The Effects of Cloud Computing
on Vendors' Data Center Network Component Design

by
Carolyn J. Sher DeCusatis

Submitted in partial fulfillment
of the requirements for the degree of
Doctor of Professional Studies
in Computing

at

Seidenberg School of Computer Science and Information Systems

Pace University

May 2011

We hereby certify that this dissertation, submitted by Carolyn J. Sher DeCusatis, satisfies the dissertation requirements for the degree of *Doctor of Professional Studies in Computing* and has been approved.

_____-_____

Ronald I. Frank Date
Chairperson of Dissertation Committee

_____-_____

Aparicio Carranza Date
Dissertation Committee Member

_____-_____

Lixin Tao Date
Dissertation Committee Member

_____-_____

Fred Grossman Date
Dissertation Committee Member

Seidenberg School of Computer Science and Information Systems
Pace University 2011

Abstract

The Effects of Cloud Computing on Vendor's Data Center Network Component Design

by
Carolyn J. Sher DeCusatis

Submitted in partial fulfillment
of the requirements for the degree of
Doctor of Professional Studies
in Computing

May 2011

This study examines how the infrastructure requirements of cloud computing affect the design of data center network components. The global market for cloud computing is projected to grow by over 20% (CAGR) over the next five years; infrastructure for cloud computing is expected to be a $60B market by 2015[88]. The requirements of cloud computing are driving significant transformations in data center networking components and topologies. This approach is related to the theory of innovation in modular systems[61][9], to develop a data center network device decision process, which suggests criteria to help switch manufacturers decide whether to include a technology that supports cloud computing in their products. Eight cloud computing supporting switch innovations are characterized in three ways: by stated importance to the manufacturer, as incremental, modular, architectural, or radical innovations, and by their relationship to several cloud computing trends.

A census survey is then conducted of the ten largest data center switch manufacturers by revenue, with revenues ranging from less than 100 million US dollars to more than 10 billion US dollars and number of employees ranging from more than 100 to less than 50,000. The census focuses on the eight technology innovations in data center networking described in the model. Key results feature the current state of the art and future plans of the manufacturers, as well as measuring how well decisions to include a technology in their products match stated priorities of the manufacturers.

Acknowledgements

I am deeply grateful to everyone who has helped me achieve this formidable goal.

I would like to thank my husband, Casimer M. DeCusatis, whose support, guidance and encouragement made this project possible. I would also like to thank my daughters Anne, my on-site Linux tech, and Rebecca, my sounding board.

I would like to thank my parents, Lawrence and Judith Sher, and my brothers David and Kenny for making me feel math and science are wonderful things that I should study. I would also like to thank my father for the Apple II computer he kept in the basement and let me program in the 1980s.

I would like to thank my team, Kirk M. Anne, John Stewart, Joe Massi, and Jill O' Sullivan, whose help and encouragement made this process both possible and fun. I would especially like to thank Kirk for the many hours he spent helping me with open source computer programming and virtual machines. I understand the data center protocols much better because of his help with OMNeT++ models of them.

I would like to thank my advisor, Ron Frank, and my committee, Fred Grossman and Aparicio Carranza, and Lixin Tao for their time and encouragement.

I would like to thank the ten data center switch manufacturers who participated in my survey. They all responded quickly, and their responses showed both their helpfulness and their pride in their products.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

In this dissertation, how the infrastructure requirements of cloud computing affect the design of components used in data center network equipment is examined. This information is used to create a model for the Data Center Network Device Design Decision Process, which will clarify current and future trends in the evolution of data center networks.

Traditional data center designs do not provide for extremely low transaction processing costs, high performance resource pooling, and rapid, elastic provisioning of resources which are among the essential characteristics of a cloud computing environment. For these reasons, there is interest in modifying the design of the data center network.[63]

The hierarchical topology of data center networks can create problems with the increased server-to-server traffic formed by virtualization and consolidation. Flattening the topology reduces latency created by data traveling up and down the layers.[55]

On demand service and rapid and elastic provisioning of resources also imply a need for scalability, the incremental expansion of resources. The implications of this must be included in the topological design. In general, replacing routing protocols such as Spanning Tree Protocol (STP), which requires all traffic to travel a single route through the data center, with an alternative such as Transparent Interconnect of Lots of Links

(TRILL), which allows data to travel on multiple paths, will allow more flexible topologies and greatly improve scalability.[41]

Traditional computer data centers usually contain different types of networks, each with its own protocol and management system. For example, storage networks may use Fibre Channel protocol, client-server networks use Ethernet, and clustering applications may use InfiniBand[108].

The large variety of protocols simultaneously present, but not working together, in the data center is not well suited to emerging cloud computing environments.[4] There is considerable interest in converging on a single protocol and data center fabric, which should lead to reduced capital and operational costs, and will help enable new features for emerging Cloud Computing data centers. The first step towards protocol convergence is the Fibre Channel over Ethernet (FCoE) protocol standard which has been adopted in June 2009 by ANSI/INCITS as a new networking standard that attempts to converge storage and local area networking traffic.[141] There are also new protocols that allow RDMA (remote direct memory access) to be used with Ethernet switches and hardware, such as iWARP (internet wide-area RDMA protocol) and RoCE (RDMA over Converged Enhanced Ethernet), which may allow cluster computing architectures to converge with Ethernet-based datacom systems.[108]

The final design of cloud computing data centers is strongly influenced by the availability of data center networking equipment. The perspective of this work is that of the switch vendor. Cloud data center designers can only use parts that have been made, and what is available is determined by the switch manufacturers. By developing a model of how data

center switch manufacturers include innovative technologies such as TRILL, FCoE, iWARP and RoCE in their products, as well as other protocols that solve problems created by the new infrastructure demands of Cloud Computing, current and future trends in the evolution of data center networks are clarified.

1.1 Problem Statement

This study is dedicated to answering the question, "How do the infrastructure requirements of cloud computing affect the design of data center networks from the switch vendor's perspective?"

Several related sub problems were identified by the researcher in the course of this study:

- What are the key ways in which cloud computing affects data center design?
- How does widespread use of virtualization affect current data center design?
- What are the proposed changes in data center network design, and how does this affect data center network switches?
- What innovative technologies that affect data center network switches will support these changes?
- What are the factors that will affect the adoption of innovative data communication component designs to support cloud computing (these may include factors other than technical performance of the design)?
- How can this information be used to develop a model of the data center device design decision process?

1.2 Scope

This is a study of how Cloud Computing, which is a new method of delivering computing services, leads to design changes in data center network switches. By examining how Cloud Computing drives design changes in the data center, and how modular innovation theory[61][9], which describes how manufacturers interact in an environment where components of a modular system are built by competing companies, applies to it, a model was developed for the data center device design decision process in data center switches.

This study focuses on eight innovative technologies that apply to data center network switch design, which each solve a problem caused by cloud computing demands. These technologies are:

- TRILL (Transparent Interconnect of Lots of Links)
- FCoE (Fibre Channel over Ethernet)
- iWARP(internet Wide Area RDMA Protocol)
- RoCE (RDMA over Converged Ethernet)
- VEPA (Virtual Ethernet Port Aggregator)
- MPLS(MultiProtocol Label Switching)/VPLS(Virtual Private LAN Service)
- IPv6(Internet Protocol version 6)
- 40/100 Gb Ethernet

A description of each of these innovative technologies, and how they solve problems caused by cloud computing demands, is located in Chapter 4.

This model characterizes these technologies in three ways: by rated importance by the manufacturers, by their relationship to cloud computing trends, and by the Clark Henderson modular innovation theory type of innovation.

A survey questionnaire was developed to perform a census of the ten largest data center switch manufacturers, both to develop a current picture of state-of-the-art in switch design, but also to help weight the importance of various criteria in data center switch design decisions, and see how actual decisions to build products match the characterizations of technology. Special consideration was also placed on interoperability and proprietary protocols, which relate to several criteria in the model of the data center device decision model, and also has the virtue of being measurable.

This survey was distributed to thirty-seven salesmen, engineers and managers at the ten largest data center network switch manufacturers based on revenue. The participants were experienced personnel chosen based on their knowledge of the field and their company, and their ability to give us insight on the process. All respondents stated that they helped define product requirements, but did not make the final decision on what features are included in a product.

Vendors 1-2 are large global companies (> 50,000 employees) that produce WAN equipment, core routers, top of rack switches and integrated blade switches, network management software, and in general, provide end-to-end solutions.

Vendors 3-4 are fairly large companies (>1000 employees) that offer a full set of networking products for the data center market, but do not have WAN products.

Vendors 5-10 do not offer a full set of networking products, but instead a subset intended for specific markets. For example, one is mostly a WAN vendor, provides larger data center switch manufactures with optical parts used in TOR and Core switches because of 40/100 Gb Ethernet. Another mostly produces InfiniBand RDMA Network Interface

Cards (RNICs), but produces InfiniBand TOR and Blade switches that work with them, and has entered the RoCE RNIC and TOR market. Another is a recently acquired division of a larger computer manufacturer and focuses on Blade Systems. Another company focuses on FC and FCoE cards, which it sells in its own TOR and Blade switches, but also has a business reselling the chips to the large companies and co-branding.

A chart listing the basic demographic information by vendor, and the types of switches and routers they manufacture is listed in Chapter 8.

When companies choose to build a product, the new product development process usually involves executives, design engineers, and sales representatives agreeing on a product requirements document and a business case. This study is looking at industry-wide trends in product requirements. However, the details of individual business cases are typically confidential, and in any case, beyond the scope of this study.

1.3 Problem and Solution Strategy

In this work, this researcher proposes to determine the fundamental principles behind networking-related design choices in contemporary Data Centers, and the potential ways Cloud Computing affects these choices.

The starting place was studying Cloud Computing and Data Center Network Design. By identifying how Cloud Computing leads to changes in Data Center Design, eight innovative technologies were identified that would support these changes if they were included in data center switches.

The next step was to study the theory of how innovative technologies[10][64][128][61][9] are included in product design. In particular, the data center meets the definition of a modular system [9][121][61][137], so the process that leads to design changes in modular systems, and the motivations that determine whether manufacturers support particular innovations was applied.

Case studies were used to support a model, which up to this point depended mainly on general trends and theory. Specific examples of traditional data center design, as compared to specific examples of cloud computing data center design, were shown as evidence. The next part of the case studies section was devoted to supporting the manufacturers' motivations for building a product, which were identified by modular systems theory[126], by examining principal motivations demonstrated by two specific global networking companies.

By combining the theory of how innovative technologies are included in product design with the motivations of the data center switch manufacturers, the innovative technologies that support cloud computing which are currently under consideration in data center switch design, and the evidence from specific examples in the industry, a model for the Data Center Network Device Design Decision Process for switch manufacturers was developed.

A survey questionnaire to census the data center switch manufacturers was developed. The questionnaire discovered:

- Which data center switching innovations are becoming available
- The timeline for producing switches that support data center network innovation
- The importance of the different motivations to switch manufacturers

- How the switch manufacturers ranked the importance of innovative technologies and how it is related to manufacturing products which include them
- The view of switch manufacturers on whether innovation in the data center networks in the next five years is incremental, modular, architectural or radical, and how their view translates into manufacturing data center switches that support incremental, modular, architectural or radical innovation.
- How the market position of switch manufacturers influences their support of interoperability and proprietary versus industry standard protocols

The results of the survey are analyzed and conclusions are drawn.

The problem and solution strategy is shown in Figure 1.

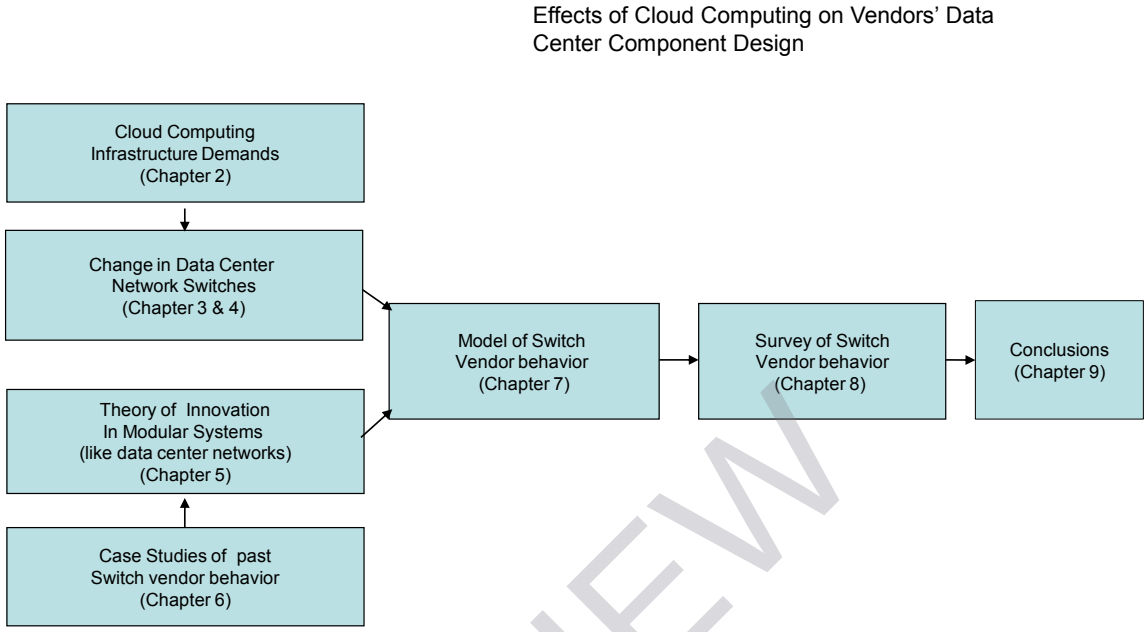

Figure 1 : The Effects of Cloud Computing on Vendor's Data Center Component Design Problem and Solution Strategy

1.4 Significance

A typical business uses computers to keep records, develop budgets and forecasts, prepare marketing documents, process transactions, manufacture products, conduct research, and stay in contact with other employees and customers. A data center is a facility that houses computer equipment and associated components. The computer equipment and associated components are critical resources for enterprises, because they run applications from financial and human resources to external e-commerce and business-to-business applications, as well as supporting network operations. Every time