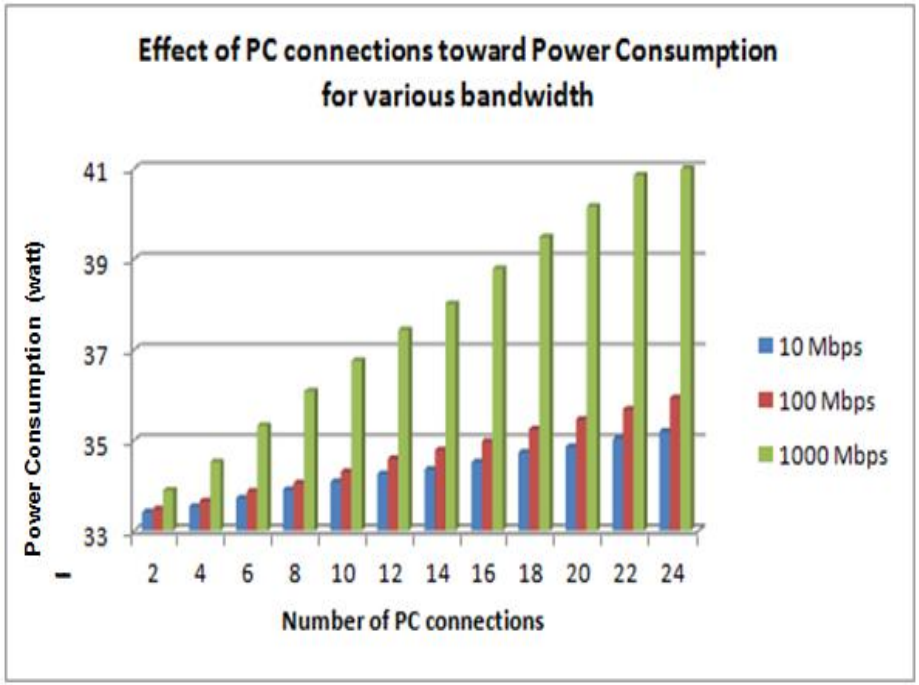
- Parameters
  - Bandwidth
    - 10Mbps
    - 100Mbps
    - 1Gbps
  - Number of connected PC (active link)
    - 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24
  - Link Load
    - Link load = Total incoming traffic/ (Number of Pc's connected * Bandwidth) %
    - Different link load value is used by varying traffic.

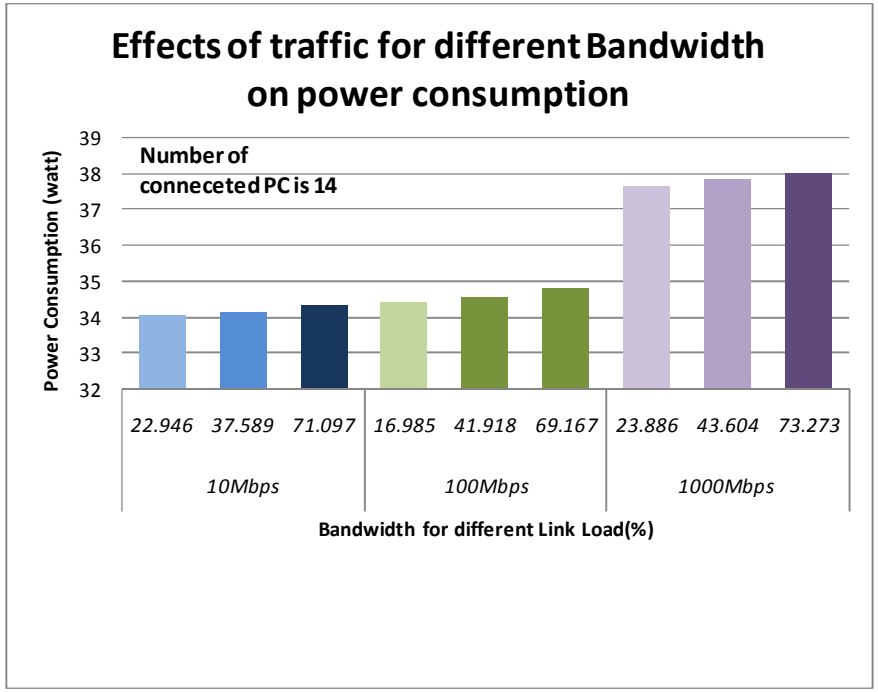
Tools and Test-bed Architecture

- Tools:
  - Jperf
  - PowerSpy2
  - Minitab 17
- Network Architecture:



Initial Result

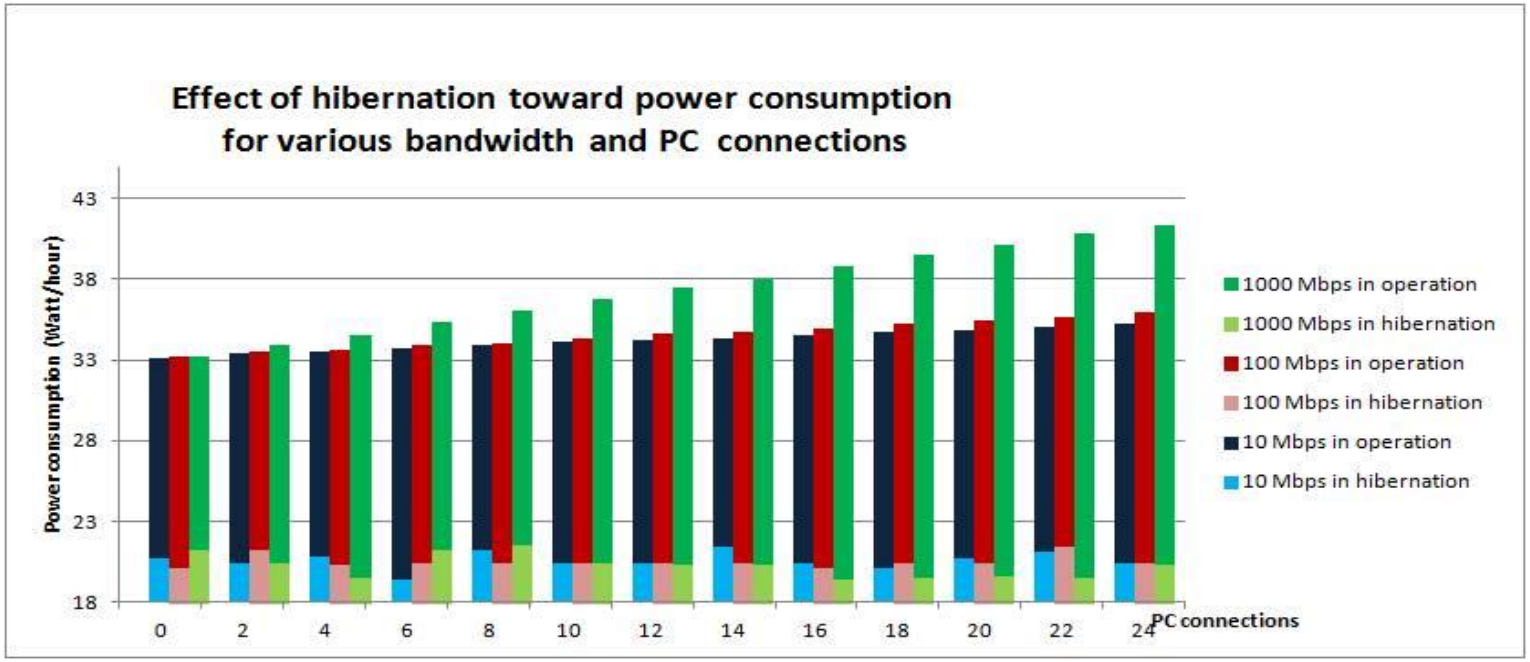




- When the Bandwidth or number of connected PC is increased, the power consumption is also increased.

- For a fixed bandwidth even if the Link Load is changed, power consumption does not change much.

Initial Result



- During hibernation the power consumes in the range of 19 to 21 watt regardless of bandwidth and connected link

- Hibernation on average saves 43% power.

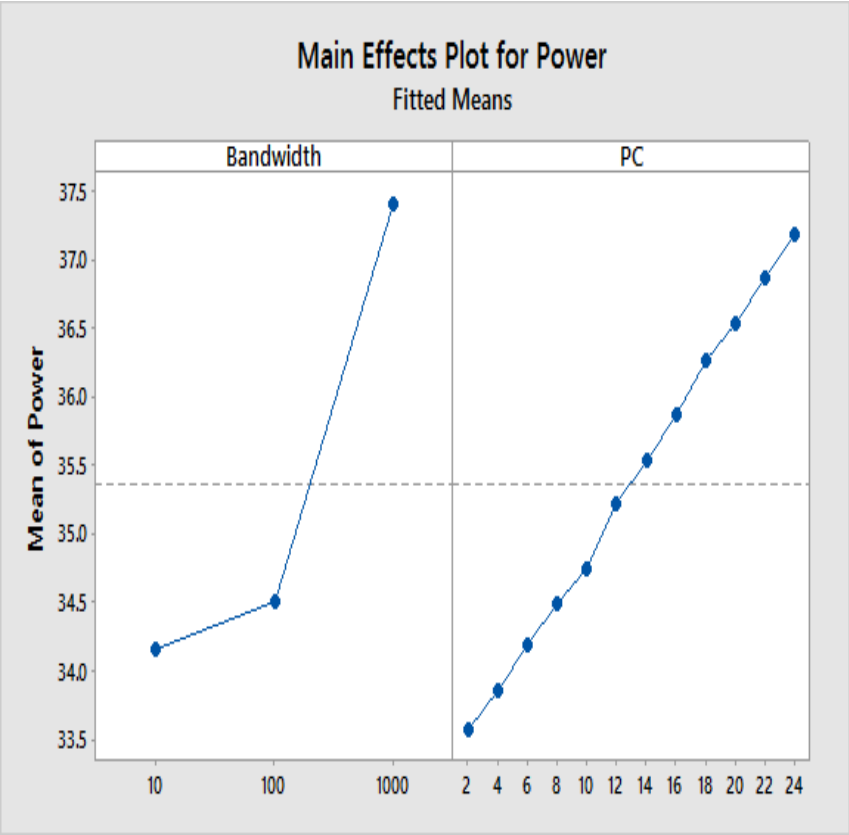
Full Factorial Analysis
(Switch on operation mode)

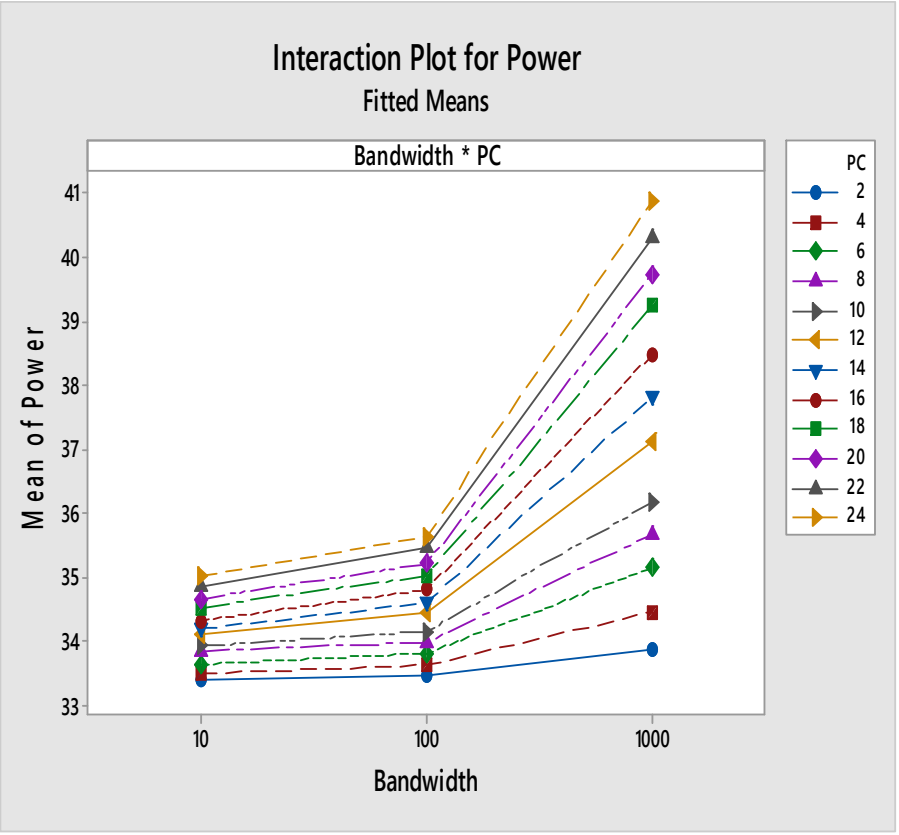
- To reduce the complexity two variable has been used
  - Bandwidth (3 levels)
  - Number of PC connected (12 levels)

- P-value from the analysis
  - P-value is used to reject null hypothesis
  - P-value < .025 means significant impact

Source	P-Value
Bandwidth (Mbps)	0.000
PC	0.000
Bandwidth (Mbps)*PC	0.000

Full Factorial Analysis
(Switch on operation mode)





Full Factorial Analysis
(Switch on operation mode)

- Equation:

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

- {x1,x2,x3} = {10Mbps, 100Mbps and 1000Mbps}
- {y1,y2,y3…,y12} pairs of connected pc = {2,4,6,…,24}

- General formula:

  Power (watt) = 35.3642 + αX + βY + γ(X*Y)

  - Where X= Bandwidth, Y= Number of PC connected

- The model has a R-sq adjusted value of 98.53%.
  - It means 98.53% of the time the variation in response variable is caused by these factors.

Linear Regression Analysis
(Switch on operation mode)

- In this case Three parameter has been used
  - Bandwidth
  - Number of PC connected
  - Link Load= Total incoming traffic/ (Number of Pc's connected * Bandwidth)
- Reason:
  - Future use in context of IEEE802.3az energy efficiency Ethernet protocol. [4]
  - Less Complex than Full factorial

[4] Christensen, K., Reviriego, P., Nordman, B., Bennett, M., Mostowfi, M. and Maestro, J. (2010). IEEE 802.3az: the road to energy efficient ethernet

Linear Regression Analysis
(Switch on operation mode)

- Equation:

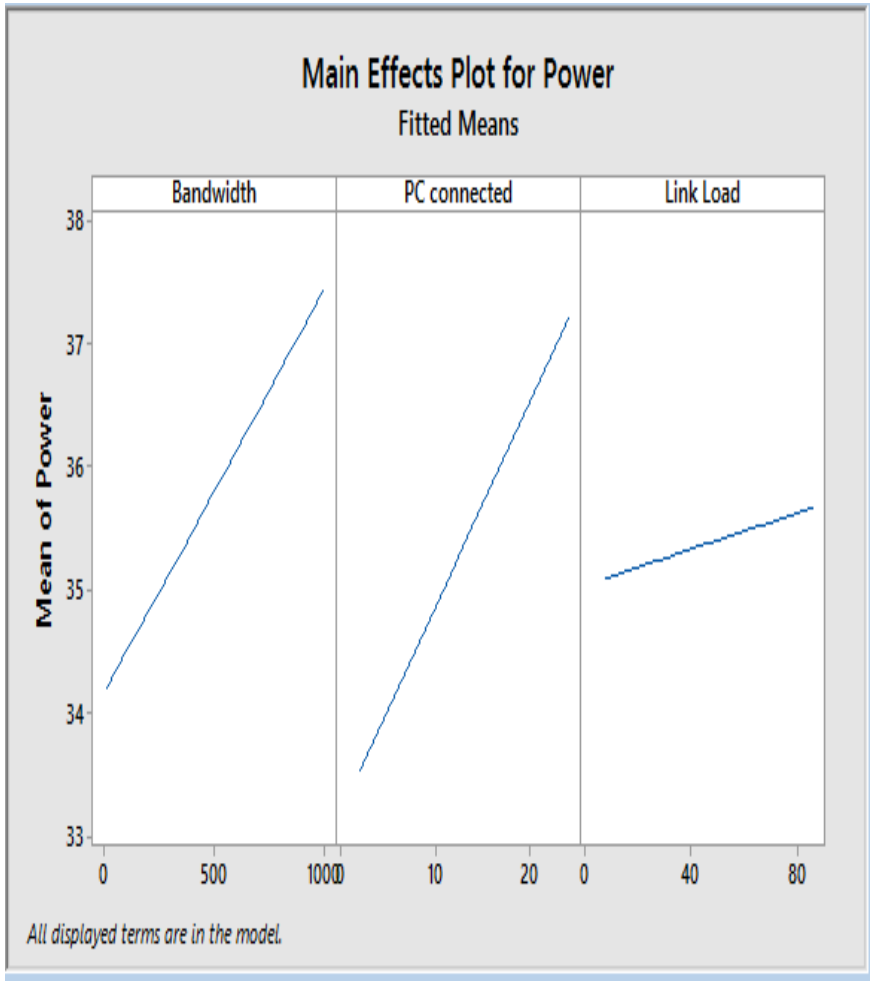
  Power = 33.2708 - 0.000318 Bandwidth+0.05156 PC connected - 0.001329 Link Load+0.000253 Bandwidth*PC connected+ 0.000006 Bandwidth*Link Load +0.000477 PC connected*Link Load

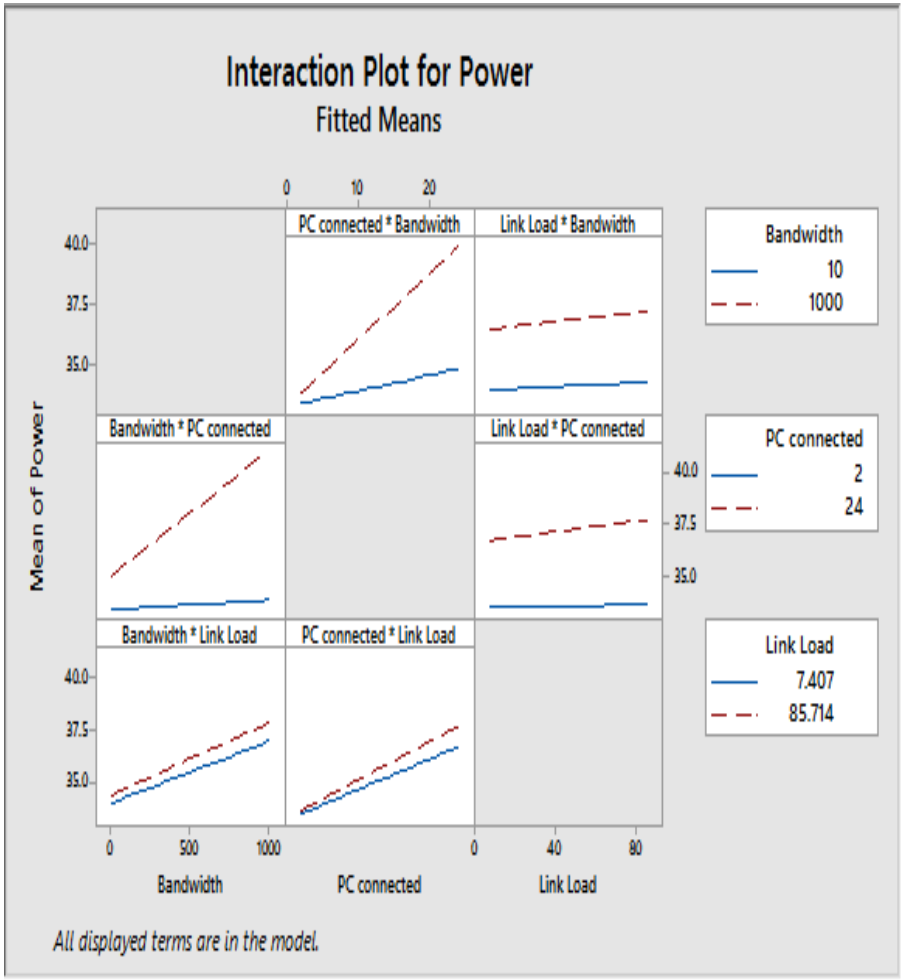
- P- value :

Source	P-Value
Link Load	0.177
Bandwidth (MBPS)	0.000
PC	0.000
Bandwidth (MBPS)*PC	0.000
Link Load* PC	0.000
Bandwidth(MBPS)*Link Load	0.000

- R-sq value of 99.75%
  - It means 99.75% of the time the variation in response variable is caused by these factors.

Linear Regression Analysis
(Switch on operation mode)

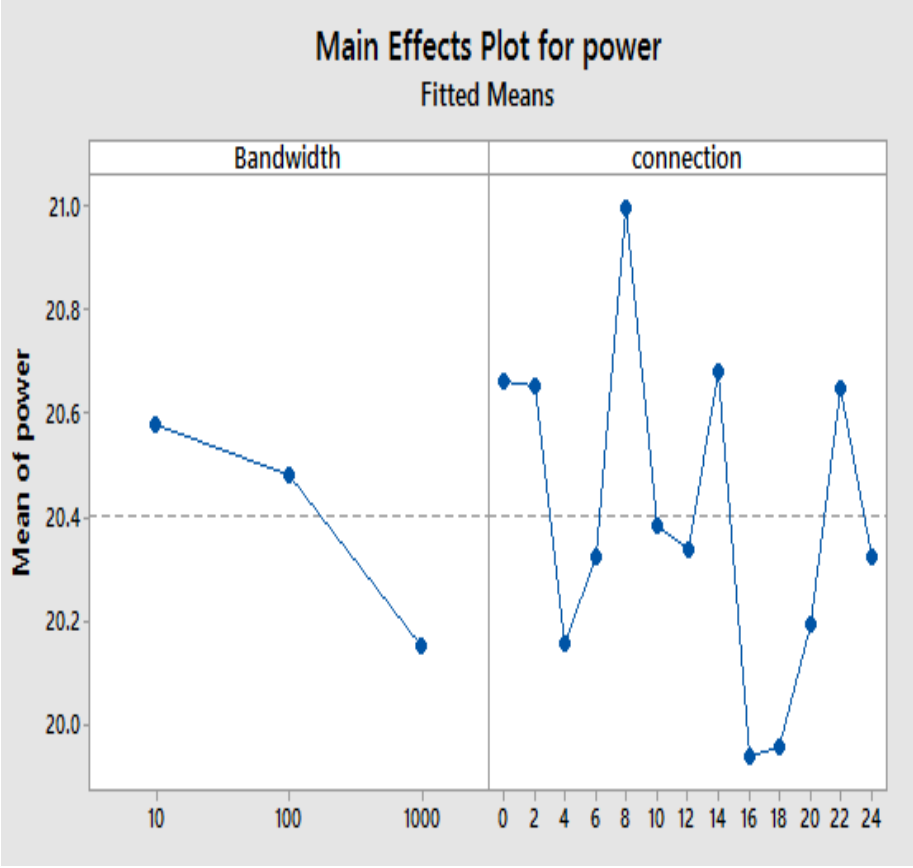




Switch on Hibernation mode

- Parameter
  - Bandwidth
  - Number of connection
- P-value

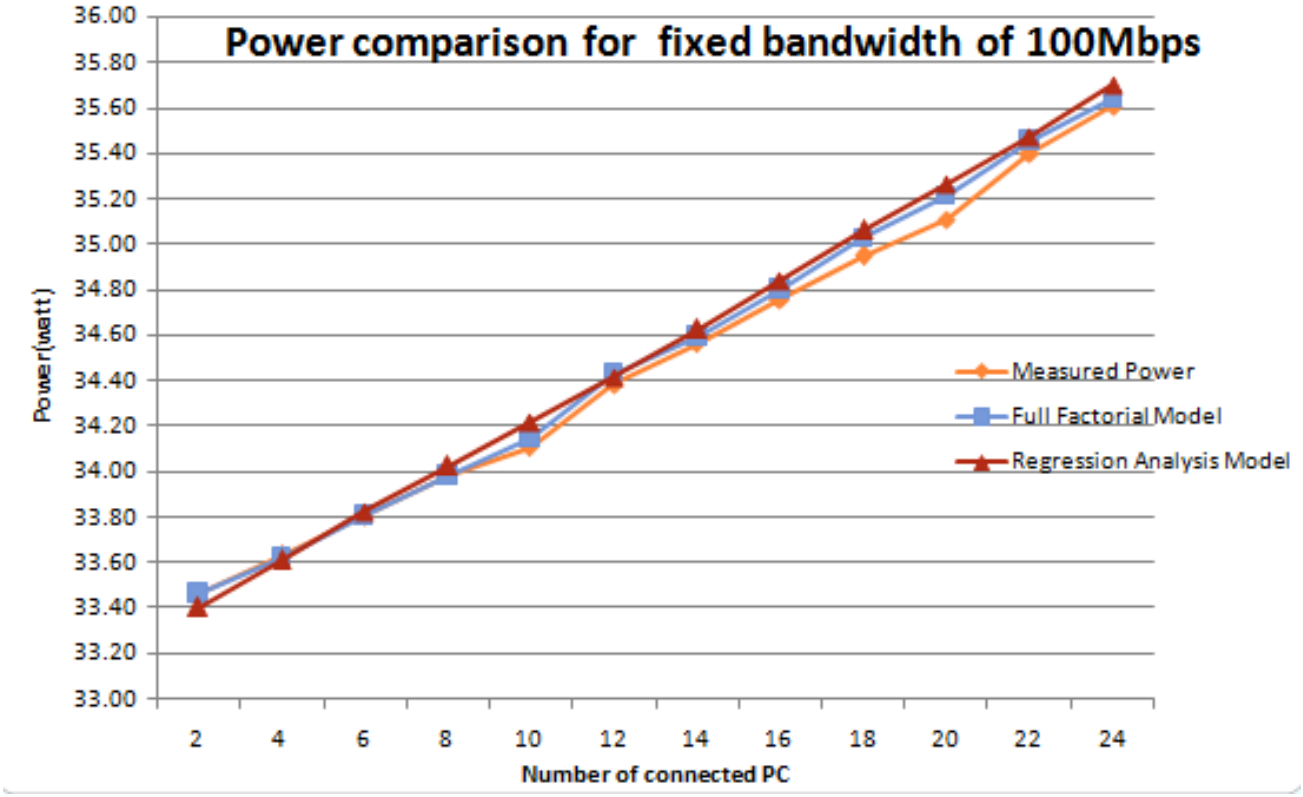
Source	P-Value
Bandwidth (Mbps)	0.175
PC Connection	0.610



Result: Non Deterministic

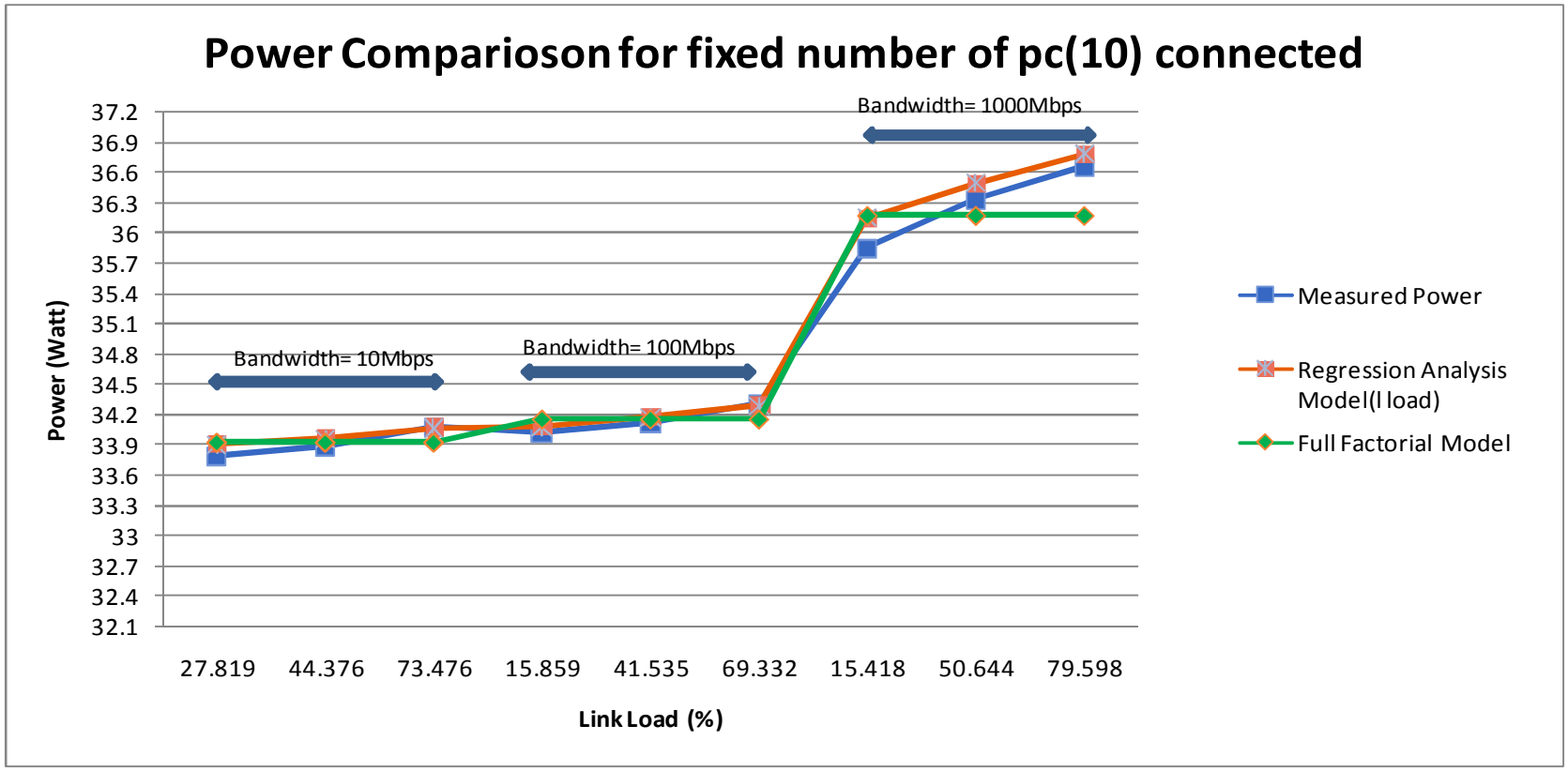
Validation

- Power consumption comparison for fixed bandwidth of 100Mbps
- Average percentage error: Full factorial: .1%
  Regression analysis: .09%



Validation

- Power consumption comparison with change of traffic for fixed number of connected pc
- Average percentage error: Full factorial: .5%
  Regression analysis: .29%



Discussion

- **Hibernation vs. Power-off**
  - Hardware Reliability
    - Coffin-Manson model [5,6]
  - Quality of Service

Mode	Time to wake up (get a stable power)	Time to get ready to send a data
Switch in Hibernation mode	240 seconds	260 seconds
Switch Power off	270 seconds	290 seconds

[5] L. F. Coffin Jr. and U.S. Atomic Energy Commission and General Electric Company, A Study of the Effects of Cyclic Thermal Stresses on a Ductile Metal, Knolls Atomic Power Lab., 1953
[6] Luca Chiaraviglio, Pawel Wiatr, Paolo Monti, Jiajia Chen, Josip Lorincz, Filip Idzikowski, Marco Listanti, and Lena Wosinska Is Green Networking Beneficial in Terms of Device Lifetime?, EEE Communications Magazine, May 2015

Discussion- Practical Usage

- **Measuring the power consumption of a cluster of switch**
  - Total power consumed by a enterprise for switch having '**n**' number of switches

$$P_{Total} = p_1 + p_2 + p_3 + \ldots + p_n$$

- **Measuring the maximum allowable life-time decrease**
  - Used to calculate the ***trade-off*** between ***savings coming from a green strategy*** and the ***extra costs related to the decreased lifetime*** of a device.[7]

$$d_{\max,\mathrm{thr}\%} = \frac{\mathrm{thr}\% * P_{\mathrm{eq}} * C_{\mathrm{kWh}}}{\mathrm{thr}\% * P_{\mathrm{eq}} * C_{\mathrm{kWh}} + \frac{\mathrm{FR}}{10^6} * (\mathrm{MTTR} * \mathrm{Pers.} * C_m)} [\%]$$

P_{eq} = Power consumption in active mode
thr% = given threshold
C_{kWh} [USD/kWh] = electricity cost
FR = equipment failure rate
C_m [USD/h] = hourly rate of a reparation crew
MTTR [h] = mean time to repair,
Pers. = number of reparation crew members

[7] P. Wiatr et al., "Energy Efficiency Versus Reliability Performance in Optical Backbone Networks," J. Optical Commun. and Networking, vol. 7, Mar. 2015, pp. A482–91

Discussion- Practical Analysis

Enterprise Scenario

Total number of switch =50

Lets Assume all the switch has 24 links and following traffic rate.

- 8 links have a traffic rate in between: 100-1000mbps
- 12 links have a traffic rate in between: 10-100mbps
- 4 links have a traffic rate in between: 1-10mbps

- Now considering 10% switch is always on due to web server, mail server and other general purposes,

	Runtime Duration	Adaptive Link Rate
Case 1	24x7	No, Maximum Available link is used
Case 2	24x7	Yes
Case 3	Only on office hours, hibernated during weekend and office closing	Yes
Case 4	Only on office hours, Powered off during weekend and office closing	Yes

**Adaptive Link Rate: reduction of the bandwidth is done according to the traffic rate

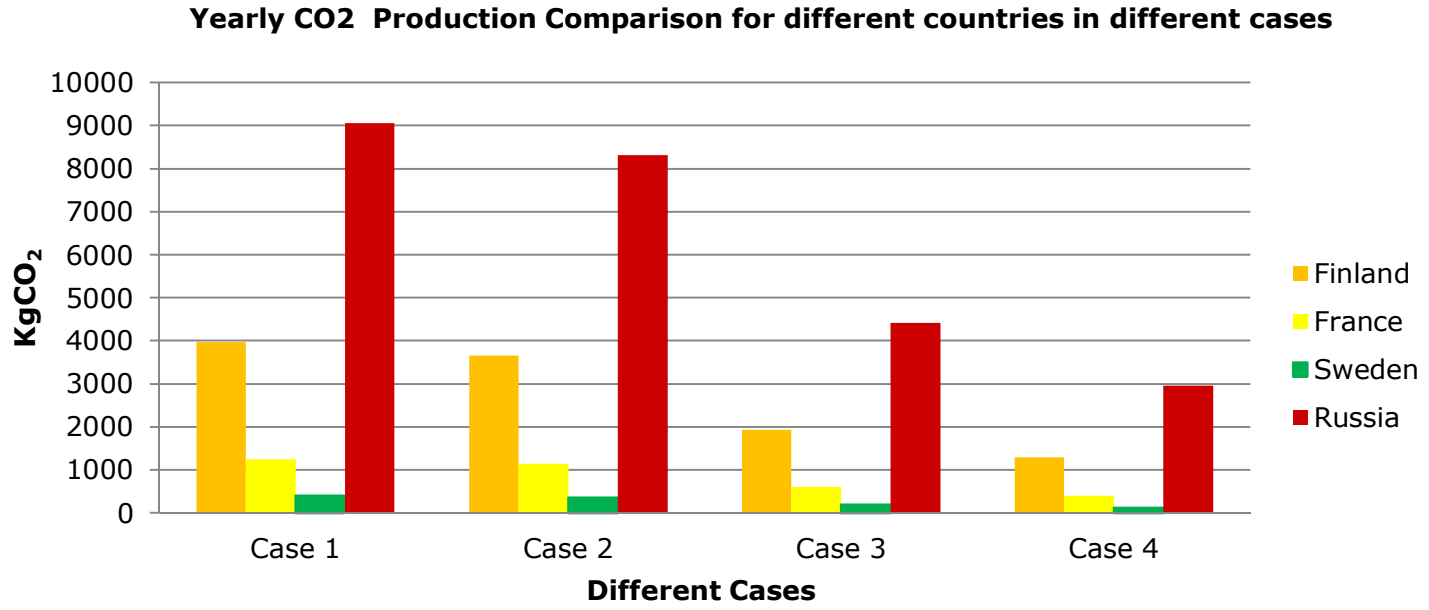
Power consumption for different cases

Using the equation achieved from ***full factorial*** method

Case	Power Consumption in 1 switch (watt)	Per day Energy Consumption for 1 switch (kwh)	Monthly energy consumption for 1switch (kwh)	Yearly energy consumption for 1switch (kwh)	Total Yearly energy consumption from all the switches (kwh)	Energy Savings compare to Case1 (%)
1	40.987	.9816	29.446	353.352	17667.6	----
2	37.2128	.8928	26.784	321.41	16230.21	**8.13574**
3	37.2128	.652	12.7	152.4	8624.76	**51.18318**
4	37.2128	.372	7.44	89.28	5784.36	**67.26007**

Yearly CO2 Production Comparison for different countries in different cases

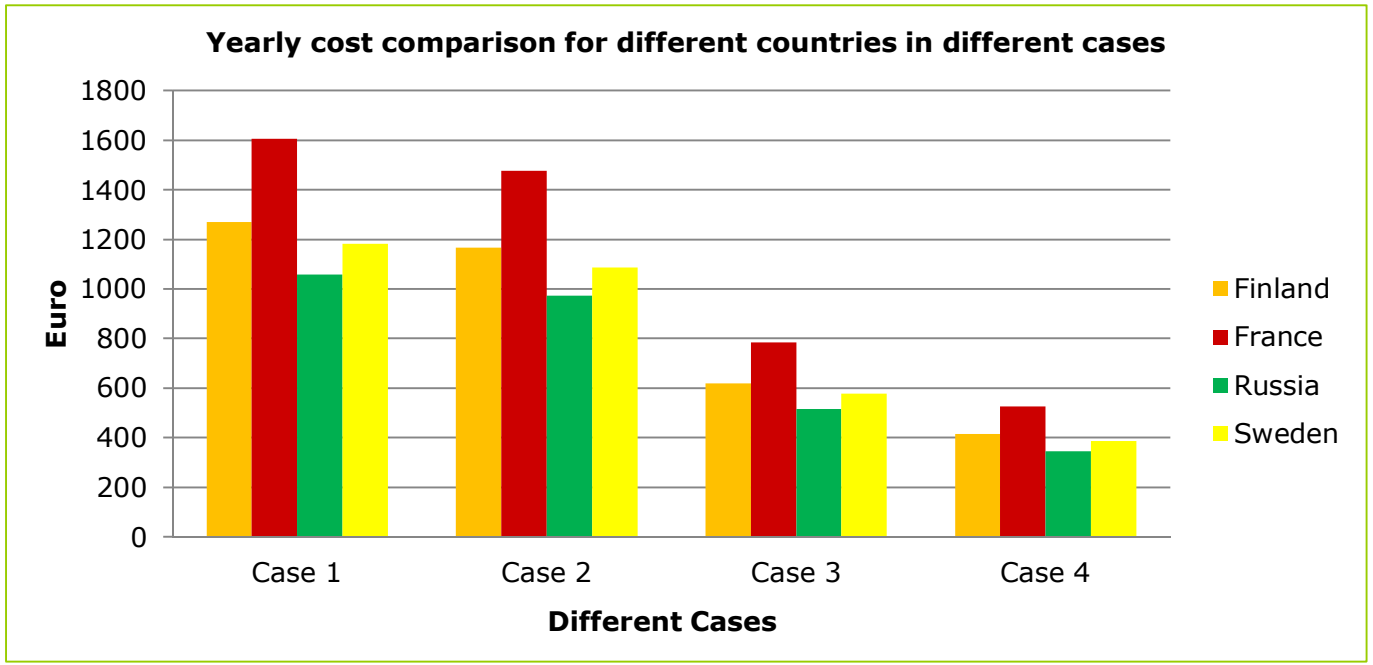
Country	Electricity-specific emission factors (kgCO2/kWh)	Case 1	Case 2	Case 3	Case 4
Finland	0.225457295	3983.28931	3659.21924	1944.51506	1304.12616
France	0.070927465	1253.11808	1151.16765	611.732363	410.269991
Sweden	0.023033883	406.953431	373.844758	198.661713	133.236271
Russia	0.513180381	9066.6657	8329.02535	4426.05762	2968.42007



Source: Matthew Brander, Aman Sood, Charlotte Wylie, Amy Haughton, and Jessica Lovell, *Electricity-specific emission factors for grid electricity August* 2011,Eco-metrica.

Yearly cost comparison for different countries in different cases

Country	average national electricity price (Eur)/kwh	Case 1	Case 2	Case 3	Case 4
Finland	0.072	1272.067	1168.5751	620.9827	416.4739
France	0.091	1607.752	1476.9491	784.8532	526.3768
Russia	0.06	1060.056	973.8126	517.4856	347.0616
Sweden	0.067	1183.729	1087.4241	577.8589	387.5521



Source

a. Eurostat Statistics explained, 2015, available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics

b. Energy Research Estore, August 2014. available at: https://estore.enerdata.net/power-market/russia-electricity-report.html

Conclusion

- Achievements
  - Provides a method for calculating power consumption for switch
  - Discuss the characteristics of Hibernation
  - Discuss few uses of the model
- Future work
  - Same experiment for other network equipment like router
- This thesis work is a small step towards green networking and sustainability.

Thank You

Appendix

- Information about Traffic:
  - Traffic
    - Total incoming traffic into the switch
    - Varies from 3Mbps to 17000Mbps
    - Varied by Maximum Segment Size (256 – 1460Bytes)
    - and Window size (8kBytes -123kBytes)
  - How to calcu full factorial and linear regression
  - How t o calcu p value
  - IEEE802.3az read the paper
  - What is emission factor?
  - What is the difference between hibernation and sleep mode
  - Why so less parameter?

References

- Asq.org, (2015). *What Is Design of Experiments (DOE)? | ASQ*. [online] Available at: http://asq.org/learn-about-quality/data-collection-analysis-tools/overview/design-of-experiments.html.
- Ayguade, E. and Torres, J. (n.d.). *Creating power-aware middleware for energy-efficient data centres*. [online] Available at: http://ercim-news.ercim.eu/en79/special/creating-power-aware-middleware-for-energy-efi¬cient-data-centres.
- Barth, U., Wong, P. and Bourse, D. (n.d.). *Key challenges for green networking*. [online] Available at: http://ercim-news.ercim.eu/en79/special/key-challenges-for-green-networking.
- Beckmann, E., Jauco, L. and Koo, S. (2014). Green networking: Developing sustainable computer networks. *2014 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*.
- Bianzino, A., Chaudet, C., Rossi, D. and Rougier, J. (2012). A Survey of Green Networking Research. *IEEE Commun. Surv. Tutorials*, 14(1), pp.3-20.
- Bilal, K., Khan, S., Madani, S., Hayat, K., Khan, M., Min-Allah, N., Kolodziej, J., Wang, L., Zeadally, S. and Chen, D. (2012). A survey on Green communications using Adaptive Link Rate. *Cluster Computing*, 16(3), pp.575-589.
- Blackburn, J. and Christensen, K. (2015). *Green Telnet*. [online] Dr. Dobb's. Available at: http://www.ddj.com/cpp/211600219.
- Blanquicet, F. and Christensen, K. (2007). An Initial Performance Evaluation of Rapid PHY Selection (RPS) for Energy Efficient Ethernet. *32nd IEEE Conference on Local Computer Networks (LCN 2007)*.
- Chou, J., Kuo, A., Tseng, D., Lin, J. and Huang, K. (2008). *Proposal of Low-Power Idle 100Base-TX*.
- Christensen, K., Nordman, B. and Brown, R. (2004). Power management in networked devices. *Computer*, 37(8), pp.91-93.
- Christensen, K., Reviriego, P., Nordman, B., Bennett, M., Mostowfi, M. and Maestro, J. (2010). IEEE 802.3az: the road to energy efficient ethernet. *IEEE Communications Magazine*, 48(11), pp.50-56.
- Drouant, N., Rondeau, Ã‰., Georges, J. and Lepage, F. (2014). Designing green network architectures using the ten commandments for a mature ecosystem. *Computer Communications*, 42, pp.38-46.
- Evolution.berkeley.edu, (2015). *Warming to evolution*. [online] Available at: http://evolution.berkeley.edu/evolibrary/news/060701_warming.
- Foll, L. (2008). Techniques dâ€™estimation de consommation sur la hauteur, la structure et lâ€™Ã©volution de lâ€™impact des TIC en France. *Ph.D Thesis, Institut national des tÃ©lÃ©communications.*.
- Foundation for IT Sustainability, (n.d.). *What is Green IT?*. [online] Available at: http://www.greenitweek.org/index.php/learn/what-is-green-it.
- Gendy, M., Bose, A., Wang, H. and Shin, K. (2003). Statistical characterization for per-hop QoS. *Lecture Notes in Computer Science*, 2707, pp.21-40.
- Griffith, J. and Persons, K. (2010). *â€™How to guideâ€™ on Iperf and Jperf*. 1st ed.
- Gunaratne, C., Christensen, K., Nordman, B. and Suen, S. (2008). Reducing the Energy Consumption of Ethernet with Adaptive Link Rate (ALR). *IEEE Trans. Comput.*, 57(4), pp.448-461.
- Gupta, M., Grover, S. and Singh, S. (2004). A Feasibility Study for Power Management in LAN Switches. *ICNP '04 Proceedings of the 12th IEEE International Conference on Network Protocols*, pp.361-371.
- Hu, C., Wu, C., Xiong, W., Wang, B., Wu, J. and Jiang, M. (2011). On the design of green reconfigurable router toward energy efficient internet. *IEEE Communications Magazine*, 49(6), pp.83-87.

References

- Iea.org, (2014). *Publication:- More Data, Less Energy: Making Network Standby More Efficient in Billions of Connected Devices*. [online] Available at: http://www.iea.org/publications/freepublications/publication/more-data-less-energy.html.
- Johhnson, T. (n.d.). *The future of networking: The green movement*. [online] Available at: http://www.cse.wustl.edu/ jain/cse574-10/ftp/green/.
- Kawamoto, K. (2002). Electricity used by office equipment and network equipment in the US. *Energy*, 27(3), pp.255-269.
- Lanzisera, S., Nordman, B. and Brown, R. (2011). Data network equipment energy use and savings potential in buildings. *Energy Efficiency*, 5(2), pp.149-162.
- Lanzisera, S., Nordman, B. and Brown, R. (2011). Data network equipment energy use and savings potential in buildings. *Energy Efficiency*, 5(2), pp.149-162.
- Lucent, A. (n.d.). *Game-changing speed and services*. [online] Available at: http://www3.alcatel-lucent.com/features/100GE/gamechangingss.html.
- Mahadevan, P., Shah, A. and Bash, C. (2010). Reducing lifecycle energy use of network switches. *Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology*.
- Mahadevan, P., Sharma, P., Banerjee, S. and Ranganathan, P. (2009). A Power Benchmarking Framework for Network Devices. *NETWORKING 2009*, pp.795-808.
- Mayo, R. and Ranganathan, P. (2005). Energy Consumption in Mobile Devices: Why Future Systems Need Requirementsâ€"Aware Energy Scale-Down. *Power-Aware Computer Systems*, pp.26-40.
- Meyer, R. and Krueger, D. (2005). *A Minitab guide to statistics*. Upper Saddle River, NJ: Pearson/Prentice Hall.
- Mohanoor, A., Radhakrishnan, S. and Sarangan, V. (2007). On energy aware routing in wireless networks. *IEEE, Broadband Communications, Networks and Systems, 2007. BROADNETS 2007. Fourth International Conference on*, pp.690 - 697.
- Nedevschi, S., Popa, L., Iannaccone, G., Ratnasamy, S. and Wetherall, D. (2008). Reducing network energy consumption via sleeping and rate-adaptation. *NSDI'08 Proceedings of the 5th USENIX Symposium on Networked Systems Design and Implementation*, pp.323-336.
- Pamlin, D. and SzomolÂ´anyi, K. (2007). *Saving the Climate @ the Speed of Lightâ€"First Roadmap for Reduced CO2 Emissions in the EU and Beyond*. 1st ed. World Wildlife Fund and European Telecommunications Network Operatorsâ€™ Association.
- Penttinen, A. (2012). *Green Networking - A Literature Survey*. Aalto: Aalto University, Department of Communications and Networ king.
- PowerSpy2 User maual, (2015). [online] Available at: http://www.alciom.com/images/stories/downloads/.
- Publishing, O. and Agency, I. (2014). *Capturing the Multiple Benefits of Energy Efficiency*. Paris: OECD Publishing.
- Raritan.com, (2015). *Intelligent Rack Power Distribution Units | Power Management | Raritan*. [online] Available at: http://www.raritan.com/products/power-distribution.
- Rivoire, S., Shah, M., Ranganathan, P. and Kozyrakis, C. (2007). Modeling and Metrology Challenges for Enterprise Power Management. *IEEE Computer*, 40, pp.39-48.
- Robert, N. (2014). *Notes on linear regression analysis*. [online] Duke University. Available at: http://people.duke.edu/~rnau/notes_on_linear_regression_analysis--robert_nau.pdf .
- Rondeau, E. and Lepage, F. (2010). Vers une ingÃ©nierie de rÃ©seaux respectueuse de l'environnement. *CIFA 2010, 6Ã¨me ConfÃ©rence Internationale Francophone dâ€™Automatique*.
- Rondeau, E., Lepage, F., Georges, J. and Morel, G. (2015). Measurements and Sustainability, Chapter 3. In: M. Dastbaz, C. Pattinson and B. Akhgar ed., *Green Information Technology: A Sustainable Approach*, 1st ed. Elsevier.