Research and Innovation in Europe on Cloud for 6G Networks

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***Abstract*—Cloud is becoming increasingly important in the telecommunication sector in view of 6G networks. Moreover, cloud has gained major attention after the European Commission published a white paper proposing the creation of the "3C Network", a European telco edge/cloud infrastructure, which aims to increase collaboration between European players and ensure innovation, and economic and digital security in Europe. In a 6G network, a telco cloud can play three different roles. First, it is a basis to implement 6G Radio Access Network (RAN) and other network functions. Second, the telco cloud can implement Artificial Intelligence (AI) and other applications for 3rd party providers in the edge. Third, it allows devices/cars/drones/persons to outsource compute capabilities to the 6G edge. Currently, there are various ongoing European activities that address cloud, but they often have different focus and requirements. This paper provides an overview of ongoing activities related to telco edge/cloud. The analysis on the ongoing activities showed a clear trend towards providing open-source and/or standardised solutions. Furthermore, it has been identified that the topic of security is widely addressed.**

***Index Terms*—6G, cloud, Europe, research and innovation**

I. Introduction

6G - the next generation of telecommunication networks is set to combine connectivity services with compute capabilities. The compute capabilities in 6G will not only be used for Artificial Intelligence (AI) based network optimization and virtualised network control, but also for the host of intelligent user applications that 6G will need to support. Compute for applications can be provided in the cloud, but time critical applications and control of network infrastructure need processing nearer to the end-user or distributed network elements. This requires a 6G telco edge-cloud continuum that stretches from the (hyperscaler) cloud, via core network entities, to distributed edge locations.

The market of Information Technology (IT)-cloud services is currently dominated by a number of hyperscalers based in the United States. There is still an opportunity for edge/cloud services to be provided by European players, such as network operators which have a much more distributed infrastructure. However, within Europe, edge computing is still at its infancy [1], thus creating a potential dependency on the large global hyperscalers here as well. Because 6G will provide the basis for the European digital society, ensuring European sovereignty of telco cloud becomes a critical concern for European telco stakeholders. To support different business models, in which next to hyperscalers also different European providers can play a role, it is important to create a disaggregated 6G architecture with standardized interfaces [2]. The challenges faced in creating a European cloud are also recognized and range from regulatory challenges to technical complexity, including integration and support challenges, as well as attracting investments and talent.

The European Commission addressed telco cloud in their white paper "How to master Europe's digital infrastructure needs?" [1], which specifically addresses the "Connected Collaborative Computing" Network ("3C Network"), a European-wide telco edge/cloud. This initiative is also supported by the global association of mobile operators (GSMA) that embraces the efforts towards a public-private collaboration that will foster the innovation and developments necessary to make 3C networks a reality [3]. Telco cloud sovereignty has also been addressed by the 6G Smart Networks and Services – Industry Association (6G-IA) in their position paper "European Vision for the 6G Network Ecosystem" [4], where they highlight the European stakeholders' expectations for a cloud native network and advocate for the development of innovative solutions that will enable the edge-cloud continuum. The importance of "cloud" for future networks is recognized by the two largest European telco vendors, who directly reference Cloud-Radio Access Network (RAN) and cloud native services as key components of their vision for 6G networks [5] [6]. Moreover, the relevance of "cloud" in European 6G research is illustrated in a position paper [7] that was based on a workshop between cloud experts from Smart Networks and Services (SNS) and

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other European research initiatives.

Given the growing importance of cloud, this paper showcases the European research landscape by providing an overview of ongoing activities that address cloud-related topics. The overview consists of different types of activities, e.g. projects, organisations, and standardisation bodies, which often have different focus and requirements. An analysis of the overview is also provided, which allows to better understand the European research landscape around "cloud".

The rest of the paper is organized as follows. Section II illustrates the different roles cloud plays in 6G networks. Section III provides an overview of the primarily European considered activities. Section IV presents the analysis and comparison of the different ongoing activities. Finally, Section V provides conclusions and a way forward.

II. The role of Cloud in 6G Networks

This paper distinguishes three different roles that cloud plays in 6G, *(i)* supporting 6G functions, *(ii)* supporting 3rd party applications and *(iii)* supporting intelligent agents. Each role comes with specific requirements and considerations.

Supporting 6G functions is the basic role that a telco cloud plays in 6G. Mobile network functions can be supported by compute capabilities in a telco edge/cloud. Already the 5G core network, with its service based architecture, can be implemented on cloud infrastructure. Additionally, in 6G, it is expected that centralized radio functionality will be implemented in the cloud. Already there are efforts, e.g. within the O-RAN Alliance, on the disaggregation and cloudification of the RAN, and the development of open interfaces between the RAN and the cloud. Specific for 6G is the use of AI for network optimization, which implies AI processing in the telco cloud. Other network functions such as media processing or positioning can also be implemented as cloud functions.

The disaggregation of the RAN, as well as different RAN functionalities place stringent requirements on latency and jitter and will therefore different RAN components and functionalities should be deployed in the edge. For functions that process or forward large amounts of data (e.g. gateways, cloud RAN, or AI optimization) performance optimization beyond generic Central Processing Unit (CPU) processing may be needed. Network control functions such as session management or subscription management rely on general cloud compute and storage capabilities.

6G networks will be multi-provider with interconnect and roaming interfaces between different network operators. The underlying cloud layer should also support a multi-provider eco-system with private cloud from network operators, local edge/cloud providers and hyperscalers. Because of sovereignty and resilience considerations it should be possible to port 6G network functions from one cloud to another. Standardised interfaces are required between different network functions, even when these are deployed on different clouds. Moreover standardized interfaces are needed between network functions and the underling cloud infrastructure.

Support 3rd party applications is most similar to the role IT-clouds play. The difference is that in a 6G telco cloud, applications may need to be supported in the edge. This can be because of latency requirements, but also to reduce core traffic transport, or for privacy data protection or resilience reasons. Mobility of the end-users implies that applications may have to follow their end-user from one edge to another edge. The mobile operator will hide this mobility, offering the 3rd party application provider a single application interface independent of in which mobile network and edge/cloud the application is deployed. Because there can be many different applications, it is difficult to provide standardised cloud support. Furthermore, the application interface should not be much more complicated than the web-interfaces that the 3rd party application provider are used to. To create scale for a viable ecosystem, the initial services provided via the application interface should follow the Keep It Simple Stupid (KISS) principle.

The telco edge/cloud may also provide compute resources to devices/phones/cars/drones/persons that want to offload processing for intelligent agents to the cloud. These intelligent agents can interpret intent, interact with the environment, access contextual information, make decisions, and take actions autonomously or in collaboration with other AI agents. The 6G telco cloud should provide an AI agent hosting ecosystem that provides basic functionality to support AI agent interactions (e.g. identification/authentication of AI agents).

III. Ongoing Activities

This section provides an overview of primarily European cloud-related activities, which are different in nature, e.g. projects, open-source initiatives, and standardisation and regulatory bodies, to showcase the wide interest in cloud research. The overview is based on publicly available information.

A. Important Projects of Common European Interest in Next Generation Cloud Infrastructure and Services (IPCEI-CIS)

IPCEI-CIS [8] aims to develop the first "Multi Provider Cloud Edge Continuum" in Europe, which will provide a.o. a distributed, openly accessible and interoperable cloud and edge infrastructure. The primary focus of the project is on interoperability, sustainability, cybersecurity and standardisation. Overall, twelve European Union (EU) Member States are involved (namely, Belgium, Croatia, France, Germany, Hungary, Italy, Latvia, Luxembourg, The Netherlands, Poland, Slovenia, and Spain) and 120 projects have been launched in December 2023. The first results are expected by the end of 2027, and the projects will end the latest by the end of 2031. Moreover, the 8ra initiative is established as a long-term support of the project results in terms of continuity, adoption, completion, sustainability and collaboration.

IPCEI-CIS addresses a range of topics [9]. First of all, the infrastructure of the edge-cloud continuum will be developed, which includes the development of the necessary hardware and software for the interconnection of networks. Moreover, a common reference architecture for the "Multi Provider Cloud Edge Continuum" will be created, which will serve as a

guideline for the edge/cloud system deployments. Additionally, tools and services ensuring the run of applications and the fulfillment of their requirements, as well as edge/cloud operating system and Application programming Interfaces (APIs) will be developed. Furthermore, data processing tools and services will be developed to allow the exploitation of the edge-cloud continuum. Finally, a first industrial deployment will be performed to demonstrate scalability, security, and interoperability of services in different domains, including the telecommunication domain.

B. European Alliance for Industrial Data, Edge, and Cloud

The goal of the European Alliance for Industrial Data, Edge, and Cloud [10] is to ensure that edge and cloud technologies are developed and deployed such that digital innovation is secured and requirements on sensitive data handling are met. The alliance stems from the European data strategy and the declaration of EU Member States on building a European cloud. The kick-off event on the initiation of the alliance was hosted by the European Commission in December 2021. As of July 2024, the alliance comprises 56 members.

To fulfill their goal, the alliance provides a platform for investment synergies, recommendations, a matchmaking platform on EU investments for business and public authorities a coordination platform for the European Commission and the EU Member States, a stakeholder consultation platform to the European Commission in regards to the EU Cloud Rulebook, expertise for the public procurement of cloud services, and a platform for synergies with Common European Data spaces. Moreover, the alliance provides strategic roadmaps. Specifically, the published "European Industrial Technology Roadmap for the Next-Generation Cloud-Edge" [11] provides insights on important technologies for investment. Additionally, focusing on the telecommunication domain, the "Telco Cloud Thematic Roadmap" [12] was published, which includes requirements for the telco and edge application use cases, ongoing activities, a gap analysis for various technologies, challenges and recommendations.

C. Gaia-X

Gaia-X [13] is a non-profit association that strives for digital sovereignty. For that, Gaia-X aims to provide a federated and secure data infrastructure that enables data sharing and ensures that users retain the control over their data access and usage. The envisioned transparent and fair ecosystem will link cloud service providers and users. To achieve their goals they develop specifications, rules, policies, and a verification framework. Moreover, Gaia-X implements their open-source specifications also via collaborations with others. Currently, Gaia-X has more than 350 members.

Through the Gaia-X Ecosystems, businesses and organisations can create and develop data spaces that are interoperable, and projects. The creation of a data space refers to a relationship establishment between partners who follow the same data-related standards and rules. One of the key goals of Gaia-X is to create and deliver data spaces in a single or multiple ecosystems, e.g. health, energy, and tourism, which could increase the business impact and allow to replicate additional data spaces in as many vertical ecosystems as possible. Finally, Gaia-X addresses three conceptual pillars, namely, *(i)* compliance, providing decentralised services to enable measurable trust *(ii)* federation, which facilitates interoperable and portable cross-sector services, and *(iii)* data exchange, with contract rules for data access and usage.

D. Global System for Mobile Communications (GSMA)

GSMA, a global organisation representing mobile network operators, drives innovation and standardisation in the mobile communications industry. Two key initiatives, the Open Gateway Initiative and the Operator Platform Group, aim to enhance mobile network capabilities and support the broader digital ecosystem. The Open Gateway Initiative [14] focuses on creating standardised APIs that provide access to essential network functions, such as network slicing and quality of service, enabling developers and businesses to leverage telecom infrastructure more effectively. The Operator Platform Group, on the other hand, is dedicated to building a unified, federated edge computing platform, allowing operators to offer low-latency computing resources for applications like autonomous vehicles and smart cities.

The initiatives address key challenges, such as integrating telecom networks with digital services and enabling consistent, scalable solutions. The Open Gateway Initiative emphasises standardised APIs for traffic management, security, and 5G integration, while the Operator Platform Group [15] focuses on edge computing architecture and federated service delivery. Collaborative working groups involving telecom operators, technology partners, and industry experts ensure the scalability, security, and interoperability of the solutions. GSMA oversees these efforts, aligning them with industry standards and incorporating feedback from trials to refine the roadmaps and accelerate adoption.

E. CAMARA

CAMARA [16] is an open-source project in the Linux Foundation and it aims to define, develop and test APIs for the telco industry. The adoption of these standardized APIs will enable seamless customer experience and application portability. CAMARA consists of more than 26 API families and sub-projects, and there are more than 1100 contributors and 396 organizations participating in the project.

In 5G, it is envisioned that the network will work in a service based approach, hence enabling Network as a Service (NaaS). CAMARA aims to provide an abstraction from Network APIs to Service APIs, which will enable user-friendly APIs development, satisfy data privacy and regulatory requirements and facilitate application to network integration. Moreover, CAMARA addresses availability across networks, platforms and countries. CAMARA is only focusing on the northbound interface, i.e. between the operator/network and

the capability consumer/application. Overall, with the CAMARA APIs, the network capabilities can be more easily exploited, develops more easily obtain access to network information and new applications can be developed.

F. European Telecommunications Standards Institute (ETSI) Network Function Virtualisation (NFV)

ETSI [17] supports the development, ratifications and testing of globally applicable standards for systems, applications and services in the Information and Communication Technology (ICT) sector. ETSI is recognized by the EU as a European Standards Organisation and addresses a number of different technologies, including NFV and Open Source NFV Management and Orchestration (OSM).

Founded in November 2012, ETSI NFV [18] originates from standardising VNFs and still continues to address new developments. Additionally, ETSI NFV extended its work to address developments on Cloud-native Network Functions (CNFs). ETSI OSM [19] works in alignment with ETSI NFV and aims to enable NFV vendors to deliver their solutions to users in a quick and cost-effective way.

ETSI NFV is an Industry Specification Group (ISG), which operates alongside the standards-making committees in a specific technology area. Both ETSI members and non-members, under specific conditions, can be part of ETSI NFV. As a community-led project, ETSI OSM is developing a production quality open source Management and Orchestration (MANO) stack aligned with the ETSI NFV Information Models. As of October 2024, there are in total 43 members and 110 participants to ETSI OSM.

G. Cloud Native Telecom Initiative (CNTI)

The Cloud Native Telco Initiative (CNTI) [20] is a project under Linux Foundation Networking (LFN) aiming to accelerate the adoption of cloud native technologies within the telco sector. For that, CNTI set the goal to meet the needs of vendors and services providers, as well as create a conformance programme which unifies cloud native goals. To achieve their goals and create common guidelines, CNTI seeks collaboration with other communities. The solidification of CNTI mission is highlighted by its evolvement from an initiative to a project within LFN in July 2024. This provides increased visibility, more collaboration, and additional resources and infrastructure.

The increasing demand for scalability, agility, and cost-efficiency, which currently the telcos are facing, has made the transition to cloud-native architectures imperative. This transition ensures better resource efficiency, improved resiliency and availability, higher development velocity, and improved interoperability. CNTI supports this transition by working on three areas, i.e. *(i)* development of best practices for cloud native networking, *(ii)* development of a test catalog, with which applications can be validated for adhering to best practices, and *(iii)* creation of a certification programme, which verifies that a cloud native vendor or user follows cloud native principles and best practices.

H. Anuket

Anuket [21], an open-source project under LFN, was formed through the merger of the Cloud iNfrastructure Telco Taskforce (CNTT) and Open Platform for Network Functions Virtualization (OPNFV). Anuket aims to provide standardised architectures, reference models, and conformance frameworks for cloud-native and virtualised network functions, helping telecom operators reduce costs and accelerate 5G deployment.

The project addresses critical challenges in the telecom industry, focusing on automation, orchestration, and security to support the adoption of 5G and cloud-native technologies. Anuket's efforts center on edge computing to reduce latency for real-time services, network fabric programmability to optimize traffic management, and robust infrastructure for deploying virtualised and cloud-native network functions. By fostering interoperability and reducing fragmentation, Anuket enables efficient, scalable, and secure deployments across multi-vendor cloud environments. Overall, Anuket develops reference models, compliance tools, and testing frameworks. Moreover, collaboration between vendors and operators ensures standards are tested in real-world environments and the developed releases are aligned with the needs of industry.

I. Sylva

Sylva [22] is an open-source project within Linux Foundation Europe and its main goal is to enable vendors showcase the functionalities of their network functions on a general-purpose infrastructure. Specifically, they develop a cloud software framework, a reference implementation and a validation programme, focused on telco and edge scenarios. In December 2024, Sylva announced their long-term vision to develop a cloud-native, scalable, and energy-efficient telco cloud infrastructure that supports technologies like Open RAN, edge computing, and AI-driven networks. Moreover, Sylva contributes to the telco ecosystem and has synergies with the a.o. O-RAN ALLIANCE, Gaia-X, ETSI, Anuket, and CNTI. Sylva was initiated by five European operators (Telefonica, Telecom Italia, Orange, Vodafone and Deutsche Telecom) and two telco vendors (Ericsson and Nokia) and it is driven by the European telecom needs, without limiting participation within Europe.

The Sylva Project aims to provide a telco-specific Container as a Service (CaaS), which runs on top of any commercial hardware, and where a.o. 5G core and radio cloud native network functions can run. The development of such a CaaS is needed as, currently, there are applications that run only on specific CaaS, which increases complexity for both vendors and operators, and wastes compute power and energy. The developments within Sylva take EU requirements into account regarding cybersecurity, trustworthiness on data processing, service federation, and energy management.

J. Smart Networks and Services Joint Undertaking (SNS JU) Policy Working Group on 3C Networks

The European SNS JU is a Public-Private Partnership that provides funding for 6G research and innovation. One of its

main goals is to leverage the EU's strength in network supply towards the broader value chain including cloud and software as well as devices and components.

The SNS JU Governing Board has established an - invitation only - Policy Working Group (WG) on 3C Networks. The objective of this WG is to: *(i)* discuss policy, industry and business developments relevant to the "3C network" vision; *(ii)* identify and discuss potential synergies/coordination between SNS JU activities and other EU activities and *(iii)* examine a potential coordination role for the SNS JU. In particular, an important objective could be a contribution of the WG towards the stronger coordinating role advocated for the SNS JU in the Commission's White Paper "How to master Europe's digital infrastructure needs?" [1].

K. Body of European Regulations for Electronic Communications (BEREC)

The Body of European Regulations for Electronic Communications (BEREC) provides regulations related to the digital markets in Europe. BEREC aims to ensure that the EU regulatory framework is consistently applied and to promote an effective internal market in the Telecom market. Moreover, it provides opinion and advice to the National Regulatory Authorities (NRA), the European Commission, the council of the EU and the European Parliament.

In March 2024, BEREC made available a report on Cloud and Edge Computing Services to elaborate on their impact on the electronic communications sector and to reflect on their regulatory implications. The report outlines challenges related to additional investment on infrastructures, market concentration and competition, digital sovereignty, sustainability, users' uptake and development of use cases, interoperability, data protection and cybersecurity.

There are twelve active working groups within BEREC, namely, regulatory framework, open Internet, planning and future trends, market and economic analysis, digital markets, end users, international roaming, fixed network evolution, wireless network evolution, remedies and market monitoring, cybersecurity and sustainability.

IV. Topics Addressed by Ongoing Cloud Activities

This section provides a summary with the characteristics of and topics addressed by the activities mentioned in Section III, based on the best of our understanding. This summary is provided in Table I and it aims to showcase the research landscape and provide a better understanding of which cloud-related topics are mostly addressed by the ongoing activities. The table includes all activities from Section III except from the SNS JU Policy WG on 3C Networks, as no information is public, and the BEREC, as only one cloud-related report was found during our research. Note that for convenience, in Table I, the European Alliance for Industrial Data, Edge, and Cloud is mentioned in short as European Alliance.

Table I compares the activities based on their characteristics, i.e., whether they are focused on the broader IT or telco sector, the type of their deployment (if applicable), whether they provide open-source solutions (if applicable), and whether specifications are being developed. Moreover, the focus of each activity on different topics is shown, using a three-star rate system, where a "-" is used when the topic is not addressed by the activity. The topics considered are:

- Policy/Standardisation: Development of policies and/or contributions to standardisation efforts.
- Support 6G functions: Addressing challenges to enable the support of 6G network functions.
- Support 3rd party applications: Addressing challenges to enable 3rd party applications.
- Architecture/Infrastructure: Development of infrastructure and/or architectures.
- Orchestration and Management: Addressing the orchestration and management of e.g. resources and network functions.
- Security: Addressing concerns related to (cyber)security.
- Environmental Sustainability: Addressing concerns related to e.g. energy efficiency and consumption.
- Business Models: Development or adaptation of business models.

Table I shows that cloud for the telco sector is addressed by the majority of the considered activities, and that different types of deployments, i.e., commercial, industrial, and validation, are being addressed. Additionally, there is a clear trend for open-source development and focus on standardising solutions, either by developing specifications (within the respective activity) or by contributing to other standardisation efforts/bodies. Moreover, there is a distinction between telco-focused activities addressing support for 6G functions and 3rd party applications. Furthermore, the topic of security is attracting interest from all activities.

V. Conclusions and Way Forward

To ensure sovereignty, an European telco cloud is becoming a critical requirement for European telco stakeholders. The goal is to develop cloud solutions that are scalable, secure, sustainable and support a diverse eco-system of providers. The IPCEI-CIS, the European Alliance for industrial data, Edge and Cloud, and Gaia-X aim to provide a federated European cloud eco-system that should reduce the dependency on non-EU hyperscalers.

6G will be cloud-native and will be based on a telco cloud. The main role of telco cloud in a 6G network will be to support 6G network functions (e.g., 6G core, centralised radio functionality, AI optimization). A cloud-native architecture brings benefits in terms of resource efficiency, scalability, resiliency, availability, and shorter development cycles. ETSI NFV, CNTI, Anuket, Sylva and the European Alliance for Industrial Data, Edge, and Cloud, are initiatives that focus on how to support network functions on cloud infrastructure.

Network operators and edge/cloud providers see a business opportunity in offering edge/cloud compute to third party application providers. For this interfaces are needed between the third party application providers and the network operator and from the network operator to the local edge/clouds where

TABLE I
OVERVIEW OF CHARACTERISTICS OF AND TOPICS ADDRESSED BY THE CLOUD ACTIVITIES.

Topic	IPCEI-CIS	European Alliance	Gaia-X	GSMA	CAMARA	ETSI NFV	CNTI	Anuket	Sylva
Focus	IT	IT & Telco	IT	Telco	Telco	Telco	Telco	Telco	Telco
Deployment	Industrial	N/A	Commercial	Commercial	Commercial	Industrial	Industrial	Validation	Validation
Open Source	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Specifications	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Policy/ Standardisation	***	***	***	*	*	*	**	*	*
Support 6G functions	-	***	-	-	*	***	***	***	***
Support 3rd party applications	-	***	-	***	***	-	-	-	-
Architecture/ Infrastructure	***	***	**	**	-	*	**	***	*
Orchestration and Management	***	***	**	-	-	***	**	***	***
Security	***	***	***	**	***	***	**	**	***
Environmental Sustainability	***	***	*	-	-	-	*	-	***
Business Models	-	***	**	***	-	-	*	-	-

the applications are deployed. GSMA and CAMARA are initiatives that are active in this area. Also the European Alliance for Industrial Data, Edge, and Cloud includes providing 3rd party applications in the edge in their architecture work.

This paper does not identify specific initiatives related to the support of intelligent agents. Intelligent agents are a topic of discussion in the 3GPP SA1 study on 6G use cases, but it may be too early to see initiatives that are working on how to implement intelligent agents in a telco cloud.

The SNS JU policy Working Group on 3C Networks addresses policy and business development aspects relevant to the "3C network" vision of a European telco-edge/cloud infrastructure. A potential way forward is to bring proposals that are integrated with the research and innovation actions developed in the context of the SNS JU, Horizon Europe and IPCEI projects and influence European policy makers.

To stimulate European sovereignty of telco cloud it is important to provide funding for implementation and testing of cloud networks. This funding is addressed by the draft SNS Work Programme 2025, which calls for a 15M Euro Stream C project on the implementation of the 3C Network. 3C Network implementation is also addressed by the draft Horizon Europe Cluster 4 Work Programme 2025, which includes an 75M Euro indicative budget for large-scale pilots on telco edge/cloud deployments as a basis for 3C Networks.

Standardisation is essential and critical in building trust across the industries to ensure that systems, devices, and applications work seamlessly across platforms and environments. Currently, the 6G use cases are being defined by 3GPP. It is important to ensure the inclusion of compute-as-a-service with standardised interfaces for a multi-provider business model.

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