Digital Transformation of Smart Cities via Cloud Ontologies

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***Abstract*—To fully implement smart city principles, Public Administrations must perform digital transformation and master enabling technologies such as cloud computing. Hence, in 2022, the Italian government has created the *Polo Strategico Nazionale* to accelerate the digital transformation of the Public Administration and facilitate cloud migration. This flagship project requires supporting the Public Administration to overcome technical and technological challenges related to cloud computing technology. This article explores and summarises key concepts related to the description of cloud computing aspects via ontologies, well-known and established solutions in companies and academia, still scarcely adopted by Public Administrations.**

***Index Terms*—smart city, digital transformation, cloud computing, cloud ontology**

I. Introduction

A smart city is the implementation of digital transformation to make traditional services more efficient for the benefit of its population [1]. Among the enabling technologies related to smart cities, cloud computing plays a crucial role in dealing with a huge amount of real-time data that must be collected, processed, analysed, and stored efficiently [2].

This requirement has recently driven the Italian government to create the *Polo Strategico Nazionale* [3] (literally translated as National Strategic Hub) through an agreement stipulated with the newly established company Polo Strategico Nazionale S.p.A., owned by TIM, Leonardo, Cassa Depositi e Prestiti (CDP, through the subsidiary CDP Equity) and Sogei. The Polo, established at the end of 2022, will host all critical data and services of all the Italian Public Administrations (PAs), Local Health Authorities, and the main local administrations in the next few years. The creation of the Strategic Hub completes the mission of the National Recovery and Resilience Plan (Mission 1, component 1, investment 1.1 Cloud PA/National Strategic Hub) to accelerate the digital transformation of the PA and has the objective, jointly with initiative 1.2 of the PNRR Enabling and facilitating cloud migration, to bring 75% of Italian administrations to use cloud services by 2026.

It is worth noting that this revolution requires overcoming technical and technological barriers related to the difficulties by PAs in mastering cloud computing technologies due to heterogeneity in the service description, lack of service interoperability, obstacles in service discovery, and fear of vendor lock-in. A widely explored solution in the literature to mitigate these challenges is the exploitation of cloud ontologies that behave as a mapping layer to present cloud services via a unified description. While it is a common practice accepted by researchers and companies, little attention is invested in supporting PAs to consider and adopt this solution. This article aims to provide PAs with a concise overview of the advantages (Section II) and open challenges (Section III) of adopting cloud ontologies looking at the scientific literature.

II. Cloud Ontologies

An ontology is defined as a data model abstraction intended for describing domain-specific knowledge in terms of concepts, attributes, and their relationships. Hence, cloud ontologies model cloud computing technologies in terms of functional features of cloud services to classify existing services and their pricing models, non-functional features such as security and privacy, and a combination of them [4].

Cloud ontologies have been widely explored in the literature for more than 20 years. Just consider that looking at the literature reviews on cloud ontologies indexed by Scopus matching the `*cloud* and ontolog* and (survey or review)` search query in title, abstract, and keywords, 130 results are returned, of which 20 relevant published between the 2012 and 2022. It is worth clarifying that a contribution is considered relevant if it reports and discusses a (systematic) literature review on the use or evaluation of ontologies to model aspects related to the cloud.

A commonly accepted taxonomy of cloud ontologies by different surveys [4], [5] is the use of ontologies for i) service discovery to select the best services according to user-defined requirements, ii) service description, iii) achieving the interoperability among cloud services and among cloud providers and iv) dealing with security concerns.

Advantages. This section summarises key advantages listed in the literature related to the adoption of cloud ontologies.
Standard and uniform description approach. Ontology can provide a well-defined representation of cloud services, masking their heterogeneity and playing an important role

in overcoming standardisation challenges while improving the communication among cloud agents (i.e., human and software) via a common-access information layer [4].

Wide coverage of service features. Ontologies successfully model functional and non-functional features [4] related to any cloud service model [6]. Well-known examples are CoCoOn [7], which describes functional and non-functional aspects of IaaS services, while Martino et al. [8] model functional features of PaaS and SaaS services.

Service composition and integration. Developers can easily compose cloud services by combining and integrating multi-services from single or multiple clouds exploiting the high-level definition of services. The mOSAIC cloud ontology [9] is a well-known cloud ontology to achieve interoperability.

Mitigation of the vendor lock-in and migration problems. Ontologies in the cluster related to interoperability help to address the lock-in problem, which in turn contributes to addressing other problems, such as the migration problem [4].

All needs are satisfied. Besides ontologies designed for service discovery, service description, and service integration, some ontologies cover specific aspects, such as cyber-security, access control, and pricing.

III. Conclusive reflections and Open Challenges

Since cloud ontologies are considered an established and well-known solution in companies and academia, also PAs should be supported in taking advantage of them. Cloud ontologies successfully model functional and non-functional features of any service model, reduces vendor lock-in while easing cloud computing portability and interoperability issues, and support a uniform and standard service model to simplify service discovery and selection. While it is an interesting aspect that most of the ontologies are used in applications, such as service discovery tools, it makes it hard to reuse and adapt ontologies in other contexts and applications.

Challenges and Open questions. Since *all that glitters is not gold*, cloud ontologies are also attached to challenges that pave the way for future discussions.

Cloud-ontologies are scarcely evaluated. There is no framework or benchmark to evaluate cloud ontologies [4]. Recently, few attempts have appeared to evaluate cloud ontologies [10], [11], mainly focusing on error detection. Further effort should be invested in relying on experts in the field during the construction and evaluation of cloud ontologies [4]. It also affects how ontology re-users can select the best ontology according to their needs, as there is no standard way to evaluate and compare cloud ontologies.

Maintenance plan. Many ontologies are just defined as proof of concept without neither reporting and describing a maintenance plan nor updating the ontology. Given the dynamism of cloud computing technologies, this results in many deprecated and not properly updated ontologies.

No uniform terminology. The cloud services description is published as plain text on Web pages, usually only including functional description, and missing quality of services aspects, an essential detail for the user to make the purchase decision and discover accurate services [4]. Further effort should be invested in defining a registry for cloud services publication and discovery that keeps up-to-date service information.

Risk to reinvent the wheel. Due to the enormous amount of available cloud ontologies, it is easy to represent features that have already been described via an ontology. It is crucial to carefully check the literature before starting, aware of the difficulty in managing hundreds of not uniform resources. Further effort should be invested in identifying a commonly accepted reference ontology that should be used as a starting point for an extension if required.

Lack of an holistic view. While there is a plethora of ontologies describing functional or non-functional features, such as the security aspect of cloud services and all the cloud service models, covering different scenarios from service description to service discovery and integration, the definition is still fragmented without offering developers with a holistic view encompassing all the aspects at once.

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References

[1] G. V. Pereira, L. F. Luna-Reyes, and J. R. Gil-Garcia, "Governance innovations, digital transformation and the generation of public value in smart city initiatives," in *Proceedings of the 13th International Conference on Theory and Practice of Electronic Governance*, ser. ICEGOV '20, 2020, p. 602–608.

[2] R. Massobrio, S. Nesmachnow, A. Tchernykh, A. Avetisyan, and G. Radchenko, "Towards a cloud computing paradigm for big data analysis in smart cities," *Programming and Computer Software*, vol. 44, pp. 181–189, 2018.

[3] Dipartimento per la trasformazione digitale del Governo Italiano, "Polo strategico nazionale," https://innovazione.gov.it/dipartimento/focus/polo-strategico-nazionale, 2023.

[4] M. M. Al-Sayed, H. A. Hassan, and F. A. Omara, "Towards evaluation of cloud ontologies," *Journal of Parallel and Distributed Computing*, vol. 126, pp. 82–106, 2019.

[5] M. Z. Hussain, M. Z. Hasan, N. Sarwar, J. Nasir, and N. Aslam, "Cloud application importance and challenges: A systematic review," in *2021 International Conference on Innovative Computing (ICIC)*. IEEE, 2021, pp. 1–6.

[6] S. Ghazouani and Y. Slimani, "A survey on cloud service description," *Journal of Network and Computer Applications*, vol. 91, pp. 61–74, 2017.

[7] S. Nepal, M. Zhang, R. Ranjan, A. Haller, and D. Georgakopoulos, "An ontology-based system for cloud infrastructure services' discovery," in *8th IEEE International Conference on Collaborative Computing: Networking, Applications and Worksharing*, 2012.

[8] B. Di Martino, G. Cretella, and A. Esposito, "Towards a unified owl ontology of cloud vendors' appliances and services at paas and saas level," in *2014 Eighth International Conference on Complex, Intelligent and Software Intensive Systems*. IEEE, 2014, pp. 570–575.

[9] F. Moscato, R. Aversa, B. Di Martino, T.-F. Fortiş, and V. Munteanu, "An analysis of mOSAIC ontology for cloud resources annotation," in *Federated Conference on Computer Science and Information Systems (FedCSIS)*, 2011, pp. 973–980.

[10] Y. M. Afify, N. L. Badr, I. F. Moawad, and M. F. Tolba, "Evaluation of cloud service ontologies," in *2017 Eighth International Conference on Intelligent Computing and Information Systems (ICICIS)*. IEEE, 2017, pp. 144–153.

[11] F. Loukil, M. Rekik, and K. Boukadi, "Antipattren-based cloud ontology evaluation," in *2016 IEEE/ACS 13th International Conference of Computer Systems and Applications (AICCSA)*. IEEE, 2016, pp. 1–8.