Service-oriented Architecture Evolution towards 6G Networks

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***Abstract*—Service-based architecture (SBA) has been introduced in the 5G core network design. It brings cloud-native features into core networks and shows implementation, deployment and service provision advantages. As cloud technologies have been penetrating radio access networks (RAN), it is beneficial to introduce service-oriented design into the last mile of mobile networks, offering a cloud-friendly end-to-end service-oriented architecture. Under such architecture, network functions are implemented as a service provider and service consumer that can be flexibly disaggregated and combined to offer different network implementations. This paper introduces 6G conceptual architecture based on service-oriented design principles. The architecture extends the service-oriented design into RAN. It allows network functions of RAN, core, and functions from applications to be integrated in a new way through service-based interfaces. The key elements of the architecture design are introduced. The paper identifies the important design aspects of 6G architecture and proposes a promising direction for the 6G architecture evolution.**

I. Introduction

5G networks show the potential to support the digital transformation of multiple industries. Still, the current design, especially for radio access networks (RAN), largely follows the basic design principles of previous generations, which impose limitations on innovations demanded by the industry. Even in the near term, the mobile industry must support diverse services with flexible and sustainable solutions.

6G networks are mainly driven by new requirements and technological progress. New requirements consider concerns from both the end-user side and the operator side. Users expect that 6G networks will support many emerging applications that demand high performance, low latency, high reliability, and high security. The network operators expect more automated network operations and zero-touch management, efficient usage of resources, including energy efficient operations, extending network coverage, capitalising on the existing infrastructure, and quickly deploying new services to increase revenues.

The technological progress significantly shapes future networks. According to the market forecast, the industry has a strong demand for cloud-native solutions, automated operation of networks, support for local edge and core, and enabling as-a-service. The cloudification of radio networks, the use of native artificial intelligence (AI) and machine learning (ML) in mobile networks, and the integration of RAN and core network functions through service-oriented architecture (SOA) solutions will be key technical enablers to meet these needs. Systematic thinking is needed to integrate these techniques and provide design principles for 6G architecture evolution.

The diversity of requirements and the trend to move mobile networks to cloud-native infrastructure calls for the architecture evolution in 6G. This paper introduces a new conceptual design of 6G SOA to address the needs. The paper will first give a highlight of 6G studies in different regions, with a focus on system design aspects. It is followed by a summary of standard activities on SOA. The concept of 6G SOA is detailed, including key elements in the architecture design and the main research challenges therein.

II. Worldwide 6G studies regarding system design and key enablers

The mentioned technologies are often linked with 6G in numerous industrial and research activities in different world regions. The first 6G activity has been triggered in Finland. The Finnish 6G Flagship project has already produced findings described in several white papers. Regarding the system design, several recommendations are proposed in the 6G Flagship White Paper on Networking [1]: system design should minimise dependencies between functions, and there is also a need for a service-oriented definition; functions should be defined and partitioned according to the services they provide, rather than how they deliver the services; the control functions and enforcement functions should be separated to allow independent implementation, deployment, and customisation; there should be support for on-demand implementation and deployment of functions to enable the flexibility to achieve the balance of flexibility and efficiency.

At the European level, multiple research projects are working on 6G architectural challenges and research problems. Among them, the Hexa-X project [2] and its successor, Hexa-X-II [3], are flagship 6G projects in Europe. The Hexa-X concept of network-of-networks (NoN) includes connectivity, cloud/edge, RANs, the operators' edges and cores, the Internet, the IoT, and cloud/edge data centres, which are networks and the intra-body networks. The new network concept strongly relies on network function virtualisation (NFV) as the key technology for the NoNs combined with AI-driven orchestration and management. It supports multi-connectivity, Terrestrial Network (TN), and Non-Terrestrial Network (NTN) integration, direct communication between mobile terminals (D2D) and wireless mesh, which has substantial implications on system architecture design [4].

In the US, the Alliance for Telecommunications Industry Solutions (ATIS) has created the Next G Alliance, which has made the '6G Applications and Use Cases' report [5]. Similarly to other initiatives, ATIS assumes AI-driven operations and distributed collaborative computing to efficiently allocate resources and services using cooperative technologies such as side-link, wireless mesh, and multi-connectivity of different wireless networks.

In China, the IMT-2030 Promotion Group has released a 6G White Paper entitled '6G Vision and Candidate Technologies [6]. Among many topics, it suggests creating User-centric networks (UCN), a decentralised architecture that allows users to define and control 'their' network functions. The UCN should reduce system complexity by reducing message exchange between network functions. Due to the networks' complexity and dynamic nature, it recommends using AI for all system operations. The distributed cloud infrastructure, network programming capability and mobility management are assumed.

It is worth mentioning a recent Next Generation Mobile Networks (NGMN) study concerning 6G, namely "6G Requirements and Design Considerations" [7]. This study lists multiple use cases grouped into enhanced human communication, enhanced machine communication, enabling services (3D localisation, object sensing, digital twins, etc.) and network evolution. The white paper emphasises automated network programmability, native AI and monitoring and provisioning of the end-to-end (E2E) (including application) performance. It proposes (if needed) an overlap between core network functions and edge locations and between access and core networks. Regarding system design, it offers multi-access convergence, cross-domain and cross-layer scheduling and management, communication, sensing and computing as a converged network, security based on zero trust, simplicity and disaggregation and softwarisation of core and RAN.

III. Standard activities on service-oriented architecture design

SBA has evolved in prior art from monolithic to service-oriented architecture (SOA) towards micro-services and serverless [8]:

- Monolithic SOA: A SOA is a software architecture style that refers to an application composed of discrete and loosely coupled software agents that perform a required function. SOA has two leading roles: a service provider and a service consumer. A software agent can play both roles. The concept of SOA lies in the following: an application can be designed and built so that its modules are integrated seamlessly and easily reused.
- Micro-service-based SOA: Micro-service is a service-oriented software architecture focusing on building a series of autonomous components that make up an app. Unlike monolithic apps built as a single indivisible unit, micro-service apps consist of multiple independent pieces glued together with APIs. The most significant advantage of micro-services over other architectures is that small single services can be built, tested, and deployed independently. On the contrary, the disadvantage of micro-services-based architecture is that each functionality communicating externally via an API increases the chance of attacks. These attacks can happen if proper security measures aren't implemented when building an app. Also, using different languages makes deployment more difficult.
- Serverless SOA: Serverless architecture is a cloud computing approach to building and running apps and services without the need for infrastructure management. In serverless apps, code execution is managed by a server, allowing developers to deploy code without worrying about server maintenance and provision. In fact, serverless doesn't mean "no server." The application still runs on servers, but a third-party cloud service like Amazon Web Service (AWS) takes full responsibility for these servers. A serverless architecture eliminates the need for extra resources, application scaling, server maintenance, and database and storage systems.

3rd Generation Partnership Project (3GPP), a unified standardisation body for mobile communications, has incorporated the SBA representation, starting from 5G system architecture. However, there are different types of SBA based on the 3GPP domain.

- 5G Core Network: 3GPP SA2, which covers the 3GPP system architecture, uses conventional SBA (as specified in [9]), where the NF is the service producer and a Service Based Interface (SBI) bus is used for the interaction with service consumers (which can be Network Functions or Application Functions). In 3GPP SA2, service is related to NF capabilities/services. Such services are discovered using NRF at a functional level.
- 5G Management System: 3GPP SA5, which covers the OAM aspects of the network, uses service-based management architecture closer to the micro-service paradigm. In OAM, Service Based Management Architecture (SBMA) is defined and comprises Management Services (MnS). A MnS is a set of offered capabilities for managing and orchestrating networks and services. The entity producing an MnS is called an MnS producer. The entity consuming an MnS is called an MnS consumer. An MnS provided by an MnS producer can be consumed by any entity with appropriate authorisation and authentication. An MnS producer offers services via a standardised service interface composed of individually specified MnS com-

ponents.

- 5G Enablement Framework: 3GPP SA6 which covers the application enablement aspects of the 3GPP systems, initially used the 5GC paradigm for some application enablers (CAPIF as specified in [10], SEAL as specified in [11]), whereas, however in more recent enablers (like EDGEAPP as captured in [12]) the service-based representation comprises different variants (e.g. SA2-based for interaction with 5GC, and micro-service-based for exchange among application layer entities).

IV. 6G SOA CONCEPT

6G is expected to adopt flexible implementation, dynamic deployment and agile provisioning of connectivity services based on connectivity needs, availability of infrastructure resources, options of access technologies and system optimisation goals. It goes beyond current connectivity services offered by 5G, which are often limited to fixed deployment of network components and network functions and cannot support new network concepts, like the NoN and NTN, which are demanded by many industry use cases.

As illustrated in Fig.1, a 6G SOA is proposed to satisfy these new requirements. It is built on a unified cloud infrastructure across multiple cloud environments and leverages intelligent network control and management to manage network complexity in hybrid network environments. The new SOA design has several key elements, including network disaggregation, service-oriented RAN, RAN-Core-service integration, distributed and programmable control and management, and native AI support. The following describes key design principles and challenges in these elements.

A. Network disaggregation

5G introduces the function split to disaggregate the network elements and allow power-intensive processes, e.g., digital baseband processing at standalone BSs, to centralised servers. The flexible, functional splits have been studied by 3GPP [13] and next-generation mobile networks (NGMN) [14]. It allows RAN functions to split into different physical network units and paves the way for moving RAN network functions to the cloud. Currently, RAN disaggregation is supported and allows for distinguishing CP and UP RAN elements as well as high and lower-layer protocols (Central Unit (CU) and Distributed Units (DU)). However, due to the tight couple of network functions in the RAN protocol, there is no notion of RAN services that can be virtualised and interact with each other (and with the core network) in a service-based manner due to the high complexity and the radical changes which are needed in the existing 5G architecture. Further disaggregation of CP and UP and the service-oriented design of network functions are required. The service-based method has been adopted by 5G core networks. It is not straightforward to apply the same design principles to RAN. New network disaggregation principles beyond current 5G DU and CU solutions must be developed to realise a genuinely cloud-friendly solution.

B. Service-oriented RAN design

A typical implementation of disaggregated RAN is shown at the bottom of Fig.1. All network functions (NF) in the central unit (CU), which contains the packet data convergence Protocol (PDCP), service data adaption protocol (SDAP), and radio resource control (RRC) from the RAN protocol stack, as the management and control entities, can be virtualised to cloud-based NF. Most NFs in DU can be virtualised as well. However, the low-layer RF processes and physical layer network functions in the RU remain hard to virtualise fully but rely on the hardware accelerators or purpose-built hardware to provide the needed performance. As we can see, even in 5G, it is possible to implement most RAN functions under the cloud platform. However, it is just another 5G RAN protocol software implementation. The service-oriented design, built upon cloud-native technologies, can bring genuine benefits of cloud-native design to the RAN architecture.

The service-oriented RAN design is depicted as an intelligent cloudified layer in Fig.1. There are three types of RAN NFs: CP NF, UP NF, and CP-UP NF. The reason for CP-UP NF is that, for some RAN functions, the CP and UP have to be tightly coupled for the performance concern and state-aware processes. These NFs can be instantiated and placed in proper places in the cloud based on resource availability, performance goals, and service requirements. They are connected through standardised interfaces by 3GPP to form a total RAN CP and UP protocol stack in a hybrid cloud environment. Some CP-UP interfaces have been designed, for instance, the E1 interface, to support the control and user plane separation (CUPS) in CU. New interfaces need to be introduced to help further CUPS separation.

These CP and UP network functions are extended with service-based interfaces. In Fig.1, a service bus is introduced as a logic connection hub to support interactions of NFs from these service-based interfaces. The service-based interface serves multiple purposes to extend NF's capability and capacity: 1) it allows a network function to expose its network state configurations; 2) it accepts the control and configuration from control apps implemented under the same service-oriented design principle; these control apps, as shown in Fig.1, can be considered as new network functions that offer control services 3) it can interact with other RAN network functions to provide flexible RAN function implementations.

The service-oriented design turns NFs into service producers and consumers. A control framework will be proposed to manage service discovery and interactions among NFs. One prominent feature of this design is introducing Control Apps, UP Apps and CP Apps as the new services offered to NFs. An NF can connect to the UP or CP app for extended capabilities or capacity through the service-based interface. The control apps provide new control logic to NFs, similar to the control apps from RAN intelligent controller (RIC), but more flexible.

The service-based interface enables RAN network state information to be quickly and directly accessible by the control and resource management framework to reconfigure the cloud-

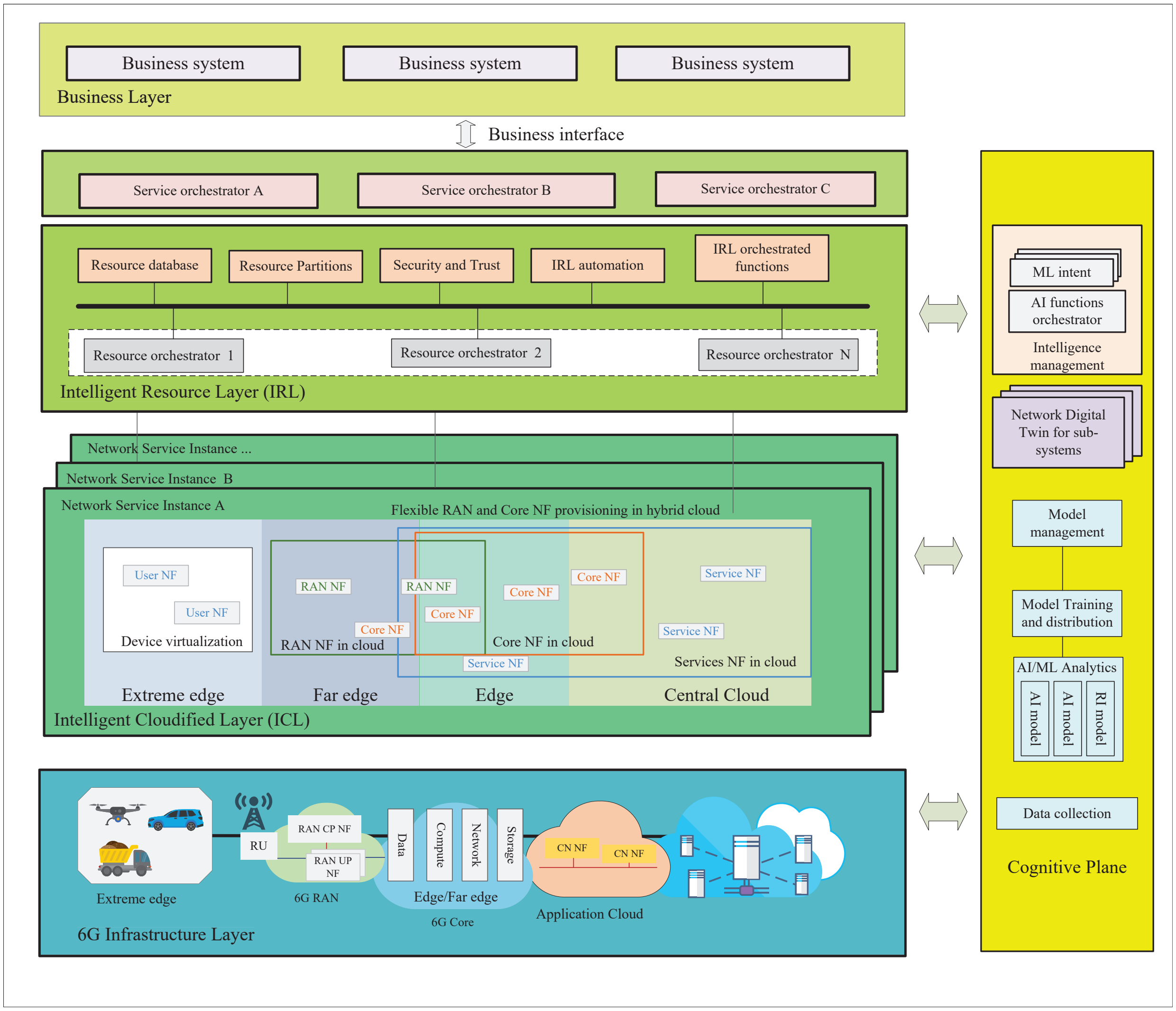

Fig. 1. A conceptual design of service-oriented system architecture for 6G networks

based CU and DU. Better management, orchestration, and execution of computing applications can be obtained through service optimisation by RAN control apps developed to provide versatile, compatible, and flexible integration with edge and RAN network function lifecycle management.

Being cloud-native by design, service-oriented RAN will ease the integration with an E2E orchestration system, including the transport and core domains. It allows the connection of RAN orchestration to the 6G E2E orchestration platform through the northbound interface (NBI) and APIs.

Hardware accelerators are needed to process computationally intensive and time-sensitive tasks. To achieve this, significant functionalities of the system (application, control/data plane, and signal processing) need to be executed on general-purpose processors (i.e., x86, etc.), offloading a subset of computationally intensive tasks to specialised processing hardware (i.e. intelligent network interface cards (NIC)). Consolidating these workloads onto a scalable and simplified platform makes implementing multi-function and multivendor solutions, such as service chaining, easier.

However, hosting several virtualised functions in a single machine requires deploying a virtual machine monitor (or hypervisor) to create an additional abstraction layer between the physical hardware platform and operator network applications. However, it adds virtualisation overheads in cache, I/O, and memory, making sharing data between applications more difficult. Solutions with hardware accelerators to deal with virtualisation overheads are needed to resolve these challenges. The increased I/O requirements of the DU/CU functions will be addressed through offloading of computationally intensive tasks from the DU and CU functions to specialised hardware, relaxing central processing unit (CPU) processing and improving resource and energy efficiencies. The orchestrator at the intelligent resource layer (IRL), as shown in Fig.1, will be able to mix and match virtualised functions to the appropriate acceleration engine and scale the accelerator power to the required demand.

C. RAN-Core-Service integration

The 5G core functions are designed based on the SBA. It allows core functions to be more decentralised to deal with the increasing traffic through the core. The cloud-native design of RAN will allow the virtualised RAN functions to be implemented with core functions in the same edge clouds for low-latency services. However, the coexistence of RAN-core functions brings limited benefits as the two domains are still logically separated. The flexible RAN-Core-service function composition under multi-stakeholder hybrid cloud environments has to be developed in 6G networks. A new way is needed to composite RAN-core functions for different services. For instance, in a network of network use case, a sub-network may need simple but standalone core functions in a local environment to deal with the network separation. The E2E service-oriented design introduced in this concept will provide a native solution to converge the RAN-core network and go one massive step beyond to flexible place the virtualised application functions used to reside on the UE side and service functions used to live on the server side under the same cloud continuum platform for extreme flexible network services.

One of the significant challenges in RAN core network integration in the 6G era is how to achieve a seamless and efficient convergence of CP functions between the RAN and core network, especially when both network functions are collocated in the same cloud infrastructure. In 5G networks, service-based interfaces are introduced to core network functions, transforming the core network to a micro-service-based architecture. This cloud-native design dramatically improves the agility to implement, provision and evolve core network functions. However, the interfaces between UE and core, and the RAN and core, are still point-to-point interfaces. Adapting SOA between RAN and Core with the current non-access-stratum (NAS) design will limit cloud-native benefits from the integration as the RAN would still be constrained to communicating with a single NF type in the Core. To fully leverage the help of the service-oriented design between the RAN and the core and to enable the RAN to communicate with multiple NF types over a service-based interface, new architecture design, especially on a new non-access-stratum architecture, is required to allow more coordination and synchronisation with the core network functions, such as mobility management, session management, QoS management, and network slicing.

As shown in Fig.2, a new approach could integrate UE-RAN-Core under hybrid cloud environments. Fig.2 shows the different cloud locations where NFs are instantiated, which include far edge, edge and central cloud. It indicates that NFs from services' RAN, core, and application functions (AF) can be deployed flexibly in the hybrid cloud environment. Based on the locations and main functions of the nodes, different physical nodes are named RU, DU, CU, and cloud servers for the core network and service farm. These terms are well-defined in 5G networks, but in 6G networks, their boundaries become blurred since NFs and AFs can be flexibly deployed.

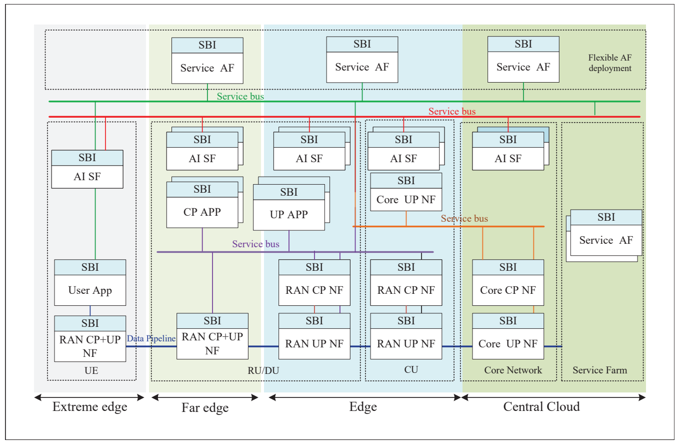

Fig. 2. The concept of UE-RAN-Core-Service integration under the service-oriented design

The core network includes the NFs to monitor the performance that can determine the location of edge processing based on the required delay or performance. The core network's user plane function (UPF) can be distributed across the access or backhaul to provide multiple endpoints for edge processing.

In 6G, a new architecture framework will converge the CP functionality of RAN and core network within a single set of network functions. This framework aims to simplify the network design and operation, reduce the signalling overhead and latency, increase the deployment-specific customisation flexibility and open interfaces, and meet the 6G requirements. It will leverage the SBA core network design, which has already used service-oriented design in Core NFs. As shown in Fig.2, the core network functions are interconnected with a service bus that facilitates representational state transfer (REST) based access to their capabilities. The service bus enables network function access via request/response or subscribe/notify patterns and allows decoupling of the network functions. Thus, the network functions can be independently provisioned and scaled, contributing to the architecture's flexibility. The service-oriented RAN design, as described above, opens the way to implement RAN NFs flexibly in the cloud. The necessary core NF can be instantiated easily at the edge and close to RAN functions for ultra-low latency use cases. On the other hand, the RAN NFs can also move to the central cloud and co-located with core NF for resource efficiency.

The NAS architecture in 5G needs to be extended to offer the interaction between RAN NFs and Core NFs. The inter-bus gateway supports this. The gateway is a logic unit and can be implemented in a distributed manner. Through the gateway, RAN NFs and Core NFs know how to be configured, interacted with, and placed in the network. A RAN NF can have connections with multiple core NFs. The local core-network breakout for private networks can be easily implemented.

From this design, the network can provide the solutions to flexibly integrate UE-RAN-CORE and enable a distributed communication and computation system. It allows tighter co-ordination between applications and the communication stack to improve end-user experiences. For instance, cross-domain (UE-RAN-Core-Service) optimisations on the network and device side can be used to assist an application in adapting its QoS requirements to radio conditions and to improve the end-user experience. It must find the right coupling level between communication and computing for optimised scalability, complexity, and performance. The heterogeneity of the computing environment and infrastructure also challenges the system design. The network must accommodate various computing services to enable a large-scale, distributed cloud in a heterogeneous and ubiquitous computing environment, where device computing is also incorporated.

D. Distributed and Programmable Control and Management

Due to the NoNs' dynamicity and the need for management scalability, control and management in the 6G network should be programmable and implemented in a distributed way with loosely coupled interactions between managed domains. It should be composed of self-managed domains and self-managed modules/functions. It also needs interfaces to business systems to map the business requirements into the network configurations. As shown in Fig.1, an IRL is proposed to support control programmability at different layers and planes of the network. The IRL will support distributed control and management in nature for the scalability concern.

Going beyond the RIC concept, the cloud-based control apps are introduced to integrate with different network functions in fine granularity through the newly developed service-based interfaces. The interfaces allow network functions to expose their states, capability and capacity to control apps and receive configuration or replace part of its functionality from the control apps. The control apps are distributed, highly programmable, and easily implemented and placed. This new level of control programmability allows the network functions and resources to be configured and manipulated through APIs and protocols in excellent grain, which support the customisation and optimisation of network behaviour and performance according to the specific needs and preferences of different applications and users.

In IRL, a distributed resource orchestration framework with proper mechanisms is used to partition resources for local orchestration. Programmability at the management level will be introduced to enable the automation and orchestration of network operations, which include intelligent network management, automated network configuration, self-organising networks, and automated network security. It will divide network management tasks among multiple entities, in controllers and orchestrators, that communicate and cooperate. The consistency and correctness of the network state and behaviour across different network domains and layers, especially in the presence of failures, conflicts and changes, must be considered.

E. Native AI support in 6G architecture

The heterogeneity of 5G networks caused by CUPS and network disaggregation has been significantly increased, leading to the challenge of managing the network. That heterogeneity ranges from multi-vendor components, multi-infrastructure hardware, and a mixture of software-defined and purpose-built radio hardware, multi-cloud environments and multi-domains. In 6G, due to the further network disaggregation and the adoption of hybrid clouds, the complexity will further increase. Providing the required service-level agreement (SLA) while at the same time, minimising the network cost and energy consumption in such a heterogeneous environment cannot be done without an intelligent solution, for instance, being able to mix-and-match different multi-vendor network functions to optimise the performance-cost-energy trade-offs. Moreover, achieving zero-touch with network self-healing and self-configuration becomes a dilemma in a multi-vendor environment. Therefore, providing a unified, intelligent solution that (a) automates the heterogeneous mobile network deployment, (b) manages the lifecycle of different network entities, (c) optimises the energy consumption, and (d) minimises the network cost and respects the required SLA is indispensable.

AI/ML is suited to the inherent complexities involved in conventional network problems for which accurate models are complicated to obtain. However, the need for standardisation and interoperability still limits the current state-of-the-art AI/ML applications in mobile networks. So far, the applications of AI/ML to radio network problems have only been implementation-based approaches constrained by existing 3GPP specifications, which need to provide explicit support for enabling such solutions. In 3GPP RAN Rel-17, there was an SI on "Enhancement for Data Collection for New Radio (NR) and Evolved-Universal Terrestrial Radio Access New Radio Dual Connectivity (ENDC)", which examined the functional framework for RAN intelligence enabled by further enhancement of data collection through several use cases. From 3GPP Service and System Aspects (SA), there has been work on the network data analytics function (NWDAF) in Rel-15 with enhancements in Rel-16 and Rel-17. These items have been primarily related to systems and higher layers of the RAN. To fully exploit the potential of AI/ML for mobile networks, there is a need for more comprehensive and systematic studies on how to integrate AI/ML into the 6G system for a native AI design.

As shown in Fig.1, an AI/ML framework is proposed to support the needs of AI in NFs, management and orchestration, and inter-NS operations. To avoid an over-complex solution, the framework of framework concept is introduced to build the AI/ML framework for individual domains with similar design principles and toolboxes while providing necessary connections among different AI/ML frameworks for joint processes. For instance, RAN and service orchestration will use separate AI/ML frameworks to support AI/ML functions. The AI functions will be dynamically orchestrated, combining the zero-touch and the CI/CD approaches.

V. Conclusion

From 5G limitations to the 6G visions of different regions, we identified the global priorities of 6G research. The need for integrating infrastructure from other infrastructure providers, providing incentives for the end-users to share their virtualised extreme edge resources, and coping with the dynamicity of the infrastructure resources will be strong in the 6G era. Our proposal is aligned with the 6G vision to provide a unique service-oriented system architecture solution from the cloudification perspective. The proposed SOA integrates multiple stakeholders' cloud resources and allows network functions from different 6G network segments to be composed flexibly and dynamically based on service needs in hybrid cloud environments using orchestration. It could release the power of cloud infrastructure for brand-new 6G solutions. More research on the proposed architecture will be followed by the authors' dedicated 6G research projects.

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