Enabling the Cloud-to-Autonomous-Vehicles continuum for future Industrial Applications: the CAVIA project approach

Marco Autili[1], Alberto Ceselli[2], Gianluca Filippone[3], Cinzia Bernardeschi[4] Christian Quadri[2], Carlo Vallati[4]
[1]*Department of Information Engineering Computer Science and Mathematics*, *Università dell'Aquila*, L'Aquila, Italy
[2]*Computer Science Department*, *Università degli Studi di Milano*, Milan, Italy
[3]*Gran Sasso Science Institute*, L'Aquila, Italy
[4]*Department of Information Engineering*, *Università di Pisa*, Pisa, Italy

***Abstract*—Autonomous Vehicles (AVs) will play a crucial role in automating many tasks in industrial environments. AVs will be connected entities leveraging the functionalities of support services for guidance, coordination and offloading complex tasks. These services will rely on a distributed cloud-to-AVs continuum computing infrastructure, allowing the services to be deployed according to their specific requirements. In this paper, we present CAVIA project, an ecosystem of different solutions to tackle the challenges in enabling the cloud-to-AVs to support industrial applications. CAVIA ecosystem comprises a set of tightly integrated solutions to manage different approaches in a holistic manner leveraging application choreography, service orchestration and infrastructure resource management.**

***Index Terms*—Cloud-to-edge continuum, IIoT, service orchestration, service composition**

I. Introduction

Autonomous Vehicle (AV) technology is expected to play a crucial role in automating industrial processes in many contexts, from logistics to production, reducing repetitive and dangerous tasks for workers, thus improving their overall health and working conditions. AVs require an infrastructure to support management services that control AVs decisions, monitor task execution and supervise safety conditions, risk prevention and fleet management. Some of such management services require high efficiency and low latency to ensure timed and reliable data collection and control. To this aim, the role of the computing and networking infrastructure is central to support these services on a large scale.

The cloud-to-things continuum represents a candidate architecture for deploying support services. However, it also represents a challenging environment [1] for both computing and networking infrastructure. Service provisioning and deployment, resource allocation, and network configuration require novel approaches to handle the extreme heterogeneity of the available resources, and to support novel applications with stringent quality of service (QoS) requirements. In this context, the introduction of mobile autonomous systems which generate large amounts of data [2], [3], introduces an additional challenge that requires a new holistic approach.

The project *CAVIA* (*enabling the Cloud-to-Autonomous-Vehicles continuum for future Industrial Applications*), aims to pave the way for this novel approach by defining an ecosystem of solutions capable of enabling the *next generation of the cloud-to-AV continuum*. Specifically, two main areas are covered: (1) network management solutions to ensure efficient data collection with mobility support for reliable and timed communication between AVs and the infrastructure; (2) models and algorithms for service composition and deployment supporting network reconfiguration and computing resource allocation. The goal is to ensure an efficient composition of management services in the cloud-to-vehicle continuum by considering the specific service requirements.

Concerning existing solutions, the CAVIA ecosystem is the first one to provide an integrated set of solutions that can provide network management functionalities and service orchestration/deployment jointly.

II. CAVIA vision and architecture

CAVIA will develop an ecosystem of solutions to enable the next generation of the cloud-to-AV continuum, to support seamless integration and management of AV fleets on a large scale. Considering the heterogeneity of the network and computing infrastructure and different industrial use cases, the project will aim to produce technology-agnostic solutions in the form of kernel components designed to be integrated into different networks or computing platforms.

CAVIA ecosystem is depicted in Fig. 1. A cross-layer ecosystem provides a holistic solution to manage service composition and deployment, and configure the network accordingly, to guarantee fine-grained support for the execution of AV management. Although developed as separate components, the solutions will be highly integrated, with a tight information exchange to handle the entire life-cycle of services. To support AV mobility, dynamic re-configurations is triggered based on the current status of the infrastructure, exploiting network reconfiguration and service migration to preserve QoS.

III. CAVIA components

An overall representation of the components of the CAVIA ecosystem and their interactions are presented in Fig. 2.

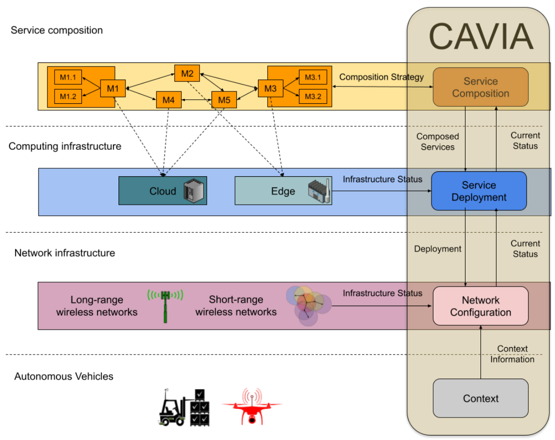

Fig. 1. CAVIA architecture

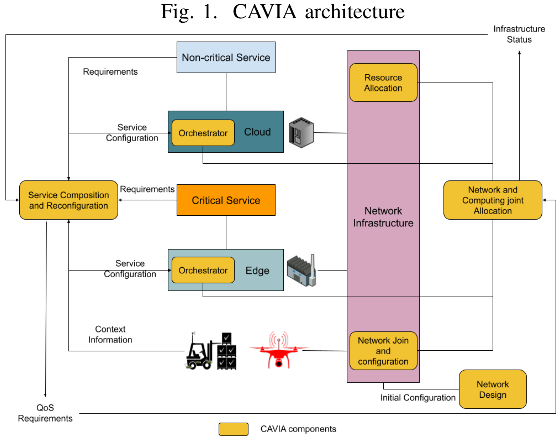

Fig. 2. CAVIA components

A. Integrated network management

Network design for optimal coverage: definition of network design strategies for network infrastructure planning, to optimize coverage, and handle mobility efficiently, minimizing AV energy consumption.

Network join and configuration: definition of zero-touch network join strategies to automate the process of network reconfiguration and integration of new AVs.

Resource management: definition of network resource algorithms for dynamic management of communication resources to enforce QoS requirements in terms of reliability and latency, including support to AVs mobility ensuring QoS continuity.

B. Joint service orchestration and network reconfiguration for fine-grained QoS requirements

Service composition and reconfiguration: definition of models and algorithms for joint service composition and reconfiguration to ensure the efficient composition of management services in the cloud-to-AV continuum, considering the service requirements. To ensure global optimization and scalability, a hybrid approach will be adopted with central and local orchestrators running on the cloud and at the edge, respectively. Moreover, a novel multi-level choreographic approach together with software synthesis techniques will be used to automate the composition and reconfiguration process.

Service orchestration: definition of models and algorithms for the assignment and deployment via a virtualized environment of the components of the management services to specific physical computing nodes over time. This task requires an online evaluation that can result in a reassignment/redeployment to handle service component variations over time. The latter will be achieved by including the following functionalities: (i) continuous monitoring of the physical network resources and constant KPIs evaluation; (ii) fast autonomous decision-making based on changing context and service configurations.

Joint computing and networking resource management: design of joint computing and network optimization models. Algorithms will be defined for (i) mid-to-long term resources provisioning to multiple end-to-end slices, each addressing a different class of QoS requirements, and (ii) dynamic re-configuration of service deployments via service migration based on current mobility patterns and changing computing requirements. Multi-objective functions and constraints will guide the optimization process considering different assets, such as economical, energetic, and system resilience.

IV. Use cases

Let us consider a smart factory that employs AVs to automate some logistics and surveillance tasks, e.g., an autonomous forklift that loads/unloads pallets and a drone that monitors the area for incident avoidance. The autonomous forklift is equipped with several sensors that communicate to the AV control box via short-range wireless technology. Both of the AVs are equipped with 5G radio for communication through which they communicate to a management service for data collection and analysis: (i) The *forklift management service* is a historical data analysis service that collects telemetry data from the AV and analyzes them for predictive maintenance. (ii) The *drone management service* is an image analysis process that receives images of the area taken and analyzes them via machine learning techniques to identify potentially dangerous situations.

CAVIA approach defines a close-loop service management solution of (i) optimal service composition, (ii) joint optimal service deployment and network configuration, and (iii) infrastructure monitoring, triggering dynamic re-configuration of the deployment and composition.

Acknowledgment

This work has been funded by the Italian MUR in the framework of the PRIN 2022 project "CAVIA: enabling the Cloud-to-Autonomous-Vehicles continuum for future Industrial Applications" (grant 2022JAFATE).

References

[1] L. Bittencourt, et al., "The internet of things, fog and cloud continuum: Integration and challenges". Internet of Things, 3, 134-155, 2018.
[2] N. Aljeri and A. Boukerche. "Mobility Management in 5G-enabled Vehicular Networks: Models, Protocols, and Classification". ACM Comput. Surv. 53, 5, September 2021
[3] F. Jameel, et al., "Internet of Autonomous Vehicles: Architecture, Features, and Socio-Technological Challenges", IEEE Wireless Communications, August 2019