Hyperconverged Infrastructure Data Centers

Demystifying HCI

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Sam Halabi

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Sam Halabi

Cisco Press

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Sam Halabi is a well-known industry figure with many years of experience in the field of information technology, multicloud, hyperconvergence, enterprise software, and data networking. Sam is a trusted advisor, capable of establishing close relationships with customers at the executive level, linking complex technologies with business benefits. Sam has worked at major companies in the United States and international markets, where he led sales, presales, consulting, marketing, and business development efforts targeting enterprises building scalable data centers. Sam is the founder of VirtuService (www.virtuservice.com), a provider of customer service, and IT consulting in private, hybrid, public cloud, and multicloud.

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Mallik Mahalingam is a Distinguished Engineer and CTO of HyperFlex product at Cisco, where he leads the technological and production direction for HyperFlex product-line.

Prior to Cisco, Mallik co-founded Springpath Inc., in 2012. Springpath built the software that was branded as Cisco HyperFlex, and he ran the company as its CEO and CTO until its acquisition by Cisco in 2017.

Prior to founding Springpath, Mallik led the core vSphere networking team at VMware, and built several features including VXLAN. As an early member of the VMware R&D team, which he joined in 2002, he built several networking and storage products during his decade of stay at VMware.

Mallik has developed several server technologies and products for enterprise markets over his 28 years of industry experience. He holds close to 80 US Patents and six published papers in leading academic conferences and journals.

Dedication

I would like to dedicate this book to my wonderful family, who continues to endure the agonizing process of book writing.

To my beautiful wife Roula: Thank you for your support and constant encouragement and for taking on double chores so I could finish this book.

To my wonderful sons, Joe and Jason: I am very proud of your academic accomplishments in the field of computer engineering, and I thank you for keeping me plugged into the latest technologies.

Last but not least, to my loving mother Josephine: Thank you for your persistence in asking me every day whether the book was done—that by itself was a huge incentive to finish writing it.

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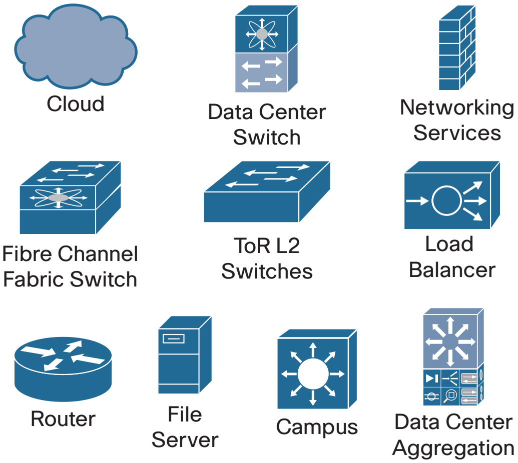
Icons Used in This Book



Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in Cisco's Command Reference. The Command Reference describes these conventions as follows:

- **Boldface** indicates commands and keywords that are entered literally as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a **show** command).
- *Italics* indicate arguments for which you supply actual values.
- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets [ ] indicate optional elements.
- Braces { } indicate a required choice.
- Braces within brackets [{ }] indicate a required choice within an optional element.

Note This book covers multiple operating systems, and a differentiation of icons and router names indicates the appropriate OS that is being referenced. IOS and IOS XE use router names like **R1** and **R2** and are referenced by the IOS router icon. IOS XR routers will use router names like **XR1** and **XR2** and are referenced by the IOS XR router icon.

Introduction

Hyperconverged infrastructure (HCI) is the integration of different technologies such as compute, storage and storage networking, virtualization, data networking, and automation, all under the umbrella of software-defined storage (SDS) and software-defined networking (SDN). Legacy data centers are normally built by system administrators, networking engineers, storage administrators, software virtualization engineers, and network management engineers, all working within their own area of expertise. This creates different silo groups within the same IT organization trying to optimize their own set of tasks without much visibility into the other groups. In essence, the IT professionals are segmented and find pride in being the experts in their own tasks. So here comes HCI with a paradigm shift that integrates all the different technology fields into one product—hence, the need for cross-technology knowledge.

This book approaches the HCI topic from the point of view that any individual working this field needs to have enough knowledge in all the different areas, including storage, storage networking, compute, virtualization, switching and routing, and automation. The book explains each area in the context of a legacy data center design, detailing the problem statement for the particular technology and how HCI solves the problem and to what extent. The *Hyperconverged Infrastructure Data Centers* book will be the bible for IT professionals, technical folk, and management in all technology areas. It will guide them through the decision process to move in the HCI direction.

Despite this being a Cisco Press book, this book tries to be vendor neutral by objectively comparing and contrasting the Cisco HyperFlex approach with other vendor implementations. The SDS and the distributed storage file systems that the Cisco HyperFlex HX Data platform has adopted, VMware vSAN and Nutanix Enterprise Cloud software, are described. A compare and contrast between the different SDN solutions—such as Cisco application-centric infrastructure (ACI), VMware network virtualization and security platform (NSX), and the open source Open vSwitch (OVS)/Open Virtual Network (OVN) and OpenStack are also described. This gives you enough ammunition to ask the right questions when choosing an HCI solution.

Aside from describing HCI in detail, a key aspect of this book is a comparison between HCI and public cloud services from Amazon Web Services (AWS). This book helps IT professionals, chief information officers (CIOs), and information technology (IT) managers in their decision to move into an on-premise HCI deployment versus a public cloud deployment. It describes in detail and from a technical and business aspect the pros and cons for building on-premise versus outsourcing. This book also covers products such as the Cisco CloudCenter, which facilitate the migration into a multicloud environment.

Last but not least, this book goes into detail about automation and software management by gathering information from different HCI vendors and approaching the topic from a vendor-neutral angle, allowing the reader to make a decision on existing and needed automation functionality.

Goals and Methods

CIOs and IT professionals who want to simplify their IT and networking environment are now challenged with the decision of whether to move fully into the cloud, build their own HCI data centers, or both. Making such decisions depends on factors that include the scale and complexity of the CIO's and IT professionals' existing setup, the level of control over their own resources, security, availability of IT and networking resources, level of expertise, and overall fixed and recurring costs.

Because many new vendors are introducing products that offer HCI and are challenging the existing network design, the new technologies are becoming confusing to IT professionals who are trying to move into next-generation architectures while maintaining a current setup that is generating revenue. This book walks the reader step by step through the existing data center setups and the issues faced in scaling current designs. The book explains all HCI elements in detail and how to achieve high availability (HA) and scale in dealing with compute, storage, networking, and virtualization requirements. As automation becomes a key benefit of HCI, this book compares the automation functions and tools of HCI with cloud offerings from the likes of AWS and others. The objective is to provide IT administrators with a solid knowledge base across all technology areas and compare and contrast HCI offerings from different vendors. This gives you the tools to ask the right questions when you embark on the transformation of your data center into private and hybrid clouds.

Who Should Read This Book?

HCI is the integration of compute, storage, networking, virtualization, and automation that is driven by software. In general, IT professionals are divided in their areas of expertise. Individuals are spread into focus areas that overlap:

- Servers and virtualization
- Storage
- Backup and disaster recovery (DR)
- Storage networking
- Switching and routing
- Security
- Software applications
- Automation
- DevOps

Because HCI offers a unified platform that combines all these areas in one system, the coverage between the areas will blur. Although HCI will simplify the implementation of each area, cross-knowledge between these areas is essential. This means that the audience of this book is the sum of all system administrators, storage administrators, networking engineers, software virtualization engineers, and network management engineers. Also, because the book touches on the business aspects of HCI and the pros and cons of moving from private clouds to public clouds, IT managers and CIOs will benefit from understanding the impact that HCI has on the transformation of their data centers and the speed of deploying highly available applications.

How This Book Is Organized

For those readers who are familiar with the author's writing style from his previous bestseller books, including *Internet Routing Architectures*, Sam Halabi emphasizes easy reading and making the difficult look easy. This book goes through a smooth progression of the topics in a storytelling style. Many of the basic concepts are laid out in advance, so you do not miss a beat and feel comfortable progressing through the chapters. It is recommended that you read the chapters in order so that you get the full benefit of this book.

Networking, storage, compute, virtualization, and automation are not easy topics and are getting more complex every day. Not only are system administrators, networking engineers, storage engineers, and virtualization engineers asked to become multifunctional, they also need to become programmers. The learning curve is huge, and many people aren't sure where to start.

Sam Halabi has put a lot of effort into putting you on the right track and giving you the launch pad into tackling HCI. His many years of experience in both vendor and system integration tracking across different technology areas make a difficult topic such as HCI sound simple. The advantages you see from this book follow:

- An easy reading style with no marketing fluff or heavy technical jargon
- Progression through the chapters from easy to advanced topics
- Comprehensive coverage of the topic at both technical and business levels
- First book to address storage, compute, virtualization, networking, and automation in detail under one umbrella to bridge the technology gap between the different IT departments
- Benefit to IT professionals trying to evaluate whether to move in the HCI direction
- Benefit to IT management, CIO, and chief technology officer (CTO) in evaluating HCI versus the public cloud
- Coverage of the latest HCI functionality
- Discussion of automation as it compares to cloud offerings such as AWS
- Comparing and contrasting of different implementations objectively and with vendor neutrality

Book Structure

The book is organized into seven parts.

PART I: Basics of Data Center Networking and Storage

Chapter 1, "Data Networks: Existing Designs": This chapter describes the different networking equipment that constitutes the data center and discusses the challenges of the existing designs in meeting the needs of application-aware data centers. It covers challenges with the three-tier architecture, including oversubscription between the tiers, stretching VLANs over large L2 networks, latency of traffic crossing tiers, flooding of broadcast traffic, complexity in dealing with IPv4 address scarcity, loop prevention, and firewall overload.

Chapter 2, "Storage Networks: Existing Designs": This chapter presents an essential background of the different storage technologies and terminology. It describes the three-tier storage network and discusses fundamental topics such as disk drives, disk speed throughput and latency, and input/output operations per second (IOPS). The chapter familiarizes you with redundant array of independent disks (RAID) systems, storage controllers, and logical unit numbers (LUNs). Block-, file-, and object-level storage are discussed, as are the different storage architectures of storage area network (SAN) with iSCSI and fibre channel, network-attached storage (NAS), and direct-attached storage (DAS). You will see an overview of storage efficiency technologies, such as thin and thick provisioning, deduplication and compression, snapshots replication and cloning, caching, disk encryption, and storage tiering.

PART II: Evolution in Host Hardware and Software

Chapter 3, "Host Hardware Evolution": Advances in processing power make an individual server more powerful than the traditional storage controllers. This chapter covers the terminology of central processing unit (CPU), virtual cores, logical cores, and virtual CPUs. It discusses the latest advancement in host bus interconnect with technologies such as Peripheral Component Interconnect express (PCIe) and Non-Volatile Memory express (NVMe). The evolution in flash memory and cache and the emergence of a new generation of flash-based storage products are covered as well.

Chapter 4, "Server Virtualization": This chapter gives an overview of software virtualization, hypervisors, and the difference between virtual machines (VMs) and containers. It discusses the concepts of datastores and logical volumes and shows the steps in the creation of a VM. Different virtualization services such as VM migration are explored to provide HA and fault tolerance and to provide load distribution. The chapter also explores the concepts of standard and distributed virtual switches in providing VMs with all the networking attributes of a physical switch. The definition of networking and storage policies at the VM level puts the application at the center of attention.

Chapter 5, "Software-Defined Storage": This chapter introduces SDS and its objectives in decoupling storage software from hardware. Some early implementations of SDS are discussed, but they do not meet the goals of hyperconvergence. You will also learn about some important topics such as vSphere APIs for storage awareness (VASA) and Virtual

Volumes (VVols). Such architectures, although fit in a legacy converged model with storage arrays, pave the way for giving the application better visibility into the storage capabilities and putting the application in the driver seat.

PART III: Hyperconverged Infrastructure

Chapter 6, "Converged Infrastructure": This chapter introduces the Cisco Unified Computing System (UCS) and how it changed the server, compute, and networking landscape. It led to the emergence of what is called converged infrastructure (CI). The objective of CI is to simplify data center rollouts and management with better integration between the different products that make up the converged solution. The pros and cons of deploying CI are presented to give you a feel for why the data center transformation into hyperconvergence is a must.

Chapter 7, "HCI Functionality": This chapter defines HCI and delves into its functionality. A detailed description of the HCI physical and logical distributed architecture is covered. Distributed data controllers create a scale-out architecture that moves away from the legacy centralized storage architecture. Data replication provides hardware resiliency and data protection. The chapter introduces the log-structured file system (LFS) and its benefits for HCI. Advanced HCI functionalities are introduced, and you learn how services such as backup and disaster recovery are native to the architecture. You also get a feel for the new provisioning, deployment, and management model that simplifies the deployment of applications and setting of policies.

Chapter 8, "HCI Business Benefits and Use Cases": This chapter discusses HCI business benefits as seen by CIOs and IT managers who want justification for moving from a legacy SAN and converged environment to hyperconverged. The chapter discusses the multitude of HCI use cases ranging from simple server virtualization to more complex environments. It includes details about sample applications such as DevOps, virtual desktops, remote office business office (ROBO), edge computing, tier-1 enterprise-class applications, backup, and disaster recovery.

PART IV: Cisco HyperFlex

Chapter 9, "Cisco HyperFlex": The chapter gives an overview of the Cisco HyperFlex platform and its physical components. It discusses the integration between HyperFlex and UCS through the use of service profiles and templates. A detailed description of the HX Data Platform is presented, which covers the data platform controller, support for VMware ESXi, Microsoft Hyper-V, and Docker containers. The chapter also covers data distribution in the cache and capacity layers, and the life of read and write input/output (I/O). HyperFlex Advanced Data Services including deduplication and compression, snapshots, clones, synchronous replication for backup and disaster recovery, and integration with third-party backup software vendors are described. Also discussed is HyperFlex security with the use of self-encrypting drives and the adoption of industry security standards.

Chapter 10, "Deploying, Provisioning, and Managing HyperFlex": This chapter covers the deployment provisioning and management of the HyperFlex platform. It includes reference tools to help with sizing the platform depending on the workload. Different software products are used to help in managing all aspects of deploying and monitoring the data services from inside the private data center as well as from the public cloud.

Chapter 11, "HyperFlex Workload Optimization and Efficiency": This chapter describes the different issues that face enterprise workloads, including reactive mode to growth, lack of visibility into their applications, overprovisioning, and cloud creep. Better visibility into the traffic flows and the service chain between the applications is done using the Cisco Tetration platform. The Cisco Workload Optimizer (CWOM) automation tool monitors the performance consumption of applications and matches the resources with the needs of the application. Cisco AppDynamics is an application and business monitoring platform that allows enterprises to monitor their business applications and transactions and make sure they are delivering the best performance. The platform gives root cause analysis of performance issues at the code level.

PART V: Alternative HCI Implementations

Chapter 12, "VMware vSAN": vSAN is VMware's hyperconverged software product. This chapter describes vSAN's hardware implementation, including ready nodes and integrated systems. It also introduces the vSAN hyperconvergence software, including the object file system and the input/output (I/O) operation within the cache and capacity layers. The vSAN advanced data services, such as deduplication, compression, erasure coding (EC), snapshots and clones, disaster recovery, and backup are discussed as well. In addition, the chapter covers the integration of vSAN with legacy SAN and NAS. You will also see a high-level comparison between HyperFlex and vSAN, pointing out architectural differences and giving you enough ammunition to ask the right questions from your vendors.

Chapter 13, "Nutanix Enterprise Cloud Platform": This chapter describes the Nutanix Enterprise Cloud Platform software components. The distributed storage fabric, read/write I/O path, and data protection techniques are discussed. Similar to HyperFlex and vSAN, you will see a detailed description of the advanced data services, including deduplication, compression, EC, and support for backup and disaster recovery. The chapter also covers a competitive landscape, comparing the Nutanix architecture with HyperFlex, highlighting pros and cons in different areas.

Chapter 14, "Open Source—Compute and Storage": This chapter gives an overview of the open source approaches to hyperconvergence. It presents a description of OpenStack and the different components that are relevant to HCI, including Nova for Compute, Cinder for block storage, and Swift for object storage. Also, a description of important open source initiatives such as Ceph for combined block, file, and object services is presented.

PART VI: Hyperconverged Networking

Chapter 15, "Software-Defined Networking and Open Source": This chapter discusses SDN and its background and adoption in today's networking implementations. Host-based and switch-based networking options are presented, with a discussion of how they compete for the networking landscape. The chapter covers the benefits of the new leaf/spine 2-tier networking architecture. The Overlay/Virtual Extensible LAN (VXLAN), and Underlay networking models are covered, as is the important topic of microsegmentation. Open source networking via implementations from OpenStack Neutron, open source OVS, and Open Virtual Network (OVN) are also discussed.

Chapter 16, "VMware NSX": This chapter introduces VMware Network Virtualization and Security platform (NSX). This is VMware's solution for bringing automation, policy, and security into the networking environment. You will see a description of the NSX components, including the NSX manager and controllers cluster. In addition, you will read about the vSphere distributed switch (vDS) enhancements in support of VXLAN. Alternatively, VMware introduced a host-based networking solution by implementing IP routing using the concept of a distributed logical router (DLR) and an edge services gateway (ESG).

Chapter 17, "Application-Centric Infrastructure": The Cisco ACI is a measure to introduce a level of automation into setting and enforcing policies at the application level as well as configuring the switch fabric to support the connectivity requirements of the applications in the data center. This chapter describes how ACI works and presents the microsegmentation constructs, including endpoint groups (EPGs), application network profiles (ANPs), and bridge domains (BDs). The chapter covers the Application Virtual Switch (AVS) and the ACI switching and routing constructs, including overlay/VXLAN and underlay. ACI Multi-Point of Delivery (Multi-PoD), ACI Multi-Site, and ACI Anywhere concepts are also discussed. The chapter ends with a comprehensive comparison between Cisco ACI and VMware NSX, highlighting similarities and differences.

PART VII: Public, Private, Hybrid, and Multicloud

Chapter 18, "The Public Cloud": This chapter defines the different cloud models, such as infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). It introduces services from AWS and highlights the AWS networking, storage, and compute capabilities. A description of how to launch a multitier application in AWS is presented, including initiating compute instances, identity and access management (IAM), security groups, storage, and monitoring. The chapter also covers the topic of cloud automation and the notion of infrastructure as a code.

Chapter 19, "The Private Cloud": This chapter describes, through the use of automation and orchestration, how to transform hyperconverged data centers into private clouds. It covers the characteristics and different models of a private cloud, distinguishing between automation and orchestration. Examples are drawn from the Cisco UCS Director (UCSD) and how it defines storage, compute, and networking policies to create service catalogs. Also discussed are the interaction between UCSD and HyperFlex and the creation of infrastructure as a code.

Chapter 20, "Hybrid Cloud and Multicloud": This chapter concludes the book with a definition of the hybrid cloud and multicloud and a description of the use cases and benefits. It draws on products from Cisco Systems to allow the ease of migration of applications and services between the different clouds. The chapter briefly presents the Cisco CloudCenter and its ability to decouple the application from the underlying cloud and orchestrating applications over private as well as public clouds. Finally, this chapter summarizes the HyperFlex hyperconvergence ecosystem and how it integrates with CloudCenter.

Figure Credits

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PART I

Basics of Data Center Networking and Storage

Chapter 1 Data Networks: Existing Designs

Chapter 2 Storage Networks: Existing Designs

Data Center Networking and Storage went through many evolutions. However, when discussing the latest and greatest technologies, many assume that enterprises already went through major overhauls and that the network is on par with the latest on the market. The fact is that marketing always superseded engineering by leaps. While it is easy to draw the most efficient architectures in PowerPoint, it takes months of planning before network, compute, and storage professionals can attempt a network change. And when the decision is made, it takes many more months, or maybe years, before a network goes through a major overhaul. Add to this the many justifications to management on why new equipment is needed and why tweaking the current network does not do the job.

The point is that many networks are still built with older technologies and are not to the point of adopting newer technologies. So before getting into hyperconvergence, it helps to go back to the basics of data center designs—from both a networking and storage perspectives—to understand some of the existing challenges and why you need to move to newer architectures.

Chapter 1 discusses the data networks, existing designs, starting by listing the networking components, discussing multitier architectures, and exploring the existing networking challenges. While this might be basic for a networking engineer, virtualization and storage engineers will appreciate some of the networking intricacies.

Chapter 2 covers the storage multitier architecture and storage basics from types of disks, storage networking alternatives, the different storage file systems, and the data services deployed by enterprises. While this chapter might be familiar to storage engineers, some of the basics are not so obvious to virtualization and networking engineers.

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Chapter 1

Data Networks: Existing Designs

This chapter covers the following key topics:

- **Information Technology Equipment of a Data Center:** A highlight of networking equipment that constitutes the data center. This includes network equipment such as switches and routers, network services equipment including traffic optimization with load balancers, wide area network (WAN) optimizers, and security equipment such as firewalls.
- **Multitier Data Networking Architecture:** Describes the three-tier data networking architecture from access to aggregation and core. It discusses the placement of networking services and the logical server grouping for multitier applications.
- **Challenges of Existing Designs:** Discusses challenges with the three-tier architecture, such as oversubscription between the tiers, stretching virtual local area networks (VLANs) over large L2 networks, latency of traffic crossing tiers, flooding of broadcast traffic, complexity in dealing with IPv4 address scarcity, loop prevention, and firewall overload.

The existing networking designs in today's data centers, with all their flaws, served their purpose providing robust infrastructures. Some of the largest data centers were built based on networking architectures that are now called *legacy*. However, the shift in traffic patterns, the introduction of server virtualization, and the introduction of multitier applications challenge the existing designs. This chapter discusses the existing network equipment and services and how they are deployed. It also goes into detail about the challenges of the current designs in scaling to meet the needs of application-aware data centers.

Information Technology Equipment of a Data Center

There are different types of data centers depending on their particular usage. Enterprise data centers normally house customer-facing applications such as web servers as well as the applications and services needed for the day-to-day operation of the enterprise. Such applications include email servers, enterprise resource planning (ERP), customer relationship management (CRM), and relational databases. Other larger data centers operated by cloud service providers (CSPs) house many software applications that are sold as a service to enterprises and consumers that connect to the data center over the Internet or private lines. Although data centers differ in size and functionality, the basic blocks for compute, storage, networking, and software applications remain the same. Although data centers contain many elements, such as facility management, physical security, power, cooling, and so on, this book covers only the information technology (IT) equipment of the data center in the context of data center convergence and hyperconvergence, which is defined later. The basic IT equipment of a data center falls under the categories of network equipment and networking services.

Network Equipment

Network equipment encompasses the basic switching and routing equipment of two layers:

- **Layer 2 (L2):** Switches that work at the Media Access Control (MAC) and VLAN levels
- **Layer 3 (L3):** Switches and routers that work at the Internet Protocol (IP) level

This chapter does not go into the details of switching and routing, but Chapter 15, “Software-Defined Networking and Open Source,” discusses underlay and overlay networks that essentially combine L2 and L3 networking to allow the mobility of applications between different servers and virtual machines.

It is worth noting that the word *networking* normally describes both data networking and storage networking. The difference between data networking and storage networking becomes clearer in the next sections.

In the context of data networking, switches and routers have different types of interfaces—ranging from Fast Ethernet to 1 Gigabit Ethernet (GE), 10 GE, 25 GE, 40 GE, 50 GE, and 100 GE—that connect the local area network (LAN). In the context of storage networking, switches also have 2 Gbps, 4 Gbps, and 8 Gbps fibre channel (FC) interfaces that connect the storage area network (SAN).

Networking Services

Networking services in the data center are standalone appliances, software running on hardware modules inside network equipment, or software running inside servers. Because data centers are moving toward a hyperconverged space, most of these services will eventually move from standalone appliances and become more integrated into the hyperconverged equipment. Networking services are grouped as either traffic redirection and optimization or security.

Traffic Redirection and Optimization

Traffic redirection involves redirecting the traffic to a certain target based on certain criteria, such as port numbers inside the Transmission Control Protocol (TCP) / Internet Protocol (IP) packets, or based on actual traffic content, or other. There are a lot of products in this space that offer different functionality such as load balancing, WAN optimization, content switching and caching, TCP optimization, Secure Sockets Layer (SSL) offload, data compression, and so on. A sample of such products includes load balancers and WAN optimizers.

Load Balancers

Server load balancing (SLB) distributes traffic across multiple servers to get better server utilization and higher availability for applications. Applications are normally spread over multiple servers in the same data center or multiple data centers for higher fault tolerance. The client trying to reach an application points only to one target—such as a URL or an IP address that is directed to the load balancer. Once the traffic reaches the LB, it distributes the traffic to different servers according to the rules or criteria. LBs work at layer 4 (L4) to balance traffic based on information in transport and session layer protocols, such as IP, TCP, File Transfer Protocol (FTP), and User Datagram Protocol (UDP), or they work at layer 7 (L7) based on information in application layer protocols, such as on Hypertext Transfer Protocol (HTTP) headers and cookies. LBs balance traffic based on various algorithms, such as round robin, response time, and sending traffic to healthy servers only.

WAN Optimizers

WAN optimizers efficiently carry traffic over WAN links. Because most data centers are connected through the WAN to service providers or to other data centers in the case of large enterprises or CSPs, it becomes crucial to make the most of the WAN link bandwidth. The WAN optimizers make sure that traffic is prioritized and bandwidth is adequately allocated. They also perform data compression, traffic shaping, and data deduplication.

Security

Securing the data and transactions between clients and a data center is extremely important, whether the access to the data center is done from the Internet toward an enterprise or from within the enterprise itself. The security terminology and functionality in the industry are overwhelming. Security is done via standalone appliances or software that covers these different areas:

- Packet firewalls
- Proxy firewalls
- Stateful inspection firewalls
- Next-generation firewalls that work at the application level

- VPN with encryption and decryption
- Network address translation (NAT)
- Intrusion detection systems (IDSs)
- Intrusion prevention systems (IPSs)
- Access key and token management
- Protection against denial of service (DoS) attacks

The term *unified threat management (UTM)* combines some of the functionality just mentioned into one product. For the purposes of this book, let's refer to the security functions as firewall (FW), which can encompass one or many of the functionalities. Now let's examine a sample description of the main FW functionality.

Firewall

FWs constitute the first entry point from the Internet into the data center, and they allow only authorized users to enter the data center while blocking unauthorized users. They are applied within the enterprise campus to secure traffic between the different departments of the same enterprise. They are also applied at the server level to allow appropriate access between clients, applications, and databases.

There are different types of firewalls. The most basic ones are packet-based firewalls that allow or deny traffic based on source and destination IP address, TCP port numbers, and direction of traffic. These are comparable with the access control lists (ACLs) on routers that basically deny or allow inbound or outbound traffic from an IP address and port. With the sophistication of attacks based on IP addresses and port numbers, more advanced firewalls do stateful inspection and track the progress of the full TCP session, not just the port number. Also, next-generation firewalls (NGFWs) work at the application level and track traffic based on the application itself. For example, an FW can track a Structured Query Language (SQL) session toward a database and allow or deny access based on an IP address and application type being SQL. Other applications of such firewalls are filtering traffic based on HTTP headers and the content itself.

As you move toward a hyperconverged data center where servers, storage, and network equipment are collapsed into one product, the layer where you apply networking services becomes important because it makes or breaks the network. Things can get complicated with virtualized environments where applications move around between different servers and security policies have to follow. As you'll see later, networking services are moving toward being applied at the application level.

Multitier Data Networking Architecture

When networking (switching and routing) vendors talk about three-tier and two-tier designs, they are referring to how switches and routers are deployed in a data center. The traditional switching and routing layers in the legacy data center are as shown in Figure 1-1.

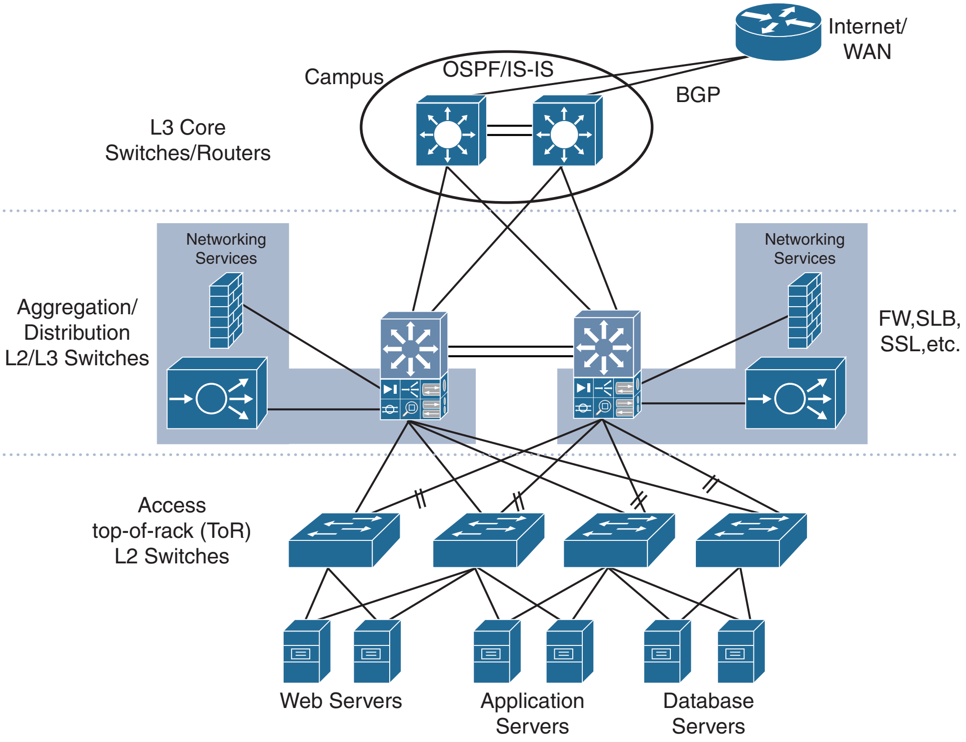

Figure 1-1 *Networking View of Three-Tier Data Center*

Access switches normally connect to the server network interface cards (NICs) and form the first level of data multiplexing. These are also called top-of-rack (ToR) switches because they sit on top of the rack connecting all Ethernet NICs coming from the servers within the same rack. Access switches are usually L2 switches, but they can also be L2/L3. The choice depends on cost and particular designs. L2 switches are a lot cheaper than L2/L3 switches because they deliver less functionality.

Aggregation switches, also called distribution switches, aggregate toward the core all Ethernet interfaces coming from the access switches. The aggregation switches normally work at L2. Traditionally, this layer existed because it reduced the number of "expensive" interfaces at the core router, it created a certain level of redundancy by having dual connections between the access switch and the aggregation layer (keeping in mind that aggregation switches are cheaper than core routers), and it shielded the core layer from L2 functionality. As shown later in this book, the newest designs can skip this layer and go directly from the access (now called leaf), to the core (now called spine). In this case, L3 functionality must start at access switches. The aggregation layer also offers connectivity to the networking services such as firewalls, load balancers, and others, as seen in Figure 1-1. The networking services are either standalone appliances or embedded inside the aggregation switches.

Core switches/routers collect all interfaces coming from the aggregation layer and multiplex them toward the WAN or the campus LAN. Most layer 3 functionality—such as routing between subnets, running routing protocols such as Open Shortest Path First (OSPF), Intermediate System to Intermediate System (IS-IS), and Border Gateway Protocol (BGP)—is done at this layer. As discussed earlier, in the newest leaf and spine designs where there is no aggregation, the core switches connect directly to the access layer and support L2 and L3 functionality. The access switches have to do some L3 functionality as well.

Logical Server Grouping

Servers are connected to access switches and grouped logically into multiple tiers, such as a web tier, an application tier, and a database tier. This distributes functionality over multiple servers, which gives higher availability to the application. Failure in one of the tiers does not affect the others. Also, a more distributed approach spreads each tier over multiple servers; for example, the web server actually runs on multiple servers located in the same data center or multiple data centers. If a web server is down, other servers absorb the load. The same distributed approach applies to application servers and database servers. As discussed earlier in this chapter, load balancers distribute the traffic between different servers based on L4 or L7 and different criteria. Figure 1-1 shows a web server, an application server, and a database server design, with load balancers distributing traffic between different servers and firewalls protecting traffic at the entry point to the data center and between the different application components.

Multitier designs require the existence of multiple servers within the same tier talking to each other and to the other tiers. This communication is normally done at L2 using a logical separation via VLANs. In the simplest form, an IP subnet is associated with a VLAN, and servers within the same subnet share the same VLAN ID and talk to each other via their MAC addresses. The VLAN is considered a broadcast domain and is isolated from other broadcast domains. This means that broadcast packets generated within a certain VLAN are contained within that VLAN. This is important in scaling the network as the number of servers and applications increase. In Figure 1-2, web servers, application servers, and database servers are grouped in different subnets, and each subnet is associated with a VLAN. There could be many web/app/database servers in the same subnet, but for simplicity, only one of each is illustrated here.

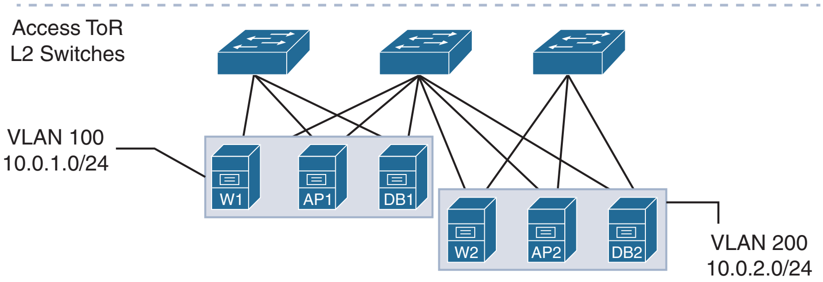

Figure 1-2 *Logical Server Grouping*

Servers house one or many NICs, and the NICs contain one or more Ethernet, 1 GE, 10 GE, or higher speed interfaces. The NICs are dual homed to the access switches for better redundancy and fault tolerance, and NIC ports work in active-active or active-passive modes. Servers within the same VLAN do not need to be connected to the same access switch or in the same rack; they can be connected to different access switches as long as the VLANs are extended across the network. Note that VLANs 100 and 200 stretch across the access and distribution switches.

As a simple example, subnet 10.0.1.0/24 is associated with VLAN 100 and contains web server 1 (W1), application server 1 (AP1), and database server 1 (DB1). Subnet 10.0.2.0/24 is associated with VLAN 200 and contains web servers, application servers, and database servers W2, AP2, and DB2, respectively.

Challenges of Existing Designs

There are many challenges for the three-tier designs in scaling to meet the demands of today’s web applications. Today’s traffic patterns in the data center have changed. Traditionally, the bulk of the traffic was north-south, meaning from the Internet to the data center and from the data center to the Internet. This affects where the firewalls are placed and how VLANs are designed. With the continued growth in data and storage and with the introduction of virtualization and three-tier web/app/database architectures, traffic is shifting toward an east-west pattern that challenges the three-tier design. This presents the following challenges:

- Oversubscription between the tiers
- Large flat L2 networks with stretched VLANs
- Traffic hopping between tiers, inducing latency
- Complexity of mechanisms used for IP subnet scarcity
- Flooding of broadcast, unknown unicast, and multicast (BUM) traffic
- Loop prevention via spanning tree
- Firewall overload

These issues are described next.

Oversubscription Between the Tiers

One of the challenges of the three-tier architecture is due to oversubscription between the tiers. For example, 20 servers can be connected to an access switch via 1 GE interface, while the access switch is connected to the aggregation switch via a 10 GE interface. This constitutes a 2:1 oversubscription between the access and the aggregation layer. Traditionally, this created no problems because most of the traffic is north-south toward the Internet. Therefore, it was assumed that traffic is limited by the Internet WAN link, and oversubscription does not matter because there is ample bandwidth in the LAN.

With the shift to east-west traffic, the bulk of traffic is now between the servers within the data center, so oversubscription between the access layer and the distribution layer becomes a problem. Access layer switches are normally dual homed into two aggregation layer switches. With the addition of servers, more access switches need to be deployed to accommodate the servers. In turn, more aggregation switches must be added to accommodate the access switches. Usually this is done in pods, where you duplicate the setup repeatedly. This is seen in Figure 1-3.

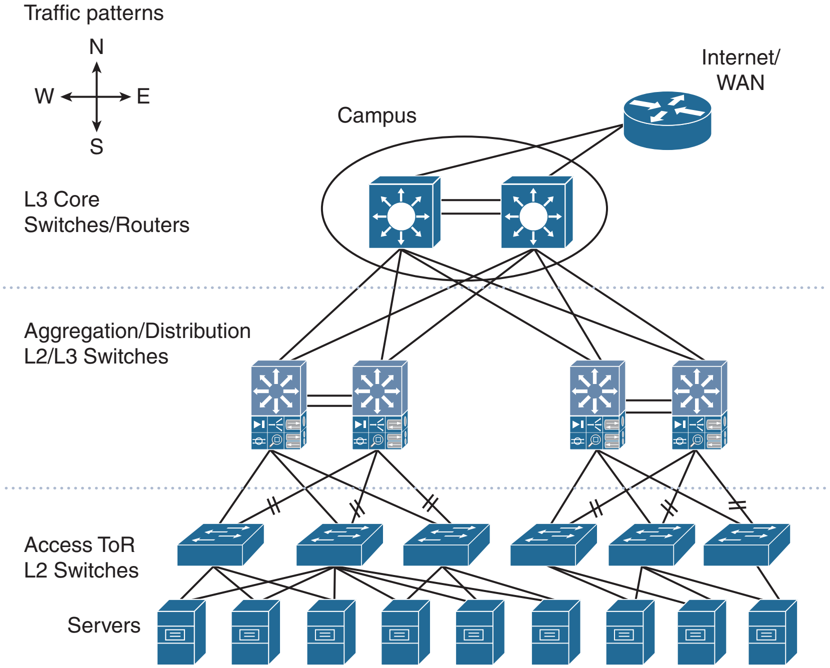

Figure 1-3 *The Challenge of Scaling Three-Tier Designs*

As you see, the addition of aggregation switches shifts the problem of oversubscription from access and aggregation to aggregation and core.

Large Flat L2 Networks with Stretched VLANs

With multitier applications, traffic moves around between web servers, application servers, and databases. Also, with the introduction of server virtualization, virtual machines move around between different servers. When virtual machines move around, they have to maintain their IP addresses to maintain connectivity with their clients, so this movement happens within the same IP subnet. Because the virtual machines could land anywhere in the data center, and because the IP subnet is tied to the VLAN, VLANs must be stretched across the whole data center. Every access and distribution switch must be configured with all VLANs, and every server NIC must see traffic of all VLANs. This increases the L2 flat domain and causes inefficiencies as broadcast packets end up touching every server and virtual machine in the data center. Mechanisms to limit L2 domains and flooding must be implemented to scale today's data centers.

Traffic Hopping Between Tiers, Inducing Latency

Latency is introduced every time traffic crosses a switch or a router before it reaches the destination. The traffic path between nodes in the data center depends on whether the traffic is exchanged within the same VLAN (L2 switched) or exchanged between VLANs (L3 switched/routed).

Traffic exchanged within the same VLAN or subnet is normally switched at L2, whereas traffic exchanged between VLANs must cross an L3 boundary. Notice the following in Figure 1-4:

- Intra-VLAN east-west traffic between W1, AP1, and DB1 in VLAN 100 is L2 switched at the access layer. All are connected to switch 1 (SW1), and switch 2 (SW2) traffic is switched within those switches depending on what ports are blocked or unblocked by spanning tree.
- Intra-VLAN east-west traffic between W2, AP2, and DB2 in VLAN 200 is L2 switched at the access layer. All are connected to switch 2 (SW2), and switch 3 (SW3) traffic is switched within those switches depending on what ports are blocked or unblocked by spanning tree.
- Inter-VLAN east-west traffic between W1, AP1, and DB1 and W2, AP2, and DB2 goes to the aggregation layer to be L3 switched because traffic is crossing VLAN boundaries.

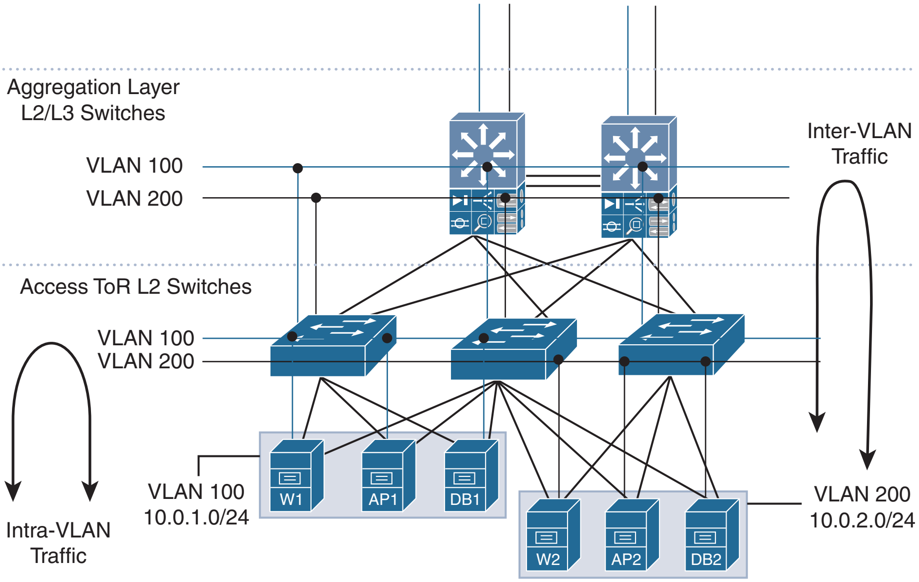

Figure 1-4 *Traffic Hopping Between Tiers*

Every time the traffic crosses a tier, latency is introduced, especially if the network is heavily oversubscribed. That's why it is beneficial to minimize the number of tiers and have traffic switched/routed without crossing many tiers. Legacy aggregation switches used to work at layer 2 and offload layer 3 to the L3 core; however, the latest aggregation switches support L2/L3 functions and route traffic between VLANs via mechanisms such as a switch virtual interface (SVI), which is described next.

Inter-VLAN Routing via SVI

An SVI is a logical interface within an L3 switch that doesn't belong to any physical port. An SVI interface is associated with a specific VLAN. L3 switches have IP L3 switching/routing between VLANs. Think of them as logical routers that live within the switch and that have their connected SVI interfaces associated with the VLAN. This allows inter-VLAN routing on an L3 switch (see Figure 1-5).

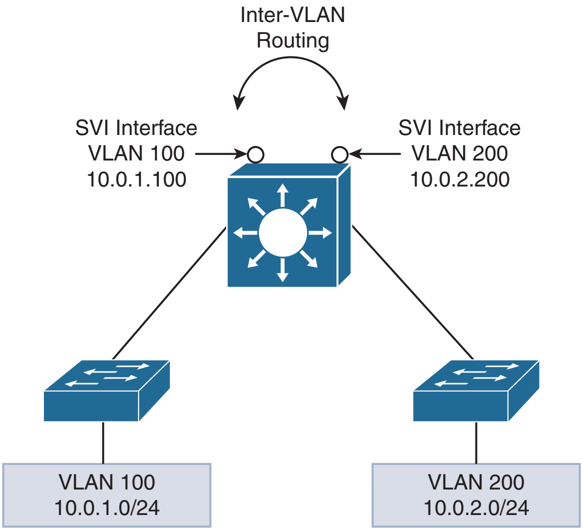
Inter-VLAN Routing
SVI Interface VLAN 100 10.0.1.100
SVI Interface VLAN 200 10.0.2.200
VLAN 100 10.0.1.0/24
VLAN 200 10.0.2.0/24

Figure 1-5 *Inter-VLAN Routing via SVI*

As shown earlier, traffic between VLAN 100, subnet 10.0.1.0/24, and VLAN 200 10.0.2.0/24 was L3 switched at the aggregation layer. To do so, two SVI interfaces must be defined: SVI interface for VLAN 100 with an IP address 10.0.1.100, and SVI interface for VLAN 200 with an IP address 10.0.2.200. When routing is turned on the L3 switch, traffic between the two subnets is routed. Servers within VLAN 100 use SVI 10.0.1.100 as their default gateway, and servers within VLAN 200 use SVI 10.0.2.200 as their default gateway.

Complexity of Mechanisms Used for IPv4 Address Scarcity

Defining many subnets in a data center easily consumes the IP space that is allocated to an enterprise. IPv4 subnetting is a complex topic, and this chapter does not go into detail, but if you are starting to get lost with what 10.0.1.0/24 represents, here is a quick review.

A 10.0.1.0/24 indicates classless interdomain routing (CIDR). An IP address is 32 bits, such as a.b.c.d., where a, b, c, and d are 8 bits each. The /24 indicates that you are splitting the IP address, left to right, into a 24-bit network address and an 8-bit host address. A /24 means a subnet mask of 255.255.255.0. Therefore, 10.0.1.0/24 means that the network is 10.0.1 (24 bits) and the hosts take the last 8 bits. With 8 bits, you can have 2 to the power of 8 (2^8 = 255) hosts, but you lose hosts 0 and 255, which have special meaning for local loopback and broadcast, respectively, and you end up with 253 hosts. 10.0.1.1 inside subnet 10.0.1.0/24 indicates host 1 inside subnet 10.0.1. You can try on your own what 10.0.1.0/27 results in.

IPv4 addresses are becoming scarce. There is a shift toward adopting IPv6 addressing, which provides a much bigger IP address space. However, so far not everyone is courageous enough to dabble into IPv6, and many enterprises still use IPv4 and mechanisms such as NAT. NAT allows the enterprise to use private IP addresses inside the enterprise and map to whatever public IP addresses they are allocated from a provider.

If a provider allocates the enterprise 128.0.1.0/27 (subnet mask 255.255.255.224), for example, the enterprise has practically one subnet 128.0.1.224 with 32 (2^5) hosts, but you lose 0 and 255, so the address range is from 128.0.1.225 to 128.0.1.254. Therefore, the maximum public IP addresses the enterprise has are 30 addresses inside one subnet.

If the enterprise chooses to divide the network into more subnets, it can use /29 to split the /27 range into 4 subnets (29–27 = 2, and 2^2=4) with 8 (32–29 = 3, and 2^3=8) hosts each. The subnets are 128.0.0.224, 128.0.0.232, 128.0.0.240, and 128.0.0.248. Each subnet has 8 hosts, but for every subnet, you lose 0 and 255, so you practically lose 4×2 = 8 IP addresses in the process.

As mentioned, most implementations today use private IP addresses internally and map these IP addresses to public IPs using NAT. The Internet Assigned Numbers Authority (IANA) reserved the following three CIDR blocks for private IP addresses: 10.0.0.0/8, 172.16.0.0/12, and 192.168.0.0/16. With the 128.0.1.0/27 allocation, an enterprise saves the 30 public addresses for accessing their servers publicly and uses as many private IP addresses and subnets internally.

However, early designs used what is called private VLANs to save on the IP space. Although this method is not straightforward and needs a lot of maintenance, it is still out there. This topic is covered briefly because it is revisited later in the book when discussing endpoint groups (EPGs) in Chapter 17, “Application-Centric Infrastructure.”

Private VLANs

This is a mechanism that allows one VLAN, called a primary VLAN (PVLAN), to be split into multiple sub-VLANs, called secondary community VLANs. The IP address space within the PVLAN can now be spread over multiple secondary VLANs, which can be isolated from each other. In a way, this removes the restriction of having one subnet per VLAN, which gives more flexibility in IP address assignment. In the traditional north-south type of traffic, this allows the same subnet to be segmented into sub-VLANs, where each sub-VLAN is its own broadcast domain, and flooding is limited. The secondary community VLANs allow hosts to talk to one another within the community. Any host from one secondary community VLAN that needs to talk to another secondary community VLAN must go through an L3 router for inter-VLAN routing. This is illustrated in Figure 1-6.

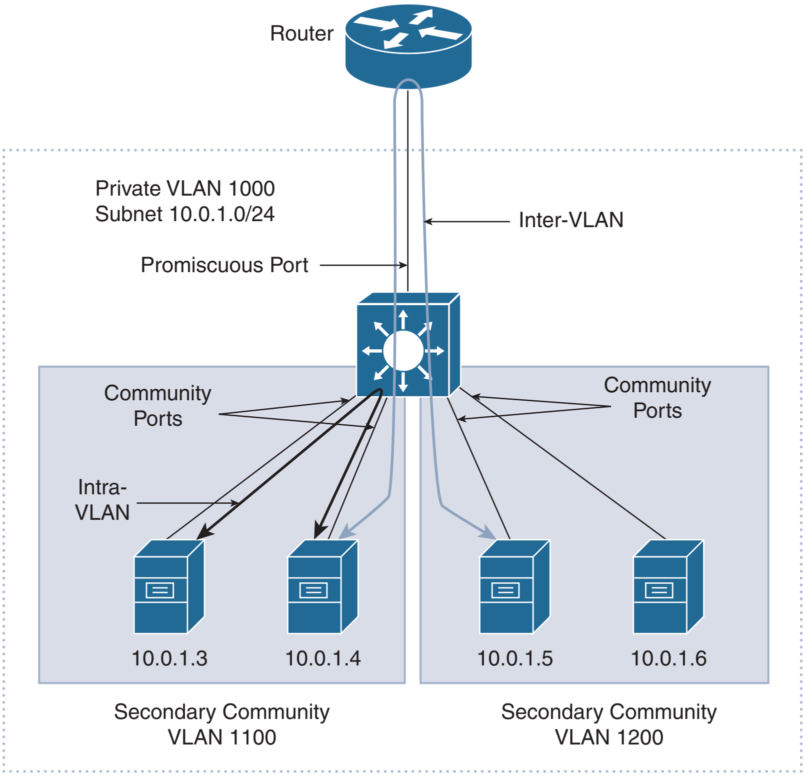

Figure 1-6 *Primary and Secondary VLANs*

The switch ports that connect to the hosts are community *switch ports*, whereas switch ports that connect to the router are called *promiscuous ports*. Ports within the same community talk to each other and to the promiscuous port. Ports between communities must go through the router. Note that hosts 10.0.1.3 and 10.0.1.4 belong to secondary community VLAN 1100, and hosts 10.0.1.5 and 10.0.1.6 belong to secondary community VLAN 1200. All of these hosts belong to the same IP subnet, but they are segmented by the secondary VLANs. So, although 10.0.1.4 talks directly to 10.0.1.3 through intra-VLAN switching, it needs to go through an L3 router to reach 10.0.1.5 or 10.0.1.6 through inter-VLAN routing.

The discussed example is simplistic. As you add multiple access switches and aggregation switches, you need to decide whether L3 routing is done in the aggregation layer or in the core layer. Also, as more and more sub-VLANs are created, such VLANs need to be carried across the network and maintained on every switch. Although these methods give flexibility in decoupling subnets from VLANs, they also add extra overhead. When Cisco's implementation of EPGs is discussed, the decoupling of IP subnets from VLANs will become much clearer, and the whole deployment model will become automated as complexities are hidden from the end user.

Flooding of Broadcast, Unknown Unicast, and Multicast (BUM) Traffic

A main issue of L2 networks is flooding of BUM traffic. Each station needs to have an IP address–to–MAC address mapping to send traffic to a certain IP address on a LAN. If a source station is trying to reach another destination station and it does not know its IP-to-MAC address mapping, an address resolution protocol (ARP) packet is sent to a broadcast address. If a VLAN is configured, then the broadcast address is flooded by a switch to all switch ports that belong to that VLAN. Whenever a device sees the ARP request for its own IP address, it responds to the source station with its MAC address. The source station that sent the original ARP request stores the IP-to-MAC address mapping in its ARP table, and from then on it uses the MAC address it learned to send traffic to the destination station. This is seen in Figure 1-7.

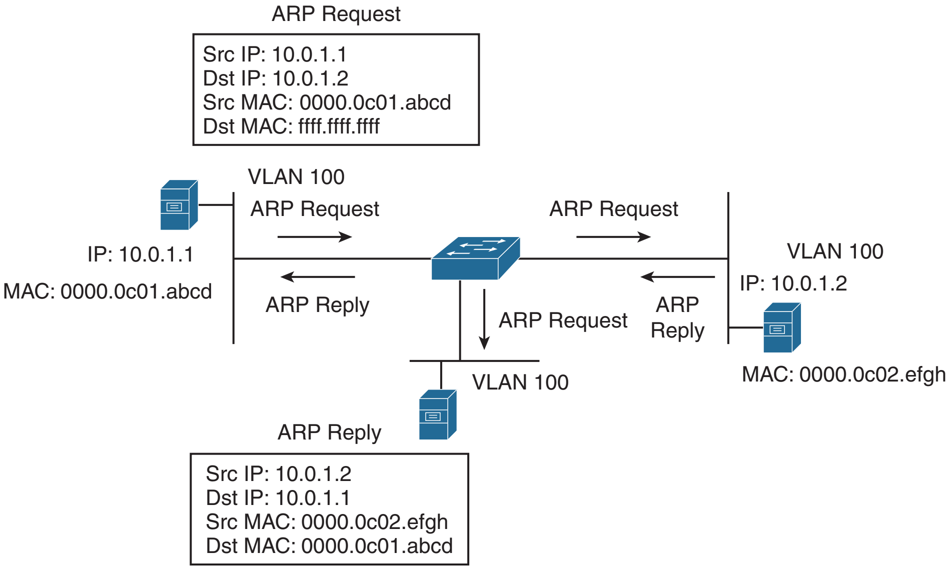

Figure 1-7 *ARP Flooding*

As seen in Figure 1-7, server 1 (S1) with IP 10.0.1.1 must send traffic to server 2 (S2) with IP 10.0.1.2, which is in the same subnet. The switch is configured to have subnet 10.0.1.0/24 mapped to VLAN 100. If S1 does not know the MAC address of S2, it sends an ARP request with a broadcast MAC address of ffff.ffff.ffff. If the switch does not have the IP/MAC address mapping in its ARP table, it floods the ARP to all the ports that belong to VLAN 100. Once S2 sees the ARP, it responds with its MAC address 0000.0c02.efgh directly to S1 (0000.0c01.abcd). After that, S1, S2, and the switch update their own ARP tables.

ARP broadcast is one type of packet that is flooded. Other types could be unknown unicast or multicast. Say, for example, that S1 knows the MAC address of S2 and sends a packet to 0000.0c02.efgh; however, the switch flushed his ARP table and does not know the mapping. In that case, the switch floods that packet to all of its ports on VLAN 100 until a station replies; after that, the switch updates its ARP.

The problem of flooding consumes bandwidth, and many measures are taken to limit it. A side effect of flooding is broadcast storms that are created by loops, as discussed next.

Loop Prevention Via Spanning Tree

The problem with L2 networks is in the potential of broadcast storms occurring in case of loops. Say that an ARP packet is flooded over all switch ports, and that packet finds its way back to the switch that flooded it because of a loop in the network. That broadcast packet circulates in the network forever. Spanning trees ensure that loops do not occur by blocking ports that contribute to the loop. This means that although some ports are active and passing traffic, others are blocked and not used. This is seen in Figure 1-8. Note that an ARP packet that is flooded by SW1 and then flooded by SW4 could return to SW1 and create a loop. To avoid this situation, spanning tree blocks the redundant paths to prevent loops from occurring and hence prevent potential broadcast storms.

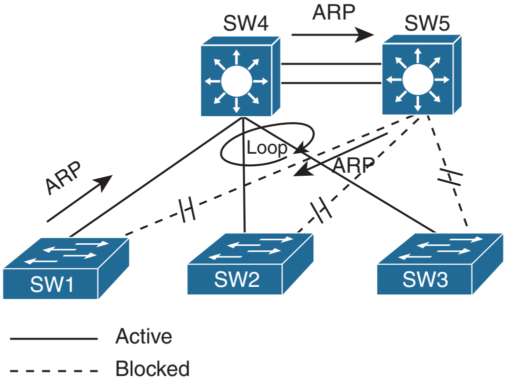

Figure 1-8 *Loop Prevention Via Spanning Tree*

The drawback is that expensive resources such as high-speed interfaces remain idle and unused. More efficient designs use every link and resource in the network.

Firewall Overload

Another issue with the existing three-tier design is that the firewalls that are traditionally connected to the aggregation layer become a catch for all traffic. These firewalls were originally meant to enforce policies on north-south traffic between the Internet and the data center. Because the traffic in the data center dramatically increased as east-west between the multiple application tiers, securing the data center from the inside is now essential. As such, policy enforcement for east-west traffic now must go through the same firewalls. This is seen in Figure 1-9. With practically all traffic going to the firewall, the firewall rules are enormous. Normally, administrators define such policies for a specific service, and when the service disappears, the policies remain in the firewall. For anyone who has worked with ACLs and setting firewall rules, it is well known that nobody dares to touch or delete a rule from the firewall for fear of breaking traffic or affecting an application. Moving into hyperconverged infrastructures and a two-tier design, you see how policy enforcement for applications shifts from being VLAN centric to application centric. Cisco's ACI and VMware's networking and security software product (NSX), covered later in this book, describe how policies are enforced in a hyperconverged environment.

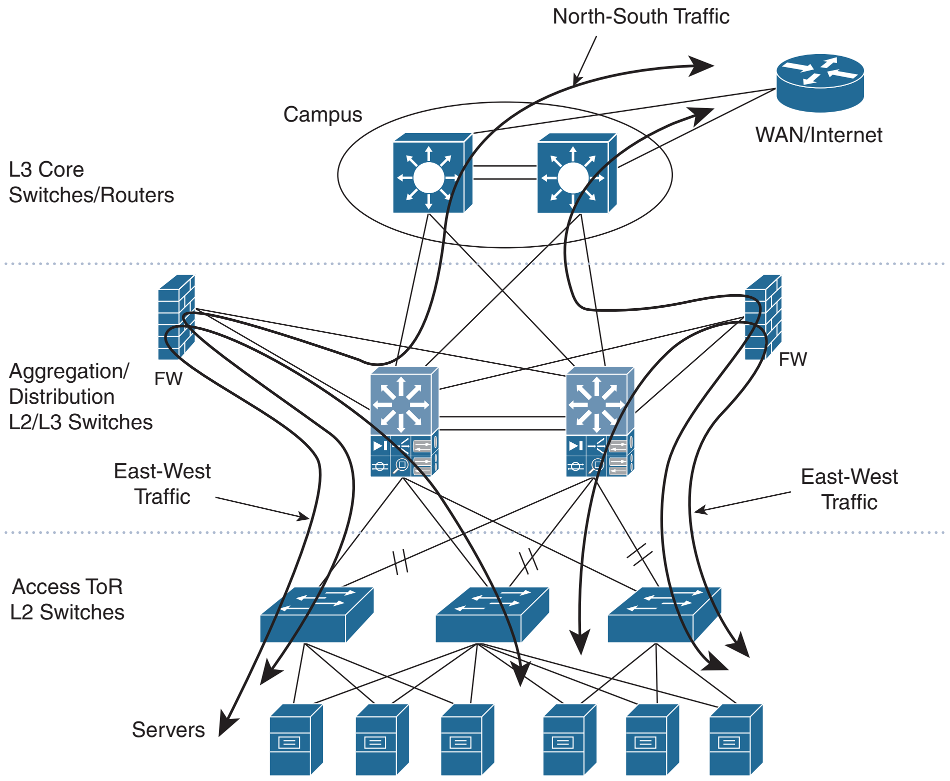

Figure 1-9 *Firewall Overload*

With so many issues in legacy data centers, newer data center designs are making modifications, including these:

- Moving away from the three-tier architecture to a two-tier leaf and spine architecture
- Moving L3 into the access layer and adopting L2 tunneling over L3 networks
- Implementing link aggregation technologies such as virtual port channel (vPC) and multichassis link aggregation (MLAG) to offer greater efficiency by making all links in the network active; traffic is load-balanced between different switches
- Moving firewall policies for east-west traffic from the aggregation layer to the access layer or directly attaching them to the application

The preceding enhancements and more are discussed in detail in Part VI of this book, "Hyperconverged Networking."

Looking Ahead

If you look at the combined picture of data networking and storage networks, it is obvious that something must change. Storage traffic constitutes different protocols, such as Internet Small Computer System Interface (iSCSI), Network File System (NFS), Server Message Block (SMB), and others. Merging such protocols with data traffic over an oversubscribed infrastructure can have huge implications on the stability of storage access and the performance of applications. Also, networking in general needs to move from complex manual configuration to a more automated and dynamic way of network deployment. The advances in switching and routing hardware and software allow you to dramatically simplify the network and minimize the tiers. Advances in server virtualization have changed the way servers and compute are deployed in the data center, which challenges the existing storage networking designs. Hyperconvergence collapses the compute, networking, and storage tiers, offering a pay-as-you-grow approach to storage.

However, the basic needs of the enterprises do not change. Simplifying network deployments should not come at the expense of having highly available and robust networks. To understand the benefits of hyperconvergence, it helps to understand the current storage deployments and their challenges. You cannot solve a problem if you do not understand what the problem is.

Chapter 2, "Storage Networks: Existing Designs," discusses some storage basics that might be familiar to a storage administrator but challenging for a virtualization or a networking engineer. It covers the storage multitier architecture; block, file, and object file systems; storage connectivity; storage protocols and protection methods; and advanced storage functionality. Part II of this book, "Evolution in Host Hardware and Software," discusses the evolution in compute, storage, and networking that allows you to build next-generation hyperconverged data centers.

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