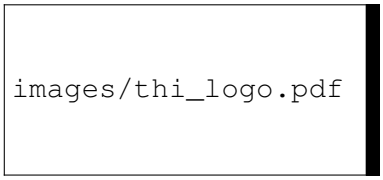

Technische Hochschule Ingolstadt

Specialist area Computer Science
Bachelor's course Computer Science

Bachelor's thesis

Subject:	Conception, Implementation, and Evaluation of a Highly Scalable and Highly Available Kubernetes-Based SaaS Platform on Kubernetes Control Plane (KCP)
Name and Surname:	David Linhardt
Issued on:	TODO: Insert Issue Date
Submitted on:	TODO: Insert Submit Date
First examiner:	Prof. Dr. Bernd Hafenrichter
Second examiner:	Prof. Dr. Ludwig Lausser

Abstract

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2.1 Kubernetes and Multi-Tenancy

Kubernetes as the Foundation for Cloud-Native Applications As the de facto standard for deploying and managing *cloud-native applications*, Kubernetes plays a pivotal role in modern cloud architecture (Nigel Poulton and Pushkar Joglekar, *The Kubernetes Book*, p. 7–8). Kubernetes works as an application orchestrator for *containerized, cloud-native microservice* apps, meaning it can deploy applications and dynamically respond to changes (Nigel Poulton and Pushkar Joglekar, *The Kubernetes Book*, p. 3). It offers a platform for declarative configuration and automation for containerized workloads, enabling organizations to run distributed applications and services at scale (Kubernetes, *Concepts / Overview*; Red Hat, *What is Kubernetes?*).

The Importance of Multi-Tenancy in Modern SaaS Platforms Multi-tenancy plays a fundamental role in modern cloud computing. By allowing multiple tenants to share the same infrastructure through virtualization, it significantly increases resource utilization, reduces operational costs, and enables essential features such as VM mobility and dynamic resource allocation (Hussain AlJahdali et al., “Multi-tenancy in Cloud Computing”, pp. 345–346). These benefits are critical for cloud providers, as they make the cloud business model economically viable and scalable. In the context of modern SaaS platforms, multi-tenancy goes even further

by enabling unified management, frictionless onboarding, and simplified operational processes that allow providers to add new tenants without introducing incremental complexity or cost (AWS, *AWS Whitepaper - SaaS Architecture Fundamentals*, pp. 9–11).
However, while multi-tenancy is indispensable for achieving efficiency, scalability, and cost-effectiveness, it simultaneously introduces complex security challenges, especially in shared environments where resource isolation is limited. In particular, the potential for cross-tenant access and side-channel attacks makes security in multi-tenant environments a primary concern (Hussain AlJahdali et al., "Multi-tenancy in Cloud Computing", pp. 345–346). As such, understanding and addressing multi-tenancy from both operational and security perspectives is essential when designing and securing modern cloud-native platforms (AWS, *AWS Whitepaper - SaaS Architecture Fundamentals*, pp. 9–11; *Information technology - Cloud computing - Part 2: Concepts*, p. 4).

The Challenges of Multi-Tenancy and the Need for Solutions

Kubernetes Control Plane (KCP) as a Promising Approach

Background: The Evolution of Kubernetes Kubernetes was originally developed at Google and released as open source in 2014 (Google Cloud, *What is Kubernetes?*).

Background: Containerization as an Enabler of Kubernetes *Containerization* is a way to bundle an application's code with all its dependencies to run on any infrastructure thus enhancing portability (AWS, *What is Containerization?*; Docker, *Use containers to Build, Share and Run your applications*). The lightweight nature and isolation can be leveraged by cloud-native software by enabling vertical and horizontal autoscaling facilitated by quick container boot times, along with self-healing mechanisms and support for distributed, resilient infrastructures (Kubernetes, *Concepts / Workloads / Autoscaling Workloads*; Kubernetes, *Kubernetes Self-Healing*; AWS, *What is Containerization?*; Cornelia Davis, *Cloud Native Patterns - Designing change-tolerant software*, pp. 58–59) Furthermore it complements the microservice architectural pattern by enabling isolated, low overhead deployments, ensuring consistent environments (A. Balalaie, A. Heydarnoori, and P. Jamshidi, "Migrating to cloud-native architectures using microservices: an experience report", p. 209).

Background: The Role of Microservices in Cloud-Native Architectures *Microservices* play a pivotal role in cloud-native architectures by promoting agility, scalability, and maintainability of

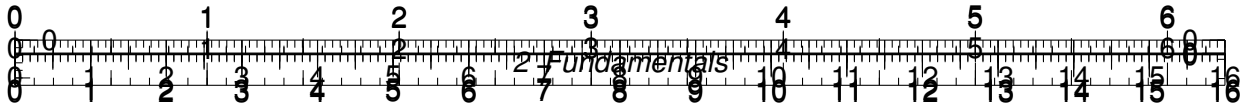
applications. By decomposing applications into independent, granular services, microservices facilitate development, testing, and deployment using diverse technology stacks, enhancing interoperability across platforms (M. Waseem, P. Liang, and M. Shahin, “A systematic mapping study on microservices architecture in devops”, p. 1; Xabier Larrucea et al., “Microservices”, p. 1) and help prevent failures in one component from propagating across the system, by isolating functionality into distinct, self-contained services (Cornelia Davis, *Cloud Native Patterns - Designing change-tolerant software*, p. 62). This architectural style aligns well with cloud environments, as it allows services to evolve independently, effectively addressing challenges associated with scaling and maintenance without being tied to a singular technological framework (A. Balalaie, A. Heydarnoori, and P. Jamshidi, “Migrating to cloud-native architectures using microservices: an experience report”, pp. 202–203). Furthermore, the integration of microservices with platforms like Kubernetes enhances deployment automation and orchestration, thus providing substantial elasticity to accommodate fluctuating workloads (S. Haugeland et al., “Migrating monoliths to microservices-based customizable multi-tenant cloud-native apps”, p. 170). Additionally, migrating legacy applications to microservices can foster modernization and efficiency, thus positioning organizations favorably in competitive landscapes (A. Balalaie, A. Heydarnoori, and P. Jamshidi, “Migrating to cloud-native architectures using microservices: an experience report”, p. 214). Overall, the synergy between microservices and cloud-native architectures stems from their inherent capability to optimize resource utilization and streamline continuous integration and deployment processes.

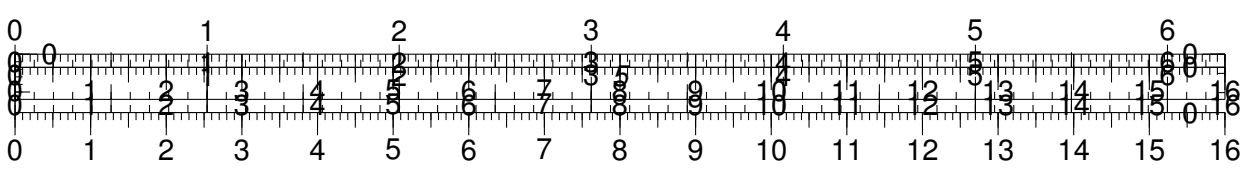
Background: Kubernetes Resource Isolation Mechanisms Kubernetes employs several resource isolation mechanisms, primarily through the use of *cgroups* (control groups) and *namespaces* to limit resource allocation for containers. Cgroups are a Linux kernel feature that organizes processes into hierarchical groups for fine-grained resource limitation and monitoring via a pseudo-filesystem called *cgroupfs* (Kubernetes, *About cgroup v2*; The Linux Documentation Project, *cgroups(7): Linux control groups*). *Namespaces* are a mechanism for isolating groups of resources withing a single cluster and scoping resource names to prevent naming conflicts across different teams or projects (Kubernetes, *Namespaces*). However, these mechanisms may not always provide sufficient isolation necessary for multi-tenant architectures, because the logical segregation offered by namespaces does not address the fundamental security concerns associated with multi-tenancy (Nguyen Thanh Nguyen and Younghan Kim, “A Design of Resource Allocation Structure for Multi-Tenant Services in Kubernetes Cluster”, p. 651) and research indicates that the native isolation strategies can lead to performance interference, where containers that share nodes can experience significant degradation in performance due to CPU contention (Eunsook Kim, Kyungwoon Lee, and Chuck Yoo, “On the Resource

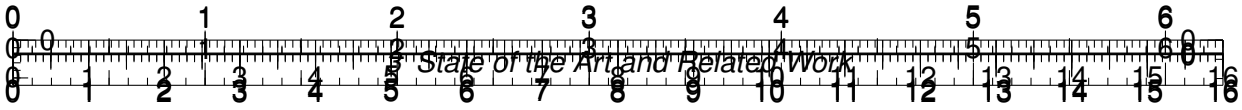
Management of Kubernetes", p. 158). Specifically, critical services may be adversely affected when non-critical services monopolize available resources, which undermines the quality of service in multi-tenant environments (Y. Li et al., "Pine: optimizing performance isolation in container environments", p. 30410).

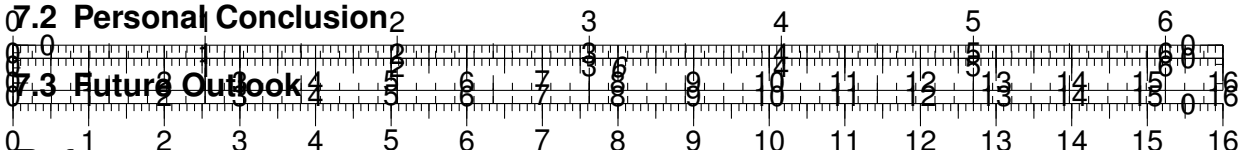
Moreover, while Kubernetes allows for container orchestration and resource scheduling, it can lead to resource fragmentation, further exacerbating the issue of performance isolation (Z. Jian et al., "Drs: a deep reinforcement learning enhanced kubernetes scheduler for microservice-based system", p. 1). A common approach in multi-tenant scenarios is to deploy separate clusters for each tenant, which incurs substantial overhead—particularly in environments utilizing virtual machines for isolation (B. Şenel et al., "Multitenant containers as a service (caas) for clouds and edge clouds", pp. 144574–144575). In summary, although Kubernetes offers essential isolation mechanisms, the complexities of resource sharing and performance consistency in multi-tenant applications highlight the need for enhanced strategies to ensure robust resource management and performance isolation (Nguyen Thanh Nguyen and Younghan Kim, "A Design of Resource Allocation Structure for Multi-Tenant Services in Kubernetes Cluster", p. 651; Z. Jian et al., "Drs: a deep reinforcement learning enhanced kubernetes scheduler for microservice-based system", p. 2; Eunsook Kim, Kyungwoon Lee, and Chuck Yoo, "On the Resource Management of Kubernetes", p. 158)

Relevance to SaaS and this Thesis









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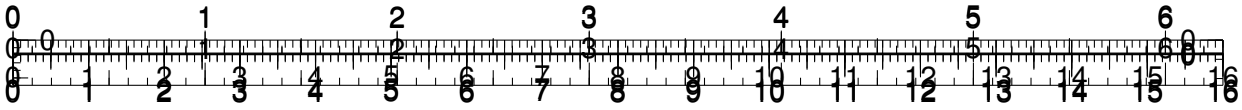

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List of Figures

Appendix