Predictive network management and orchestration towards 6G

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***Abstract* — The vision of future 6G systems is a complete interconnection of human, physical, and digital worlds as different dimensions that seamlessly interact to support new services. An essential element to empower this 6G vision is the use of automation based on Artificial Intelligence (AI) and Machine Learning (ML) within the network orchestration and management system in order to cope with the envisioned heterogeneity and distribution of infrastructures and services. The use of AI/ML needs to deal with huge amounts of data generated at all levels: infrastructure, platform, and service that need to be efficiently collected, filtered, analyzed and processed for better decision making, mainly through the enforcement of predictive actions for faster adaptation based on trained algorithms. Hexa-X is a European flagship project to build technical foundations for such a vision and is developing 6G technology enablers for new radio access technologies, connected intelligence with edge-to-network continuum and accurate network disaggregation for more dynamicity and flexibility. We provide an introductory framework for predictive management and orchestration in 6G networks as seen by Hexa-X.**

Keywords — Predictive management, data-driven orchestration, AI-enabled network and service management, B5G/6G

I. CONTEXT AND MOTIVATIONS

In the recently released latest generation of mobile networks, 5G, the major innovation regarding the management and orchestration (MANO) of network resources is to a large extent linked to the deployment and management of Virtual Network Functions (VNF) at the core, RAN and Edge networks. ETSI MANO [1] and ETSI MEC [2] standards are relevant references in this regard, as well as the different open-source network service orchestration platforms currently available (e.g., OSM [3] or ONAP [4]).

The evolution towards the next generation of mobile networks, 6G, poses new challenges that will need to be considered, and this will also affect the orchestration of network services. One of these challenges is to consider also as "orchestable" resources those devices beyond what we today consider the edge network, i.e., the user equipment (UE) connecting to the MEC data centres through the access network. This would entail the orchestration function to cover the continuum from the end devices (extreme edge) through the network edge to the cloud or central network (see Fig. 1). To enable future digital services, we foresee this continuum orchestration enabled by the convergence of IT systems and networks. Also, it must provide to users a much higher control level, that is, be more transparent when using digital services. Today the nature of these devices at the extreme edge is already diverse. We are no longer just talking about personal smartphones, but also devices in IoT networks (e.g., sensors or actuators), smart TVs, devices in factories or residential environments, or on-boarded devices (e.g., in drones), among other. And as the technology evolves towards the new 6G network this diversity is expected to increase, along with the number of deployed devices.

From the network service orchestration perspective, the challenge is to integrate and manage that great diversity of devices and supporting technologies while decentralizing orchestration functions. The benefit of this would be to be able to handle in a coordinated way those additional computing and networking resources that are in close proximity to the end users, as well as to gather data from them. This poses new challenges: unlike the resources in the mobile network operator (MNO) premises which are located in controlled datacenters, resources at the extreme edge can be very volatile, nomadic and having

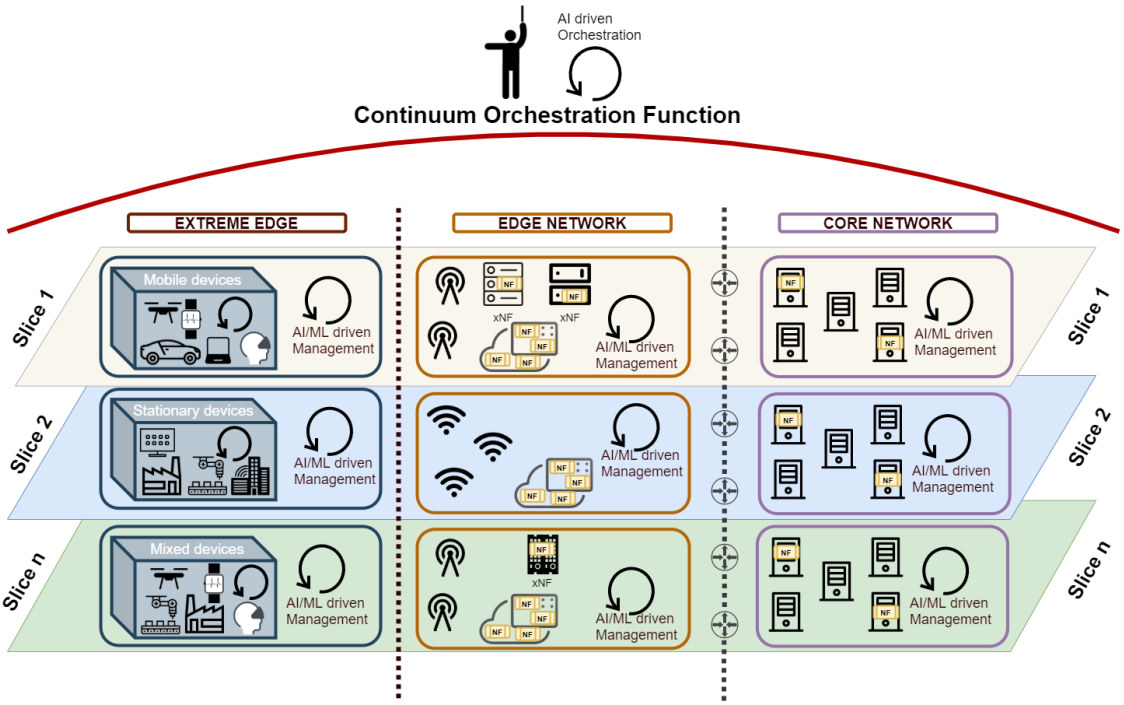

Figure 1. AI-Driven Continuum Orchestration

random behaviors; they will also be massive in scale, not to mention the diversity of supporting technologies.

This article aims to give an introductory view to what we consider would be the evolution of the current 5G networks towards the new 6G generation regarding the management and orchestration of the network, considering the integration of those resources beyond the edge and the usage of artificial intelligence techniques to leverage predictive.

II. Predictive Management & Orchestration Framework for 6G

The inclusion of artificial intelligence techniques in the management and orchestration context is important for implementing a rich variety of services in a heterogeneous end-to-end architecture. The complexity of integrating the extreme edge resources within the network imposes the management and orchestration scope to evolve, using AI techniques as a valuable resource as operation automation enablers, and to integrate data from the many and heterogeneous sources from the core, edge and extreme edge devices. AI/ML techniques can be useful to make predictions that can support the management and orchestration processes in a quick and automated way to ensure an optimal amount usage of resources, such as, processing, storage or networking. In terms of trust and risk level it is key to develop better predictive orchestration algorithms. Smart predictive orchestration and accurate embedding of security functions will help to reduce the OPEX and network resource and energy consumption while ensuring a reliable and adequate quality of service (QoS). We have relied on an overview of the use of AI/ML in network management from [5] and [6].

Learning AI-based techniques could help predicting regular events at the extreme edge associated to the subscribers' activity; for instance, when a car parking is full/empty or the moments when people are massively turning on the smart TVs at home, among many others. That information could be also correlated with the edge and the core network data in order to make predictions that could be used to orchestrate associated network services, and also, the available computing and networking resources on those end devices.

Automation is both an objective and a key enabler for intelligent orchestration and management in 6G infrastructures to face the increase in complexity and bring more dynamicity and adaptation to changing network situations pervasiveness of the infrastructures and services. While some of the current standards already consider the usage of artificial intelligence with regard to the orchestration of virtual functions (e.g., ETSI ENI [7]), we envisage that the usage of AI techniques in 6G would be even more challenging, considering the interactions with the multiplicity of the end devices at the extreme edge. ML techniques such as Reinforcement Learning (RL) have been explored for this purpose [8]. Modeling the behavior of edge devices using federated learning and cooperation approaches like multi-domain discovery or state declaration are also among the considered approaches. It is to be noted that the distribution of infrastructures imposes the distribution of network management and per-domain decision functions. For instance, ETSI ZSM [9] provides an architecture for End-to-End orchestration across separated technical domains as well as enablers like Closed-Loop Automation (CLA) and proactive incident analysis. CLA is a potential enabler for advanced domain automation in 6G [10]. As we can see on Fig. 1, there are multiple approaches for the integration of AI techniques to the management and orchestration. One possible approach is the integration of adapted AI solutions within each domain (i.e., within the core, edge and extreme edge domains), applied even in a very granular way at the level of individual devices (e.g., by means of Federated Learning [11] agents). Another way would be to apply AI techniques more globally through the continuum orchestration function integrating data from the different domains to, for instance, mixing application and infrastructure-based cognition to trigger self-adaptation and self-optimization decisions that could be based on predictive mechanisms or explicit and intent-based requests. These triggers would be used

globally to perform continuous autonomous actions to smoothly anticipate future status and potential problems of the network. This could include the (re)placement optimization of virtualized network functions, a change in slice instantiation request, scalability decisions, function migration among domains (core, edge and extreme edge), anticipation of network re-configurations, etc.

III. Summary and Outlook

This article outlines some challenges in extending the use of AI/ML from current 5G implementations to 6G for management and orchestration. Due to increased complexity and heterogeneity imposed by 6G, network service management mechanisms will be challenged to address horizontal federation or aggregation of elements across multiple domains, which we called here continuum. Also, the rising sets of use cases envisioned for the 6G era (6G IoT for smart cities, cooperative mobile robots or immersive sport event, etc.) will produce a heterogeneity of devices in the extreme edge side which translate into some goals and challenges to be addressed by the network. Some of the most relevant challenges that we envisage are:

- The management of the end-devices at the extreme edge itself. Their location in an uncontrolled environment and their largely random behavior poses new challenges in terms of their integration into regular management and orchestration loops.
- Automation and network programmability. To optimize requirements for best efficient use of resources providing network dynamicity, reliability, resilience and optimal usage of resources.
- Monitoring. An advanced monitoring mechanism should be available to support the AI/ML algorithms, combining infrastructure metrics and applications data to better support the decision making on management and orchestration. As billions of end devices are going to be connected is needed to enhance the prediction demand and resource utilisation of them by enabling a predictive and proactive network slicing.
- Security. Because the integration of the extreme edge devices and the potential aggregation of different stakeholders (e.g., private networks and hyperscalers), the orchestration functionality should provide liability to mitigate security risks.

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