A Vision for the Future of Research in the Cloud-Edge-IoT Domain

Motivation

The emergence of the Cloud-Edge-IoT continuum brought about a significant shift in computing and data processing. Horizon Europe strategy so far focused on baseline system technology and concepts by combining and building on relevant elements of computing, connectivity, IoT, AI, and cybersecurity with the goal to achieve more edge intelligence and autonomy through these R&I investments. Beyond 2025, the European Commission seeks to explore new disruptive trends, radically new visions, and emerging game changers for the Cloud-Edge-IoT research domain. As Martel, we recognise the potential impact of cutting-edge technology on our society, economy, and environment. In this vision paper we present our vision for the future in the Cloud, Edge, IoT domain, highlighting critical areas of research and development with the aim to provide a visionary perspective on the future of the European research and innovation programs for 2025-2027.

Current Status

Cloud-edge computing is already affecting the way we interact with technology and our expected services and service levels. However, there are still several challenges to be tackled to unleash the full potential of this technology. Current research and innovation investments include developing a Cognitive Cloud-Edge Computing Continuum, a hyper-distributed computing approach that exploits AI techniques to advance automation and dynamic adaptation of resource management across IoT devices and Edge and Cloud computing models. Furthermore, the Commission seeks to capture new trends like from MetaOS towards MetaWeb, for industrial IoT towards a Metaverse@theEdge, for radically new Software Engineering Challenges, or related big game changers.

Research Challenges

In order to fully realise the potential of the Cloud-Edge-IoT continuum beyond 2025, a number of key research challenges will need to be tackled and solved. In the following, a selection of the research challenges of interest is reported.

Edge-to-Cloud Interoperability and Standard Interfaces

One of the primary challenges in the Cloud-Edge-IoT continuum is achieving seamless integration between edge devices and cloud computing models. This requires the development of standard protocols that enable edge-to-cloud interoperability, which allows edge devices to communicate effectively with cloud computing models.

To address edge-to-cloud interoperability challenges, efficient data transfer and synchronisation protocols, device and platform-agnostic standards, and secure communication protocols must be developed. Additionally, dynamic resource allocation and management, service discovery and orchestration, and scalable and resilient protocols are crucial. Finally, seamless communication should be enabled through application-level integration, involving standardised interfaces, data formats, and APIs.

Massimo Neri - Chief Technology Officer, Martel Innovate   Giovanni Rimassa - Chief Innovation Officer, Martel Innovate

End-to-end Software Engineering for the Cloud-Edge-IoT Continuum

Disruption from Cloud Computing, IoT, and Edge Computing started from deployment and operations, with earlier software development activities often left untouched. More R&I is needed on programming models and languages, architectural styles and patterns, and design/simulation tools, especially at application level and somewhat verticalised for specific industries, use cases, and network topologies. Strategic connections should be made with Open Source Software and Hardware, and European digital autonomy.

AI-powered Resource Management

The Cloud-Edge-IoT continuum relies heavily on AI to achieve more intelligence and autonomy at the edge. Nevertheless, developing AI-powered resource management, dynamically adapting to changing conditions and effectively allocating resources will keep on being a significant challenge. AI-powered resource management must enable real-time decision-making, handle heterogeneous environments, and incorporate adaptive learning algorithms. They should prioritise energy efficiency, fault tolerance, and resilience while ensuring scalability. Furthermore, they must address security and privacy by integrating privacy-preserving techniques, secure communication protocols, and robust access controls.

Continuum Infrastructure Support for Trustworthy AI

A complementary facet of the previous point is that Cloud-Edge-IoT continuum should offer AI support at the infrastructure level. This is important for both European values (the traits of Trustworthy AI can be more effectively ensured with some infrastructure help) and European competitiveness (having infrastructure support for AI will lower barriers for SMEs and other players to smoothly develop and introduce their own AI models for business differentiation). Current AIOps/MLOps offers should be extended to empower trustworthy edge intelligence.

MetaWeb and Metaverse@theEdge

As new trends emerge, like from MetaOS towards MetaWeb, and for industrial IoT towards a Metaverse@theEdge, there is a need to explore how these new trends can be leveraged to achieve more intelligent and autonomous edge computing models.

"Metaverse at the edge" integrates the metaverse with edge computing technologies, offering reduced latency for improved user experiences, enhanced scalability, and better security and privacy. By processing data closer to the source, bandwidth usage becomes more efficient, lowering costs. Additionally, edge computing enables real-time processing and analytics, fostering more engaging and dynamic experiences within the metaverse.

Applications - Integrated Smart City Infrastructure

Integrating IoT, edge computing, and 6G networks in urban environments poses significant research challenges. It demands new communication protocols and security mechanisms, energy-efficient hardware and software architectures, as well as new regulatory frameworks and multiple stakeholders involved in a shared vision and ecosystem for future smart cities.

Conclusion

The Cloud-Edge-IoT continuum has immense potential for intelligent computing models.. However, challenges need to be addressed for full realisation. The European Commission's initiative to explore disruptive trends for Cloud-Edge-IoT is a step in the right direction. This vision aims to provide a contribution to Europe's innovation agenda, fostering a sustainable, inclusive, and technologically advanced future.

Massimo Neri - Chief Technology Officer, Martel Innovate   Giovanni Rimassa - Chief Innovation Officer, Martel Innovate