Openstack-based Urban Intelligence Design

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***Abstract*—This paper introduces an innovative architecture designed to serve as an open-source template for implementing a platform that supports deploying and integrating services and workflows within a complex system known as Urban Intelligence. Specifically, the proposed Smart City IT architecture builds upon an existing urban intelligence framework, primarily catering to Data Scientist activities and facilitating the use of Smart City services by citizens and users. The solution, being open-source, is fully replicable and enhances its predecessors by introducing new features: a) managing urban Cyber-Physical System facilities through a combination of Administrator and Data Scientist workflows, along with an IoT management platform; b) defining workflows directly at the Edge, even leveraging the FaaS paradigm on IoT devices; c) strengthening Smart City infrastructure security by reducing the external attack surface. The prototype of this proposed IT solution has been implemented using open-source frameworks and technologies from the OpenStack ecosystem.**

***Index Terms*—Urban Intelligence, Stack4Things, Smart City, IoT, CPS, FaaS;**

I. Introduction and Related Works

In the context of rapid urbanization, cities worldwide grapple with the urgent challenge of accommodating their growing populations while striving for sustainability, efficiency, and improved livability. The emergence of Smart Cities, characterized by the integration of Information and Communication Technologies (ICT) into urban infrastructure, offers a promising solution to these complex issues. At the heart of Smart City initiatives are advanced technologies such as the Internet of Things (IoT), Big Data Analytics, Artificial Intelligence (AI), and comprehensive connectivity solutions. These technologies are pivotal in enhancing urban infrastructure, transportation, energy management, healthcare, governance, and other services, thereby significantly improving the quality of urban life [1]. At this point, it appears clear that the Smart City concept lies in the deployment of Cyber-Physical Systems (CPS), which blends physical processes with computational resources, enabling real-time monitoring, control, and interaction with the urban environment.

OpenStack and Stack4Things (S4T) [2] stand out among various technological frameworks because they facilitate this integration. They provide a comprehensive and scalable platform for deploying, managing, and integrating CPS within the fabric of Smart Cities. This paper introduces an innovative Information Technologies (IT) architecture that leverages the flexibility of OpenStack alongside the IoT-centric enhancements of S4T. Together, they create a resilient infrastructure that simplifies the management of vast urban data and ensures interoperability across diverse systems and applications within the urban ecosystem.

The proposed architecture addresses key Smart City challenges, including data management, scalability, and interoperability, through a multi-layered approach promoting seamless urban service integration. This framework establishes the base for an intelligent urban management system by enabling efficient data flow and processing across CPS. Such a system dynamically responds to the evolving needs of the city, enhancing urban sustainability, efficiency, and residents' quality of life.

This paper contributes to the academic and practical discourse on Smart Cities by outlining the design and implementation of the proposed architecture. It emphasizes the pivotal role of CPS in driving urban innovation. It also discusses the core components of the architecture, their interactions within the urban context, and the necessary operational workflow adjustments for the effective deployment of services and applications within this framework.

II. Proposed Architecture

The Urban Intelligent (UI) architecture extends the five-layer model [3] and incorporates six layers in an open-source and OpenStack-based framework shown in Figure 1. These layers encompass Smart City's CPS active within the urban area, whether directly connected to the urban platform or not. Leveraging S4T facilities, UI manages and controls IoT devices, enabling edge computation. This customization allows specific devices to collect data at the edge, potentially performing preliminary aggregation tasks.

The CPS Layer serves as connector between CPSs deployed into the urban area and the Smart City infrastructure. Its primary role involves collecting and pre-processing data from a diverse array of devices within the CPS. This is facilitated by the Lightning-Rod (LR) component, which acts as an intermediary between these devices and cloud-based services. LR ensures reliable communication by using the Web Application Messaging Protocol (WAMP) to connect with the Cloud Computing Layer. Through this bi-directional interaction, LR supports real-time responsiveness for urban applications while maintaining robust data integrity.

Interoperability is a key focus, allowing seamless connectivity with the IoT Management Module Iotronic within the Cloud Computing Layer, enabling both data collection and potential control over physical systems in a dynamic Smart City environment. Upon the architecture presents *the Cloud Computing Layer*, that serves as the central hub of a Smart City's digital infrastructure. It provides essential resources for managing urban infrastructure and computational tasks. Key components include Zun and Kubernetes, which enable container-based computation, supporting both extensive environments and minimal functionalities in a Function-as-a-Service (FaaS) [**?**] paradigm. Kubernetes orchestrates containerized applications efficiently, facilitating data-intensive workflows crucial for urban analytics. Additionally, Glance and Swift handle image service management, while Neutron establishes networking infrastructure. IoTronic extends these capabilities to IoT, integrating urban CPS complexities. *The Data Lake Layer* stands above the Cloud Computing Layer, focusing on data collection, processing, and notification distribution. It acts as a centralized repository, providing an integrated view of the city's data streams for sophisticated analytics and decision-making. Key components include Trove, a database-as-a-service within OpenStack, automating relational and non-relational database management. Sahara complements this with a Big Data ETL framework using Apache Spark, handling extensive data sets through distributed computing. An MQTT broker facilitates asynchronous message delivery, ensuring Smart City components stay informed and responsive to the dynamic urban environment. The *Workflow Engine Layer* enables Urban Data Scientists to create and execute application workflows. It supports complex data pipelines, allowing cloud services or serverless functions (FaaS) at the network edge. Qinling, an OpenStack service within this layer, runs FaaS, simplifying code development without server management. Qinling's serverless approach promotes scalability and efficiency. Additionally, Node-RED, a browser-based tool, intuitively connects physical devices, APIs, and online services through a graphical interface. Widely used in home automation and IoT, Node-RED facilitates workflow assembly via drag-and-drop, even for users with minimal coding expertise. The *Administrator Interface Layer* serves as the gateway for administrative personnel to access and interact with privileged services and integrated dashboards within the urban platform. Designed for user-friendliness, this layer simplifies Smart City infrastructure oversight and management. Horizon, OpenStack's dashboard service, offers a graphical user interface (GUI) for cloud interactions, allowing administrators to efficiently manage resources via RESTful APIs. Grafana complements Horizon by providing powerful data visualization, refining complex datasets into actionable insights through customizable visual dashboards. Some of Grafana's dashboards are accessible via the Communication Interface Layer, ensuring transparency and informed governance among stakeholders. The *User and Urban Data Scientists Communication Interface Layer* has a dual role: managing authentication and access while exposing services through user dashboards. It ensures secure access for authenticated users, including Data Scientists. Keystone's Role-Based Access Control (RBAC) is central to this layer, securely positioned behind a proxy/bastion host system. The architecture maintains high security by allowing only authorized entities to access critical infrastructure services. Urban Data Scientists interact with computational resources, design applications, and perform analytics through this secure interface, ensuring encrypted communication and controlled access. It safeguards the city's digital realm and builds trust in the urban platform's data management capabilities.

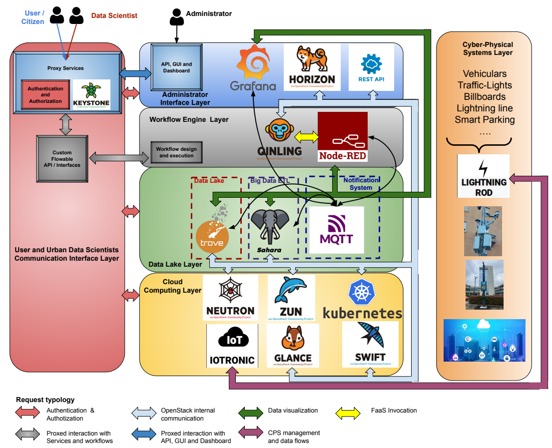

Fig. 1. The OpenStack-based Urban Intelligence Architecture

III. Discussion and Conclusion

The paper introduces a comprehensive IT architecture for integrating CPSs into Smart Cities operational workflows. Leveraging OpenStack and S4T, this architecture addresses data management, scalability, and interoperability challenges. It enables seamless urban service operation, enhancing sustainability and quality of life. The deployment of CPS transforms urban management, emphasizing technology's role. IoT integration via S4T, combined with OpenStack's infrastructure, unlocks Smart Cities' full potential. The proposed architecture enables scientists and UI workflows to directly exploit CPS's IoT capabilities.

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References

[1] G. White and S. Clarke, "Urban intelligence with deep edges," *IEEE Access*, vol. 8, pp. 7518–7530, 2020.

[2] D. Bruneo, S. Distefano, F. Longo, G. Merlino, and A. Puliafito, "Iot-cloud authorization and delegation mechanisms for ubiquitous sensing and actuation," in *2016 IEEE 3rd World Forum on Internet of Things (WF-IoT)*, 2016, pp. 222–227.

[3] S. Silvestri, G. Tricomi, S. R. Bassolillo, R. De Benedictis, and M. Ciampi, "An urban intelligence architecture for heterogeneous data and application integration, deployment and orchestration," *Sensors*, vol. 24, no. 7, 2024. [Online]. Available: https://www.mdpi.com/1424-8220/24/7/2376