TOWARDS A POWER CONSUMPTION ESTIMATION MODEL FOR ROUTERS OVER TCP AND UDP PROTOCOLS

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Abstract

Due to the growing development in the information and communication technology (ICT) industry, the usage of routers has increased rapidly. Meanwhile, these devices that are produced and developed today consume a definite amount of power, Furthermore, with limited focus on power estimation techniques and the increased demands of networking devices, it led to an increase of the vitality consumption as a result. While new high capacity router components are installed, energy intake in system elements will be rising due to the higher capability network consuming larger component of the vitality. This study considers providing estimating power model in different traffic settings over TCP and UDP protocols, this study is mainly concerned about the transport protocols power consumption. Isolating the power consuming components within an electronic system is a very precise process that requires deep understanding of the role of each component within the system and a thorough study of the component datasheet. The study started by simulating the protocols mechanism then followed by protoclos power measurements, a simple simulation has been provided for Xilinx Virtex-5, it is very complicated to simulate the whole system due to the need of an external devices, so the simulation focused on wavelengths, fequencies and traficc types. This study found that the estimated power stokes was high when the 1480nm, 1580nm, and 1750nm power source increase.while there were diferrence in the consumed power while trasiting different types of traffic such as CBR and HTTP throug UDP and TCP. The effect of different frequencies has been noticed also while applying different frequencies to the protocols. So it is believed that this study may enhance the power scenarios in the netwrok and routers throug applying different techniques to UDP and TCP.

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Ali Qusay Mohammed

UUM, Sintok, June, 2015

Dedicated to the soul of my wife

To my parents, my sisters and my son

Ali Qusay
25th June 2015

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List of Abbreviations

ARP	Adress Resolution Protocol
ARPNET	Advanced Research Projects Agency Network
CBR	Constant Bit Rate
DC	Direct Current
DVFS	Dynamic Voltage Frequency Scaling
FPGA	Field Programmable Gate Array
HDL	Hardware Description Language
HTTP	Hyper Text Transfer Protocol
ICT	Information and Communications Technology
IP	Internet Protocol
IT	Information Technology
LAN	Local Area Network
NOC	Network On Chip

RF	Radio Frequency
RPAR	Real-time Power Aware Routing
SSL	Secure Socket Layer
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
VHSIC	Very High Speed Integrated Ciruit
WLAN	Wireless Local Arean Network

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Energy consumption and estimation are important aspects that drive the technology development nowadays (Sen, 2012; Trivailo, Sippel, & Şekercioğlu, 2012). With the evolution in computer hardware design and manufacturing, the circuit demand for energy has continuously risen and is also crucial for the continued development (Pocek, Tessier, & DeHon, 2013). This was reasoned by some researcher as the need for extending the circuit capacity due to heavy traffic demands which in turn result in more power consumption (Aymerich & Rubio, 2013; McGinnis, 2014). On the other hand, almost all router devices that are produced and developed today consume a definite amount of power (Kirschbaum & Plos, 2014; C. A. Lee, Gasster, Plaza, Chang, & Huang, 2011). Due to the growing development in the information and communication technology (ICT) industry, the usage of these devices has increased rapidly. Consequently, power is being consumed at an ever increasing rate (C. A. Lee et al., 2011). Unfortunately, this trend is also producing adverse effects on circuit capability to effectively estimate power consumption and also result to undesired heating effects. Thus, power consumption estimation techniques can provide the alternative the opportunity to balance power consumption in routers.

The contents of the thesis is for internal user only

REFERENCES

Agarwal, Y., Chandra, R., Wolman, A., Bahl, P., Chin, K., & Gupta, R. (2007). *Wireless wakeups revisited: energy management for voip over wi-fi smartphones.* Paper presented at the Proceedings of the 5th international conference on Mobile systems, applications and services.

Alfredsson, S., Del Giudice, G., Garcia, J., Brunstrom, A., De Cicco, L., & Mascolo, S. (2013). *Impact of TCP congestion control on bufferbloat in cellular networks.* Paper presented at the World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2013 IEEE 14th International Symposium and Workshops on a.

Almási, B. (2012). A simple solution for wireless network layer roaming problems. *Carpathian Journal of Electronic and Computer Engineering, 5*(5), 2012.

Ancillotti, E., Bruno, R., & Conti, M. (2014). Reliable data delivery with the IETF routing protocol for low-power and lossy networks. *Industrial Informatics, IEEE Transactions on, 10*(3), 1864-1877.

Anoh, O., & Alani, O. (2011). Effect of Network Traffic Density on Energy Performance of Data Centre.

Arlitt, M., & Jin, T. (2000). A workload characterization study of the 1998 world cup web site. *Network, IEEE, 14*(3), 30-37.

Aymerich, N., & Rubio, A. (2013). *High Performance Integrated Circuits and Systems Design Group, Electronic Engineering Department, Universitat Politècnica de Catalunya (UPC), 08034 Barcelona, Spain.* Paper presented at the Nanotechnology (IEEE-NANO), 2013 13th IEEE Conference on.

Bansal, S., Shorey, R., & Kherani, A. (2004). *Performance of tcp and udp protocols in multi-hop multi-rate wireless networks.* Paper presented at the Wireless Communications and Networking Conference, 2004. WCNC. 2004 IEEE.

Barrera, I. D., Arce, G. R., & Bohacek, S. (2011). Statistical approach for congestion control in gateway routers. *Computer Networks, 55*(3), 572-582.

Biagioni, E., Harper, R., Lee, P., & Milnes, B. G. (1994). *Signatures for a network protocol stack: A systems application of Standard ML.* Paper presented at the ACM SIGPLAN Lisp Pointers.

Bolla, R., Bruschi, R., Davoli, F., & Cucchietti, F. (2011). Energy efficiency in the future internet: a survey of existing approaches and trends in energy-aware fixed network infrastructures. *Communications Surveys & Tutorials, IEEE, 13*(2), 223-244.

Bouhafs, F., Mackay, M., & Merabti, M. (2012). Links to the future: communication requirements and challenges in the smart grid. *Power and Energy Magazine, IEEE, 10*(1), 24-32.

Branch, J. W., Giannella, C., Szymanski, B., Wolff, R., & Kargupta, H. (2013). In-network outlier detection in wireless sensor networks. *Knowledge and information systems, 34*(1), 23-54.

Bryant, S. F., Shand, M., Nalawade, G., Raszuk, R., Patel, K., Ward, D. D., . . . Previdi, S. B. (2011). Providing reachability information in a routing domain of an external destination address in a data communications network: Google Patents.

Carofiglio, G., Gallo, M., & Muscariello, L. (2012). *ICP: Design and evaluation of an interest control protocol for content-centric networking.* Paper presented at the Computer Communications Workshops (INFOCOM WKSHPS), 2012 IEEE Conference on.

Chabarek, J., & Barford, P. (2011). *Power-awareness extensions for network testbeds.* Paper presented at the Communications Workshops (ICC), 2011 IEEE International Conference on.

Chabarek, J., Sommers, J., Barford, P., Estan, C., Tsiang, D., & Wright, S. (2008). *Power awareness in network design and routing.* Paper presented at the INFOCOM 2008. The 27th Conference on Computer Communications. IEEE.

Chao, H. J., & Liu, B. (2007). *High performance switches and routers*: John Wiley & Sons.

Chase, J. S., Anderson, D. C., Thakar, P. N., Vahdat, A. M., & Doyle, R. P. (2001). *Managing energy and server resources in hosting centers.* Paper presented at the ACM SIGOPS Operating Systems Review.

Chipara, O., He, Z., Xing, G., Chen, Q., Wang, X., Lu, C., . . . Abdelzaher, T. (2006). *Real-time power-aware routing in sensor networks.* Paper presented at the IEEE International Workshop on Quality of Service.

Citap. (2012). Addressing , Routing and Multiplexing. *http://www.citap.com/documents/tcp-ip/tcpip013.htm.*

Committee, I. C. S. L. M. S. (1997). Wireless LAN medium access control (MAC) and physical layer (PHY) specifications: IEEE Std.

Consumption, R. P. (2012). Increasing Bandwidth on 28-nm FPGAs. *Altera Corporation*, 21-22.

Dargie, W. (2012). Dynamic power management in wireless sensor networks: State-of-the-art. *Sensors Journal, IEEE, 12*(5), 1518-1528.

David, R., Bogdan, P., Marculescu, R., & Ogras, U. (2011). *Dynamic power management of voltage-frequency island partitioned networks-on-chip using Intel's single-chip cloud computer*. Paper presented at the Fifth IEEE/ACM International Symposium on Networks on Chip (NoCS).

De Rango, F., Guerriero, F., & Fazio, P. (2012). Link-stability and energy aware routing protocol in distributed wireless networks. *Parallel and Distributed Systems, IEEE Transactions on, 23*(4), 713-726.

Dietrich, C. J., Rossow, C., & Pohlmann, N. (2013). CoCoSpot: Clustering and recognizing botnet command and control channels using traffic analysis. *Computer Networks, 57*(2), 475-486.

Dimitrakopoulos, G., Psarras, A., & Seitanidis, I. (2015). Baseline Switching Modules and Routers *Microarchitecture of Network-on-Chip Routers* (pp. 37-59): Springer.

Dreibholz, T., Adhari, H., Becke, M., & Rathgeb, E. P. (2012). *Simulation and experimental evaluation of multipath congestion control strategies.* Paper presented at the Advanced Information Networking and Applications Workshops (WAINA), 2012 26th International Conference on.

El-Gendy, M., Bose, A., & Shin, K. G. (2003). Evolution of the Internet QoS and support for soft real-time applications. *Proceedings of the IEEE, 91*(7), 1086-1104.

Fairhurst, G. (2001). Operation of a router. *2001. EG3557.*

Fall, K. R., & Stevens, W. R. (2011). *TCP/IP illustrated, volume 1: The protocols*: addison-Wesley.

Fan, X., Weber, W.-D., & Barroso, L. A. (2007). *Power provisioning for a warehouse-sized computer.* Paper presented at the ACM SIGARCH Computer Architecture News.

Flinn, J., & Satyanarayanan, M. (1999). *Energy-aware adaptation for mobile applications* (Vol. 33): ACM.

Fodor, G., Dahlman, E., Mildh, G., Parkvall, S., Reider, N., Miklós, G., & Turányi, Z. (2012). Design aspects of network assisted device-to-device communications. *Communications Magazine, IEEE, 50*(3), 170-177.

Francini, A., Fortune, S., Klein, T., & Ricca, M. (2015). A low-cost methodology for profiling the power consumption of network equipment. *Communications Magazine, IEEE, 53*(5), 250-256.

Ghobadi, M., Yeganeh, S. H., & Ganjali, Y. (2012). *Rethinking end-to-end congestion control in software-defined networks.* Paper presented at the Proceedings of the 11th ACM Workshop on Hot Topics in Networks.

Gumenyuk, B., Vaskiv, G., & Yankevych, V. (2014). Estimation of transmission rate dependence in Wi-Fi network from information character. *International Journal of Computing*, *7*(1), 23-26.

Gunaratne, C., Christensen, K., & Nordman, B. (2005). Managing energy consumption costs in desktop PCs and LAN switches with proxying, split TCP connections, and scaling of link speed. *International Journal of Network Management*, *15*(5), 297-310.

Gupta, M., Grover, S., & Singh, S. (2004). *A feasibility study for power management in LAN switches.* Paper presented at the Network Protocols, 2004. ICNP 2004. Proceedings of the 12th IEEE International Conference on.

Gupta, M., & Singh, S. (2003). *Greening of the Internet.* Paper presented at the Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications.

Hess, B., Kutzner, C., Van Der Spoel, D., & Lindahl, E. (2008). GROMACS 4: algorithms for highly efficient, load-balanced, and scalable molecular simulation. *Journal of chemical theory and computation*, *4*(3), 435-447.

Jääskeläinen, J. (2008). ICT for Energy Efficiency, The Activities of the European. *s.l.: eSafety Forum*.

Jamieson, P., Luk, W., Wilton, S. J., & Constantinides, G. (2009). *An energy and power consumption analysis of FPGA routing architectures.* Paper presented at the Field-Programmable Technology, 2009. FPT 2009. International Conference on.

Jamieson, P., Luk, W., Wilton, S. J., & Constantinides, G. A. (2009). *An energy and power consumption analysis of FPGA routing architectures.* Paper presented at the International Conference on Field-Programmable Technology.

Jardosh, A. P., Iannaccone, G., Papagiannaki, K., & Vinnakota, B. (2007). *Towards an energy-star WLAN infrastructure.* Paper presented at the Mobile Computing Systems and Applications, 2007. HotMobile 2007. Eighth IEEE Workshop on.

Jin, M., Zhou, X., Luo, E., & Qing, X. (2015). Industrial-QoS Oriented Remote Wireless Communication Protocol for the Internet of Construction Vehicles.

Jung, H., Kim, S.-g., Yeom, H. Y., Kang, S., & Libman, L. (2011). *Adaptive delay-based congestion control for high bandwidth-delay product networks.* Paper presented at the INFOCOM, 2011 Proceedings IEEE.

Jurdak, R., Lopes, C. V., & Baldi, P. (2004). A survey, classification and comparative analysis of medium access control protocols for ad hoc networks. *Communications Surveys & Tutorials, IEEE*, *6*(1), 2-16.

Kahng, A. B., Lin, B., & Nath, S. (2012). *Explicit modeling of control and data for improved NoC router estimation.* Paper presented at the Proceedings of the 49th Annual Design Automation Conference.

Kandula, R. P., Iyer, A., & Divan, D. (2013). *Stable operation of multiple power routers.* Paper presented at the Energy Conversion Congress and Exposition (ECCE), 2013 IEEE.

Kawadia, V., & Kumar, P. (2003). *Power control and clustering in ad hoc networks.* Paper presented at the INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies.

Kazemian, P., Chan, M., Zeng, H., Varghese, G., McKeown, N., & Whyte, S. (2013). *Real Time Network Policy Checking Using Header Space Analysis.* Paper presented at the NSDI.

Kessler, C. M. (1999). Routing, RIP, and Windows NT. s.l. : Windows NT Magazine.

Khazaii, J. (2014). *Energy-Efficient HVAC Design*: Springer.
Kirschbaum, M., & Plos, T. (2014). Hardware and VLSI Designs *Secure Smart Embedded Devices, Platforms and Applications* (pp. 95-116): Springer.
Kong, J., & Ren, P. (2014). Summary of TCP Network Congestion Control Research. *Computer Technology and Development, 24*(1), 43-46.
Landsiedel, O., Ghadimi, E., Duquennoy, S., & Johansson, M. (2012a). *Low power, low delay: opportunistic routing meets duty cycling.* Paper presented at the ACM/IEEE 11th International Conference on Information Processing in Sensor Networks (IPSN).
Landsiedel, O., Ghadimi, E., Duquennoy, S., & Johansson, M. (2012b). *Low power, low delay: opportunistic routing meets duty cycling.* Paper presented at the Information Processing in Sensor Networks (IPSN), 2012 ACM/IEEE 11th International Conference on.
Lange, C., Kosiankowski, D., Betker, A., Simon, H., Bayer, N., von Hugo, D., . . . Gladisch, A. (2014). Energy efficiency of load-adaptively operated telecommunication networks. *Lightwave Technology, Journal of, 32*(4), 571-590.
Lar, S.-u., & Liao, X. (2013). An initiative for a classified bibliography on TCP/IP congestion control. *Journal of Network and Computer Applications, 36*(1), 126-133.
Lazaris, S. J. (2012). Energy management system for power transmission to an intelligent electricity grid from a multi-resource renewable energy installation: Google Patents.
Le Sueur, E., & Heiser, G. (2010). *Dynamic voltage and frequency scaling: The laws of diminishing returns.* Paper presented at the Proceedings of the 2010 international conference on Power aware computing and systems.
Lee, C., Lee, D., & Moon, S. (2012). *Unmasking the growing UDP traffic in a campus network.* Paper presented at the Passive and Active Measurement.
Lee, C. A., Gasster, S. D., Plaza, A., Chang, C.-I., & Huang, B. (2011). Recent developments in high performance computing for remote sensing: A review. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of, 4*(3), 508-527.
Lehn, P., & Irvani, M. (1999). Discrete time modeling and control of the voltage source converter for improved disturbance rejection. *Power Electronics, IEEE Transactions on, 14*(6), 1028-1036.
Lin, B., & Dinda, P. A. (2005). *Vsched: Mixing batch and interactive virtual machines using periodic real-time scheduling.* Paper presented at the Proceedings of the 2005 ACM/IEEE conference on Supercomputing.
Lixia, M., Benigni, A., Flammini, A., Muscas, C., Ponci, F., & Monti, A. (2012). A software-only PTP synchronization for power system state estimation with PMUs. *Instrumentation and Measurement, IEEE Transactions on, 61*(5), 1476-1485.
Malkin, G. (1998). RFC 2453: Rip version 2. *Request for Comments, 2453*.
Manabe, J., Funasaka, J., & Ishida, K. (2012). *A Chunked File Transfer Method Dynamically Selecting One from TCP and UDP According to Network Conditions.* Paper presented at the Networking and Computing (ICNC), 2012 Third International Conference on.
McGinnis, L. F. (2014). Ubiquitous Operations Research in Production Systems *Essays in Production, Project Planning and Scheduling* (pp. 7-28): Springer.
Nedevschi, S., Popa, L., Iannaccone, G., Ratnasamy, S., & Wetherall, D. (2008). *Reducing Network Energy Consumption via Sleeping and Rate-Adaptation.* Paper presented at the NSDI.
Niknam, T., Golestaneh, F., & Malekpour, A. (2012). Probabilistic energy and operation management of a microgrid containing wind/photovoltaic/fuel cell generation and

energy storage devices based on point estimate method and self-adaptive gravitational search algorithm. *Energy, 43*(1), 427-437.

Palaniappan, S., & Chellan, K. (2015). Energy-efficient stable routing using QoS monitoring agents in MANET. *EURASIP Journal on Wireless Communications and Networking, 2015*(1), 1-11.

Papadimitriou, D., Welzl, M., Scharf, M., & Briscoe, B. (2011). Open research issues in Internet congestion control.

Patil, P. (2012). Routers. *http://www.cse.iitb.ac.in/~yogi/resources/routers1.pdf*.

Paxson, V., Allman, M., Chu, J., & Sargent, M. (2011). Computing TCP's retransmission timer.

Pfluger, R., & Feist, W. (2013). Energy and Cost Efficient Ventilation Systems with Heat Recovery—State of the Art and Enhancement. *ASHRAE Transactions, 119*(2).

Pillai, A. S., & Isha, T. (2013). Factors Causing Power Consumption in an Embedded Processor-A Study. *order, 2*(7).

Pocek, K., Tessier, R., & DeHon, A. (2013). *Birth and adolescence of reconfigurable computing: A survey of the first 20 years of field-programmable custom computing machines.* Paper presented at the Highlights of the First Twenty Years of the IEEE International Symposium on Field-Programmable Custom Computing Machines.

Qazi, I. A., & Znati, T. (2011). On the design of load factor based congestion control protocols for next-generation networks. *Computer Networks, 55*(1), 45-60.

Rajendran, V., Obraczka, K., & Garcia-Luna-Aceves, J. J. (2006). Energy-efficient, collision-free medium access control for wireless sensor networks. *Wireless Networks, 12*(1), 63-78.

Ramachandran, K., Sheriff, I., Belding, E., & Almeroth, K. (2007). Routing stability in static wireless mesh networks *Passive and Active Network Measurement* (pp. 73-82): Springer.

Rathje, W., & Richards, B. (2014). *A framework for model checking UDP network programs with Java pathfinder.* Paper presented at the Proceedings of the 2014 ACM SIGAda annual conference on High integrity language technology.

Rotem, E., Naveh, A., Ananthakrishnan, A., Rajwan, D., & Weissmann, E. (2012). Power-management architecture of the intel microarchitecture code-named sandy bridge. *IEEE Micro*(2), 20-27.

Saleem, H. M., Hassan, M. F., & Buhari, S. M. (2014). Router Redundancy with Enhanced VRRP for Intelligent Message Routing *Recent Advances on Soft Computing and Data Mining* (pp. 581-590): Springer.

Sarkar, P., & Paul, H. (2014). Performance Comparison Of AODV, DSR, DYMO And TORA Routing Protocols In Mobile Ad Hoc Networks. *Int. J. Of Recent Trends In Engineering & Technology, 11*.

Schlottmann, C. R., Shapero, S., Nease, S., & Hasler, P. (2012). A digitally enhanced dynamically reconfigurable analog platform for low-power signal processing. *Solid-State Circuits, IEEE Journal of, 47*(9), 2174-2184.

Seferoglu, H., Markopoulou, A., & Médard, M. (2011). *NCAPQ: Network coding-aware priority queueing for UDP flows over COPE.* Paper presented at the Network Coding (NetCod), 2011 International Symposium on.

Sen, J. (2012). Ubiquitous Computing: Applications, Challenges and Future Trends. *Embedded Systems and Wireless Technology: Theory and Practical Application, Aquino Santos, R. et al.(eds.)*, 1-40.

Shih, E., Bahl, P., & Sinclair, M. J. (2002). *Wake on wireless: an event driven energy saving strategy for battery operated devices.* Paper presented at the Proceedings of the 8th annual international conference on Mobile computing and networking.

Siano, P., Cecati, C., Yu, H., & Kolbusz, J. (2012). Real time operation of smart grids via FCN networks and optimal power flow. *Industrial Informatics, IEEE Transactions on, 8*(4), 944-952.

Singh, T. P., Singh, R., & Sharma, V. (2012). Ad hoc on Demand delay Elimination (AODE) routing protocol for mobile Ad Hoc Networks and its performance comparison.

Sundararajan, J. K., Shah, D., Médard, M., Jakubczak, S., Mitzenmacher, M., & Barros, J. O. (2011). Network coding meets TCP: Theory and implementation. *Proceedings of the IEEE, 99*(3), 490-512.

Tabataba, F. S., Sadeghi, P., Hucher, C., & Pakravan, M. R. (2012). Impact of channel estimation errors and power allocation on analog network coding and routing in two-way relaying. *Vehicular Technology, IEEE Transactions on, 61*(7), 3223-3239.

Thakur, D. (2012). Types of Routers. *What is Routers? Types of routers.* *http://ecomputernotes.com/computernetworkingnotes/communication-networks/what-is-routers-explain-types-of-routers*.

Trivailo, O., Sippel, M., & Şekercioğlu, Y. (2012). Review of hardware cost estimation methods, models and tools applied to early phases of space mission planning. *Progress in Aerospace Sciences, 53*, 1-17.

Tuexen, M., & Stewart, R. (2013). UDP Encapsulation of Stream Control Transmission Protocol (SCTP) Packets for End-Host to End-Host Communication.

Van Heddeghem, W., Idzikowski, F., Vereecken, W., Colle, D., Pickavet, M., & Demeester, P. (2012). Power consumption modeling in optical multilayer networks. *Photonic Network Communications, 24*(2), 86-102.

Vasseur, J., Kim, M., Pister, K., Dejean, N., & Barthel, D. (2011). Routing metrics used for path calculation in low power and lossy networks. *draft-ietf-roll-routing-metrics-19 (work in progress)*.

Vishwanath, A., Zhao, Z., Sivaraman, V., & Russell, C. (2010a). *An empirical model of power consumption in the netfpga gigabit router*. Paper presented at the IEEE 4th International Symposium on Advanced Networks and Telecommunication Systems (ANTS).

Vishwanath, A., Zhao, Z., Sivaraman, V., & Russell, C. (2010b). *An empirical model of power consumption in the netfpga gigabit router.* Paper presented at the Advanced Networks and Telecommunication Systems (ANTS), 2010 IEEE 4th International Symposium on.

Von Werther, P. F., & Röder, S. (2013). Method for carrying out a multimedia communication based on a network protocol, particularly TCP/IP and/or UDP: Google Patents.

Wang, Hempstead, M., & Yang, W. (2006). *A realistic power consumption model for wireless sensor network devices.* Paper presented at the 3rd Annual IEEE Communications Society on Sensor and Ad Hoc Communications and Networks.

Wang, Yao, Y., Wang, X., Lu, K., & Cao, Q. (2012). *Carpo: Correlation-aware power optimization in data center networks.* Paper presented at the INFOCOM, 2012 Proceedings IEEE.

Wang, H., Liserre, M., & Blaabjerg, F. (2013). Toward reliable power electronics: Challenges, design tools, and opportunities. *Industrial Electronics Magazine, IEEE, 7*(2), 17-26.

Wischik, D., Raiciu, C., Greenhalgh, A., & Handley, M. (2011). *Design, Implementation and Evaluation of Congestion Control for Multipath TCP*. Paper presented at the NSDI.

Wolfgang, H. L. (2003). Method for packet-level fec encoding, in which on a source packet-by-source packet basis, the error correction contributions of a source packet to a plurality of wildcard packets are computed, and the source packet is transmitted thereafter: Google Patents.

Woo, A., Tong, T., & Culler, D. (2003). *Taming the underlying challenges of reliable multihop routing in sensor networks.* Paper presented at the Proceedings of the 1st international conference on Embedded networked sensor systems.

Wood, A. J., & Wollenberg, B. F. (2012). *Power generation, operation, and control*: John Wiley & Sons.

Wu, F. F., Moslehi, K., & Bose, A. (2005). Power system control centers: Past, present, and future. *Proceedings of the IEEE, 93*(11), 1890-1908.

Xylomenos, G., & Polyzos, G. C. (1999). *TCP and UDP performance over a wireless LAN.* Paper presented at the INFOCOM'99. Eighteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE.

Yang, Y., McLaughlin, K., Sezer, S., Littler, T., Im, E. G., Pranggono, B., & Wang, H. (2014). Multiattribute SCADA-specific intrusion detection system for power networks. *Power Delivery, IEEE Transactions on, 29*(3), 1092-1102.

Yang, Y., Wang, J., & Kravets, R. (2005). *Designing routing metrics for mesh networks.* Paper presented at the IEEE Workshop on Wireless Mesh Networks (WiMesh).

Yao, Y., Huang, L., Sharma, A., Golubchik, L., & Neely, M. (2012). *Data centers power reduction: A two time scale approach for delay tolerant workloads.* Paper presented at the INFOCOM, 2012 Proceedings IEEE.

Yasudo, R., Kagami, T., Amano, H., Nakase, Y., Watanebe, M., Oishi, T., . . . Nakamura, T. (2014). *A low power NoC router using the marching memory through type.* Paper presented at the COOL Chips XVII, 2014 IEEE.

Yeap, G. K. (2012). *Practical low power digital VLSI design*: Springer Science & Business Media.

Youssef, M., Ibrahim, M., Abdelatif, M., Chen, L., & Vasilakos, A. V. (2014). Routing metrics of cognitive radio networks: A survey. *Communications Surveys & Tutorials, IEEE, 16*(1), 92-109.

Yuan, W., & Nahrstedt, K. (2003). Energy-efficient soft real-time CPU scheduling for mobile multimedia systems. *ACM SIGOPS Operating Systems Review, 37*(5), 149-163.

Zhang, M., Yi, C., Liu, B., & Zhang, B. (2010). *GreenTE: Power-aware traffic engineering.* Paper presented at the Network Protocols (ICNP), 2010 18th IEEE International Conference on.