Multi-Cloud Role in the Future of Smart Cities IoT Architecture

Ramon Carvalho*, Fuad Abinader*, Sergio Takeo Kofuji† and Flávio de Oliveira Silva‡

*Centro de Pesquisa e Desenvolvimento em Telecomunicações (CPQD)
Campinas, Brazil
E-mail: ramonc@cpqd.com.br
E-mail: fuad@cpqd.com.br

†Escola Politécnica da USP - Universidade de São Paulo
São Paulo, Brazil
E-mail: kofuji@usp.br

‡Department of Informatics - University of Minho (UMINHO)
Braga, Portugal
E-mail: flavio@di.uminho.pt

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***Abstract*—Integrating multi-cloud approaches with smart city applications, particularly in the context of 5G/B5G and Open Radio Access Networks (O-RAN), presents significant opportunities for enhancing urban infrastructure and services. However, this integration also increases complexity and raises security and management issues that must be addressed to safeguard sensitive data and ensure the reliability and scalability of the system based on the technologies. This work discusses exploiting multi-cloud capabilities in Internet of Things (IoT) applications for smart cities, emphasizing the role of 5G edge computing while highlighting the associated challenges.**

***Index Terms*—multi-cloud, smart cities, 5G, O-RAN, MEC.**

I. Introduction

Cloud computing is omnipresent in our society. Recent data indicate that 96% of businesses used at least one public cloud service in 2024 [1]. With the increasing demand for cloud computing over the years, many companies have started offering this service, leading to the development of multi-cloud approaches, which distribute workloads across different cloud environments, seeking to match the task with the type of cloud best suited for it [2]. The use of multiple cloud providers within an application offers several advantages. These include enhanced availability, improved fault tolerance, and reduced costs; being particularly beneficial in situations where a single cloud provider cannot fulfill all the application requirements [2].

Although using multiple clouds to implement an application has been explored for quite some time, a growth trend in adopting multi-cloud is still expected. This is significantly driven by the emergence of smart cities, which is projected to increase the number of IoT applications running at the edge of the network [3].

5G is the first generation of cloud-native mobile communication, and it is a key technology enabling smart cities. Its architecture allows IoT applications that require low latency to be executed and orchestrated within the operators' cloud infrastructure integrated with the 5G core (5GC) and the radio access network (RAN) [4].

Due to the limitations of previous generations that relied on closed, application-specific solutions for radio access networks, operators, vendors, research institutions, and industry partners have collaborated over the past few years to develop an interoperable alternative. This effort established the O-RAN Alliance consortium in 2018 [5]. The outcome of this collaboration is the Open Radio Access Network (O-RAN), an open interface and multi-cloud-ready RAN architecture currently undergoing initial tests and implementations worldwide [6]. Multi-cloud-native 5G cores are already available on the market, and the development of O-

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RAN continues with the goal of not only supporting 5G but also ensuring compatibility with 6G and future generations [5]. This engagement demonstrates the industry's increasing interest in multi-cloud and its importance for smart cities.

Multi-cloud approaches, however, have challenges such as increased application complexity, expanded attack surface, and interoperability issues [2]. Additionally, in the context of 5G edge applications, exposing the operators' infrastructure to third-party applications also introduces risks to the mobile network integrity [5].

In this work, the use of multi-cloud approaches within the IoT architecture of smart cities will be discussed, highlighting its role in edge applications and addressing the challenges that need to be overcome to ensure the security and efficiency of services. The remainder of this paper is organized as follows: Section II discusses the relationship between multi-cloud and IoT applications in smart cities; Section III presents challenges and possible research directions in this area, and finally, Section IV presents our concluding remarks.

II. Multi-Cloud, IoT, 5G and O-RAN

With the broadest coverage in urban centers, the mobile network is the connectivity medium with the greatest capability of supporting the different types of IoT devices (IoTDs) spread across a smart city [7]. In the 5G technology specification, network slices make it possible to meet the requirements of various applications under the same physical infrastructure through network function allocation in the 5G core. This generation has three main types of services: eMBB (Enhanced Mobile Broadband), mMTC (Massive Machine Type Communication), and uRLLC (Ultra Reliable Low-Latency Communication), where each service aims to meet a specific SLA (Service Level Agreement). There is also the possibility of establishing other service profiles in collaboration with the operator to satisfy more specific B2B applications, such as healthcare, surveillance, autonomous transportation, etc.

An important aspect of 5G networks' operation is its highly flexible nature. Since the entire 5G communication system is implemented along a cloud continuum, its agility to reconfigure to meet a connecting device service profile is improved compared to previous generations. This recent telco industry's move toward multi-cloud environments accelerates coverage expansion by enabling faster time to market and lowering total cost of ownership for communication service providers [8].

Internet of Things application requirements are generally covered by the mMTC or uRLLC service profiles, which account respectively for the possibility of up to one million IoT devices per km² connected and latencies down to 1 ms with 99.99999% reliability. For applications with these characteristics, a unified approach for 5G services that integrates public and private cloud environments can enhance network resilience and scalability [9], and reduce the distance traveled by data through the allocation of resources closer to the user equipment (UE) [10].

IoT applications with a uRLLC profile or similar requirements use edge computing to minimize latency as much as possible. Currently, there are two main categories of edge computing: MEC (multi-access edge computing) and Cloudlets. Furthermore, if the edge computing infrastructure integrates with a centralized cloud, it falls into a new category known as fog computing [11]. Cloudlets are processing-capable servers deployed locally to serve devices within the context of a LAN (Local Area Network), and MEC is a software framework that can be integrated with cellular technology to serve devices within the context of a WAN (Wide Area Network). In the case of fog computing, both technologies can take advantage of using a multi-cloud-based software architecture, but in the specific case of MEC, using multiple clouds has a broader positive impact due to its importance for 5G.

O-RAN promotes a flexible and open network architecture that allows for the integration of third-party software. MEC leverages it to collect fine-grained near-real-time data for joint optimization between the RAN and service applications [12]. Furthermore, MEC also takes advantage of the cloud-native nature of 5G and O-RAN to deploy edge computing resources as near as possible to end-users, offloading computational tasks from centralized cloud servers, alleviating network congestion, and improving overall system efficiency, which is essential in urban environments with high demand for computing power [4], [13]. This architecture, linked to the concept of local breakout in 5G MEC deployments, allows for the separation of user traffic at the edge of the network. This enables immediate data processing without the need to route it through distant core network functions, making it interesting

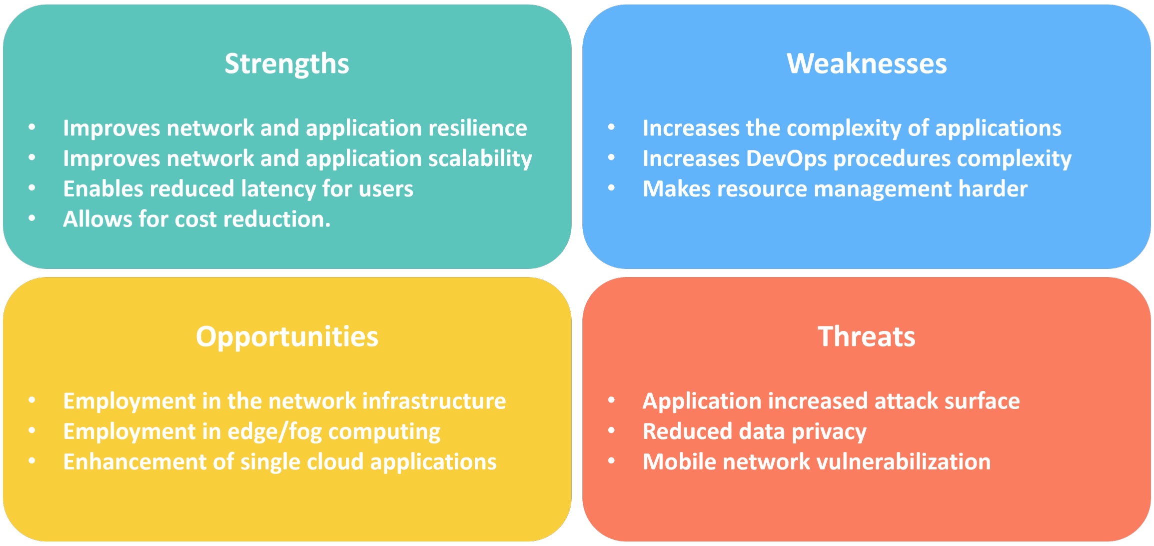

Fig. 1. SWOT analysis of multi-cloud approaches in smart city scenarios

for applications that require rapid response times [14].

Moreover, the orchestration of resources across multi-cloud environments can enhance the scalability and resilience of smart city applications. Research indicates that effective resource management strategies, such as those employing machine learning algorithms, can optimize the allocation of computational resources between edge and cloud environments [4]. This dynamic allocation is vital for managing the fluctuating demands of smart city applications, which may experience variable workloads due to changing urban conditions. By leveraging distributed computing resources, cities can ensure that critical services remain operational even during peak usage times.

III. Challenges and Research Directions

Recent literature [2] [15] shows that security and complexity are the main inherent challenges of multi-cloud approaches. From a software development perspective, the absence of standards makes it difficult to compare and integrate services from different providers; traditional DevOps principles must be adapted for multi-cloud environments; managing the complexity of communication systems in geographically distributed multi-cloud environments adds new variables to the problem, such as traffic cost and latency between providers; and, as mentioned, multi-cloud environments comes with an expanded attack surface, which decreases security.

In the same way, from the network perspective, scalability and resilience strategies that rely on machine learning algorithms may also be affected by potential adversarial attacks that manipulate the algorithms to misallocate resources and expose vulnerabilities [16].

Figure 1 summarizes the strengths, weaknesses, opportunities, and threats that encompass the possible multi-cloud deployments in a smart city scenario, indicating some topics that future research can focus on.

IV. Conclusion

Integrating multi-cloud approaches with 5G networks and MEC offers transformative potential for smart city applications. By leveraging these technologies, urban environments can enhance service delivery, optimize resource management, and foster innovative services that meet our societal needs. However, while applying multi-cloud may improve latency, resilience, and scalability, issues regarding complexity and security may also arise.

This work presented an outlook and showed the challenges associated with multi-cloud approaches in smart city scenarios. In future work, several metrics related to these deployments will be presented, shedding light on this key area for IoT systems.

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