Building a Federated Cloud Continuum Infrastructure via Crossplane

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***Abstract*—In response to the rapid evolution of the Internet of Things (IoT) and the increasing demand for edge computing solutions, the article proposes an integration of Stack4Things (S4T) with Kubernetes (K8s) and Crossplane. This integration aims to enhance infrastructure management for complex and distributed environments. The framework leverages K8s for container orchestration and Crossplane for multi-cloud resource management. The three-layer integration strategy within the S4T framework includes device provisioning, dynamic allocation of network resources, and efficient management of physical computing resources at IoT nodes. The architecture supports low-latency real-time applications and extends seamlessly from the cloud to the edge. Overall, this integrated approach offers a flexible, scalable, and secure infrastructure, crucial for the next generation of IoT applications.**

***Index Terms*—CrossPlane, Stack4Things, IoT, Federated, Cloud Continuum, Research Infrastructure;**

I. Introduction

In the contemporary era of cloud computing, K8s has emerged as the de facto standard for container orchestration, fostering a scalable and resilient approach to managing distributed applications. Concurrently, Crossplane has risen as a multi-cloud management tool, enhancing K8s' capabilities beyond simple application deployment to include configuring and managing infrastructure resources across various cloud providers. This paper investigates the use of Crossplane in conjunction with K8s to develop robust and flexible Research Infrastructure (RI)s. The declarative approach and extended control model offered by K8s [1], facilitated by Crossplane, enable the definition and management of infrastructure resources as code (IaC), thus improving operational efficiency and the replicability of research environments. Integration[1] with established cloud solutions, particularly OpenStack, signifies a substantial evolution in RI management. This article focuses on the proposed integration with S4T, an OpenStack framework that supports IoT [2]. Crossplane, through specific providers, facilitates direct interaction with these platforms, allowing users to manage resources such as computing, storage, and networking directly through K8s' API. In this way, the resulting daily operations are simplified and opened to possibilities for integration across different technological layers, from cloud to IoT, supporting increasingly complex and data-intensive research scenarios.

[1]https://github.com/crossplane-contrib/provider-openstack

Furthermore, the article discusses the challenges and opportunities associated with adopting these tools within an academic and research context, such as scalability, security, and compliance, and how universities and research centers can leverage Crossplane and K8s to build more agile and adaptive RIs. Through the analysis of concrete case studies and practical applications, a critical overview of the potential of this technological integration to advance scientific research is provided. The federated management of resources towards the Cloud Continuum is performed within the SLICES project [3] to create a supportive RI that involves European computing nodes and partners of the project itself. The project aims to construct a federated infrastructure among the resources provided by individual nodes, thus facilitating experimentation and research related to distributed computing across geographical areas and with heterogeneous resources. In this way, an architecture is proposed that integrates the IoT and Edge components within the RI. The RI is based on the synergies between the infrastructure management approach realized with K8s and the multi-cloud management capabilities provided by Crossplane.

II. Cloud Continuum Crossplane-based Management

The concept of a Cloud Continuum involves a federated system among operators of RIs, where computing resources are shared across the RI. Within this infrastructure, services are deployed, and in addition to these services, operators at the workflow level compose high-level applications [4], including those based on machine learning or federated learning.

The Crossplane facilitates the management of a federated infrastructure by abstracting and handling resources across different cloud providers. This allows the pooling of computing resources into the RI, making them available for various research projects.

Within this federated infrastructure, services are deployed to support research activities. Crossplane's declarative configuration model automates service provisioning and lifecycle management, ensuring the availability and proper management of essential services.

Operators leverage these services to create complex workflows that integrate multiple services and datasets. Crossplane supports policy-driven automation, ensuring that these workflows adhere to governance and compliance requirements. Additionally, K8s' orchestration capabilities facilitate dynamic scaling and resource adaptation to meet application demands.

Integrating machine learning and federated learning within the RI is paramount to the continuum of computing. These applications require substantial computational resources and considerations for data privacy. Crossplane efficiently manages these resources, allowing machine learning models to be trained and deployed across the federated infrastructure.

III. Proposed S4T integration

The integration of S4T within the broader architecture, as outlined in Figure 1, is strategically implemented on three pivotal endpoints, each designed to enhance the operational and functional dynamics of IoT infrastructures in a distributed Cloud Continuum.

A. Device Provisioning

At the foundational level, device or fleet provisioning is achieved through specialized plugins. These plugins serve as the primary interface for initiating and managing the deployment of IoT devices. Using a plugin-based architecture, the system enables flexible and scalable management of device operations. This modular approach not only simplifies the addition and configuration of new devices, but also ensures that each device can be optimally configured to meet specific operational requirements. The provisioning process, facilitated by the integration of K8s with S4T, leverages Crossplane's capabilities to manage and orchestrate these devices as part of a larger cloud-native infrastructure, thus improving the manageability and efficiency of IoT deployments.

B. Network Resource Provisioning

The second layer focuses on the provisioning of network resources. This involves the dynamic creation of TAP interfaces that facilitate the initialization of encrypted network tunnels. These tunnels are crucial for secure communication between distributed nodes and the central infrastructure, allowing a seamless and secure data flow throughout the network. The use of run-time configurable TAP interfaces allows for a flexible network configuration that can adapt to varying operational demands and network conditions, thus supporting a robust infrastructure for distributed IoT applications.

C. Computing Resources (on IoT) Provisioning

Finally, the third layer addresses the provisioning of computing resources made available by the IoT nodes, or fleets of nodes. This layer is instrumental in harnessing the computational power distributed across the network. By effectively provisioning these resources, the architecture supports distributed computing across the continuum, extending to edge computing scenarios. This capability is particularly advantageous in scenarios where low latency and local data processing are critical, such as real-time data analytics and on-site decision-making processes in industrial IoT applications.

The proposed integration of S4T within this heterogeneous architecture represents a strategic enhancement to the existing infrastructure, promoting scalability, flexibility, and security in managing IoT devices and their interactions across a distributed network. This approach not only leverages based on K8s and Crossplane in a cloud-native environment, but also introduces new capabilities that are tailored to the unique demands of IoT and edge computing.

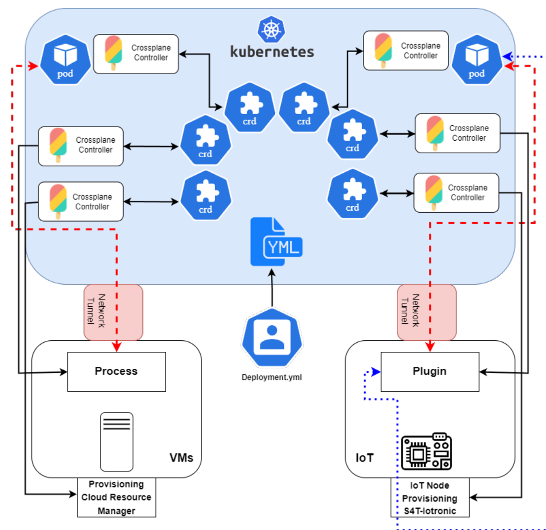

Fig. 1. Proposed S4T integration.

IV. Discussion and Future Works

Integrating Crossplane and Kubernetes with Stack4Things offers a promising approach to building scalable, flexible, and secure research infrastructures. Using the strengths of these technologies, researchers can efficiently manage complex, distributed environments that span from the cloud to the edge. The proposed architecture and integration strategies improve the manageability and efficiency of IoT deployments and pave the way for future advances in distributed computing research.

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