

Design and Implementation of a Hyperconverged Solution with Advanced Virtualization Technology

Diseño E Implementación De Solución Hiperconvergente Con Tecnología De Virtualización Avanzada

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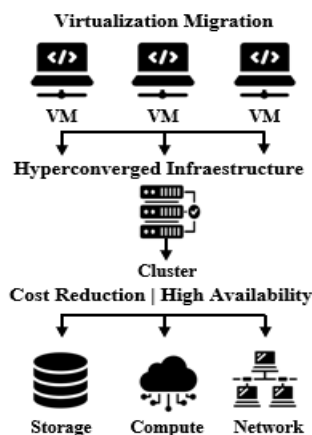
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Abstract

This study analyzes the existing infrastructure of the Potosino Institute of Scientific and Technological Research [IPICYT] and the migration from the VMware system to Proxmox VE, aiming to reduce costs and enhance technological management. A hyperconverged cluster was implemented, integrating storage, processing, and networking into a unified environment, optimizing interoperability and resource administration. The research was conducted at the National Supercomputing Center [CNS], assessing the compatibility between both systems and validating the effectiveness of the integration. The results demonstrate an improvement in availability and failure recovery, strengthening the operational continuity of the CNS. Tests confirmed the proper functioning of the cluster, consolidating an efficient and adaptable infrastructure tailored to the needs of IPICYT.



Hyper-Converged Infrastructure [HCI]; Virtualization; Hyperconvergence

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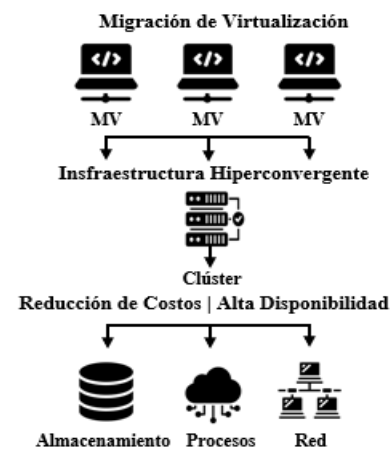
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Resumen

Este estudio analiza la infraestructura existente del Instituto Potosino de Investigación Científica y Tecnológica [IPICYT] y la migración del sistema VMware a Proxmox VE, con el objetivo de reducir costos y mejorar la gestión tecnológica. Se implementó un clúster hiperconvergente, integrando almacenamiento, procesamiento y red en un entorno unificado, optimizando la interoperabilidad y administración de recursos. La investigación se llevó a cabo en el Centro Nacional de Supercómputo [CNS], evaluando la compatibilidad entre ambos sistemas y validando la eficacia de la integración. Los resultados demuestran una mejora en la disponibilidad y recuperación ante fallos, fortaleciendo la continuidad operativa del CNS. Se realizaron pruebas que confirmaron el correcto funcionamiento del clúster, consolidando una infraestructura eficiente y adaptable a las necesidades del IPICYT.



Infraestructura hiperconvergente [HCI]; Virtualización; Hiperconvergencia

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Introduction

Currently, digital transformation and the growing demand for technological resources have driven the need to implement innovative solutions to optimize technological infrastructure [Eugenio Villar, 2023]. A Hyper-Converged Infrastructure [HCI] is an architectural model that combines the three fundamental pillars of a traditional data center: processing, storage, and networking. This model addresses various needs and problems related to the management, scalability, and efficiency of technological resources in diverse environments, tackling challenges of complexity, resilience, costs, and flexibility.

Thus, it provides a modern solution that improves operational efficiency and prepares organizations to face future technological demands, while also allowing compatibility with new cloud-based technological solutions.

The Centro Nacional de Supercómputo [hereinafter, CNS] provides customized solutions to meet technological demand in its role as a Data Center. It has a wide variety of technologies, as well as a logical and physical architecture that allows it to meet the objectives established by the institution in each of the projects in which it participates. However, as technology advances and the market diversifies, multiple challenges arise that complicate the continuous operability of the Data Center. One of the main obstacles is the high costs associated with virtualization solutions, which allow for adequate use of technological resources. Previously, this type of software was commercialized under business models different from those prevailing in the market today.

This situation has hindered the correct functioning of the systems, forcing the CNS to adapt to new technological demands, which is not always the best alternative to guarantee efficient operation. This adaptability limits the flexibility of systems to integrate with new solutions and interferes with projected growth.

In this case, the situation with VMware reflects this problem. The platform's current business model is no longer a viable solution [Perconti, 2021; Nutanix, 2024]. Although its software licenses are permanent, they no longer include technical support, which represents a considerable disadvantage.

Previously, licenses were managed per physical host and two processors, allowing unlimited virtual machines to be licensed per node. However, this has changed, and licensing is now done under a subscription scheme based on the number of logical cores. This has generated incompatibilities with current SKUs, and the costs to maintain system operation have increased significantly, becoming unaffordable for the CNS.

Currently, the CNS manages approximately 560 virtual machines, considering only the project on which this project is based. Given this situation, the implementation of free solutions such as Proxmox, together with a hyperconvergence environment, is being evaluated. This strategy aims to simplify and optimize IT infrastructure by integrating key components, such as storage, computing, and networking, into a single platform. The above seeks to facilitate IT management, reduce costs, and improve scalability, aligning with one of the fundamental principles of the institute as part of the Administración Pública Federal [hereinafter APF], according to the "Acuerdo por el que se emiten las políticas y disposiciones para impulsar el uso y aprovechamiento de la informática, el gobierno digital, las tecnologías de la información y comunicación, y la seguridad de la información en la Administración Pública Federal" published in the Diario Oficial de la Federación [hereinafter DOF] [Latam, 2023] dated September 6, 2021, which seeks "The implementation of new technological solutions based on free software for the better operation of systems prioritizes the use of free software as part of the republican austerity measure contemplated in the Ley Federal de Austeridad Republicana and the Ley General de Mejora Regulatoria, which aim to strengthen the use of free software, open standards, promote the development of institutional applications with public utility, achieve autonomy, sovereignty and technological independence within the APF, consolidate a robust and homogeneous technological base in State Institutions, as well as achieve greater efficiency based on the reduction of times and costs in contracting processes in matters of information and communication technologies, discarding those products or services that are not strictly indispensable for the functioning and operation of each institution."

Research Objective

To design and implement a novel hyperconverged cluster infrastructure that efficiently integrates storage, processing, and networking services into a unified environment. The proposed solution is presented as an original contribution to the field of technological infrastructure, by establishing a scalable, resilient, and easily manageable platform, adapted to the dynamic needs of modern organizations

Specific Objectives

To ensure compatibility between different operational environments through a software-defined architecture that facilitates centralized administration, optimizes system performance, and reduces operational complexity.

To successfully migrate model virtual machines, allowing necessary tests to be executed on the new hypervisor.

To implement a solution that fits the needs of the CNS, facilitating the management of logical infrastructure and improving efficiency in terms of time and costs.

To establish a solid solution that is a viable alternative to the subscription-based business models of the CNS's current providers [Red Hat, 2023; Red Hat, 2024; HPE, 2024].

To demonstrate the reliability of free software alternatives in the Data Center, as an efficient and continuous option for the operability of the projects in which the CNS participates.

Box 1

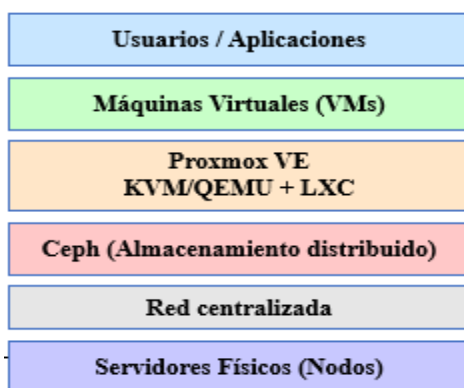


Figure 1
Hyperconverged Cluster Architecture

Box 2

Table 1

Comparison between VMware and Proxmox VE

Critero	VMware	Proxmox VE	Observaciones
Licencia	Por Cores	Libre	Reduce gastos
Soporte	Contrato	Opcional	Comunitario
Almacenaje	SAN/NAS	Ceph	No complejo
Disponible	Avanzado	Básico	Resilente

Methodology

Virtualization is defined as a technology that creates virtual representations of servers, storage, networks, and other physical machines, from a pool of physical system resources [IBM, 2024; AWS, 2024; HPE, 2024]. Allowing the implementation of this concept achieves more efficient use of physical hardware, to run multiple operating systems on the same hardware system at the same time.

To implement virtualization, software called a hypervisor is necessary, which creates an abstraction layer over the physical equipment's hardware, allowing the hardware elements of a single computer [processors, memory, storage, and more] to be divided into multiple simulated, different, and secure environments, commonly called virtual machines [VM] [IBM, 2024; Red Hat, 2023]. Each virtual machine runs its own operating system and behaves as an independent computer, although it runs on only a portion of the existing underlying computer hardware. [IBM, 2024] [AWS, 2024]. For this, virtual machines are used, which are a good option for testing new applications or configuring a production environment. A virtual machine can also be run for a single purpose, such as supplying resources for a specific process.

Hyperconverged Infrastructure [HCI] is designed for companies and organizations seeking a cost-effective, flexible, and agile infrastructure that can be managed with fewer specialists. [Syneto, 2024] This type of technology is moving closer and closer to a private or hybrid cloud as it is a modern and software-defined infrastructure that is easy and quick to deploy and manage, allowing self-provisioning and portability for the strategic placement of workloads, as it starts from the bottom and grows incrementally. [Intel, 2024].

A type 2 hypervisor is also known as a hosted hypervisor and runs on a conventional operating system as a software layer or an application. Its operation consists of extracting the guest operating systems from the host. The virtual machine resources are scheduled on the latter and run on the hardware.

These hypervisors are ideal for individual users who want to run multiple operating systems on a personal computer. Some examples are VMware Workstation and Oracle Virtualbox. However, this type of hypervisor must access computing, memory, and network resources through the host operating system, which introduces latency problems that can affect performance.

It also presents potential security risks if an attacker compromises the host operating system because they could manipulate any guest operating system running on the type 2 hypervisor, but it is very useful for personal use or for professionals who need applications only available on other software platforms. [IBM, 2024]. Proxmox Virtual Environment [Proxmox VE] [Soltecsis, 2024] is an open-source, enterprise-level hyperconverged virtualization solution [Intel, 2024; Syneto, 2024; Nutanix, 2024], that integrates virtualization through KVM/QEMU, LXC Containers, and Ceph storage on a single platform with low cost of ownership, with professional support and the possibility of obtaining official training. [Soltecsis, 2024].

High-availability infrastructure depends on the detection and elimination of single points of failure that could increase system downtime and prevent companies from achieving their performance objectives.

Single points of failure are aspects of the infrastructure that could disconnect the entire system, and there can be many of them in complex systems. It incorporates the principles of each aspect of the continuity plan, such as monitoring and automation. This allows the entire system to be resistant to any type of failure, from local and specific ones to those caused by general power outages. Furthermore, it allows it to remain running even during scheduled maintenance periods or other interruptions. [Red Hat, ¿Qué es y cómo funciona la alta disponibilidad?, 2022]

Results

By implementing a hyperconverged cluster that integrated the management of storage, processing, and networking from a single environment, compatibility between different work environments is ensured, and an efficient and easily manageable infrastructure is provided [Eugenio Villar, 2023].

After its implementation, the cluster made it easy to identify the benefits of the features it possesses and was configured with; for example, the JBOD disk format, by not having a complicated configuration, allows using disks of different sizes and characteristics without the need to configure them in a specific structure; disks can be added to the system independently without compatibility problems with the rest of the array [Pineda, 2024; HPE, 2024].

The existing virtual machines in VMware that were migrated to the new Proxmox VE cluster were successful. This process allowed verification of operational continuity and data integrity during and after the migration. During the migrations, the continuous availability of the virtual machines was verified through real-time monitoring and connectivity tests. The processing, network, and storage levels in the cluster were verified, obtaining results that demonstrated its capacity to handle critical workloads efficiently.

The implemented cluster offers centralized administration, scalability, and flexibility, which facilitates the adoption of a more robust and versatile work environment for the institute.

The implementation of the hyperconverged cluster generates significant benefits both at the technical and organizational levels; the centralized management of resources from Proxmox VE reduces the complexity in handling infrastructure, allowing focus on specific details such as the administration and configuration of the network and connectivity since it is a shared environment and a misconfiguration would mean a delay in implementation.

The solution allowed the integration and management of resources effectively between the existing VMware systems and Proxmox VE, facilitating interoperability in the institute's technological ecosystem. The consolidation of storage, networking, and processing into a single environment improved the utilization of physical and virtual resources, resulting in more efficient use of the infrastructure. Proxmox VE proved to be a more economical alternative compared to VMware, reducing costs associated with licenses and maintenance without sacrificing key functionalities.

The cluster architecture guaranteed high availability and failure recovery capacity, improving the institute's operational continuity. The created infrastructure is aligned with the institute's current and future needs, providing a solid foundation for technological growth and innovation. The implemented hyperconverged cluster not only met the set objectives but also proved to be an effective solution for optimizing the institute's operations. Its capacity to manage storage, processing, and networking from a unified environment contributed to creating a modern, scalable, and adaptable infrastructure to the demands of a constantly evolving technological environment.

Conclusions

The implementation of a hyperconverged cluster with Proxmox VE at the CNS allowed validation of the feasibility of free software solutions as an alternative to commercial platforms. The migration of virtual machines from VMware was carried out successfully, ensuring service continuity and data integrity.

The obtained results demonstrate that the designed infrastructure offers high availability, resilience, and scalability, optimizing the utilization of technological resources and reducing operational costs [Perconti, 2021; Nutanix, 2024]. Likewise, the centralized administration of the environment simplified management processes, improving efficiency in the institute's daily operation.

The project evidenced that hyperconvergent architectures not only represent an economically viable alternative but also a robust and adaptable solution for public institutions that require reliable and long-term environments.

This experience strengthens technological sovereignty and contributes to the reduction of dependence on vendors with restrictive licensing schemes [Intel, 2024; Syneto, 2024; Red Hat, 2023].

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Olvera-González, Edgar: project design, manuscript writing, and general coordination.

Cerda-García, Jorge: methodological development, results analysis, and technical review.

Viramontes-Reyna, José: bibliographic review, documentation support, and article editing.

Alfaro-Castro, Jocelyn: migration testing implementation and hyperconvergence environment validation.

Availability of data and materials

The data and materials used in this research are available upon request to the corresponding author. No legal or technical restrictions are included for their access.

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Abbreviations

APF	Administración Pública Federal
Ceph	<i>Reliable Autonomic Distributed Object Store</i> [almacenamiento definido por software]
CNS	Centro Nacional de Supercomputo
DOF	Diario Oficial de la Federación
HCI	Hyper-Converged Infrastructure / Infraestructura Hiperconvergente
IPICYT	Instituto Potosino de Investigación Científica y Tecnológica
JBOD	Just a Bunch of Disks / Conjunto Simple de Discos
KVM	Kernel-based Virtual Machine
LXC	Linux Containers
QEMU	Quick EMUlator [emulador/virtualizador]
VM	Virtual Machine / Máquina Virtual
VMware	Virtual Machine Software [plataforma de virtualización]

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