SBA-Native: Argumentation Towards a Unified End-to-End Service-Based Architecture for 6G Access and Core Networks

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***Abstract*—This article presents system design arguments to re-think the current mobile telecommunication network architecture. Undeniably, 5G has seen tremendous efforts in Access and Core Network domains to design a flexible and modern system, which aims to allow to vendor-multiplexing within the deployment of a single network and to scale (ideally) on demand. However, the vision to utilise cloud-native orchestration and operation procedures combined with microservice-based software architecture realisations did not materialise in the telco domain as of yet. This article focuses on the current system architecture, combined with proposed 6G technical Key Value Indicators, to demonstrate how 5G hinders the full end-to-end utilisation of Service-Based Architecture, ultimately allowing more end devices to utilise this standard to access services of any sort and any Quality of Service characteristic.**

***Index Terms*—Service-Based Architecture, Cloud-Native, 6G, 3GPP, System Architecture, Radio Access Network, Core Network**

I. Introduction

5G has set a tremendous pathway towards a more flexible, scalable, softwarised and inclusive mobile telecommunication system. From a systems perspective, the disintegration of RAN and CN into – functionality-wise – smaller and well-defined architectural components with standardised interfaces allowed a higher degree of flexibility in vendor-multiplexing deployments and introducing economy-at-scale cloud solutions into the telco domain. 3GPP's Release 15 can be confidently declared as the cornerstone for the architectural change with the definition of a Service-Based Architecture (SBA) and some important refinements and additions in Release 16 (e.g. the addition of the Service Communication Proxy (SCP)). In the Radio Access Network (RAN) domain, the same Release 15 saw the introduction of New Radio (NR)-RAN over the Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) which marked a similar crucial milestone in disintegrating the Next Generation NodeB (gNB) into Central Unit (CU) and Distributed Unit (DU). Also, in both parts of 5G (i.e. RAN and Core Network (CN)), the clear separation of Control and User Planes are at the forefront of the architectural design enabling programmability and multi-vendor deployments. 5G also set a new standard around inclusiveness of non-telco players, commonly referred to as the verticals, allowing operators to enter new markets with the 5G technology that cannot be served by a public network due to the vertical's both technical and non-technical requirements.

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This article taps into the success of 5G, and SBA in particular, by taking a stance at designing and specifying a 6G system which is much more agile and smart in its deployment options including the end user devices (aka User Equipments (UEs)). It has been acknowledged that telecommunication systems will become more complex [2] and that more advanced logic is required to manage the various resources (compute, networking, storage) in an inter-domain fashion, focusing on data plane performance improvements, energy efficiency optimisations across various parts of the 6G system, and a higher degree in robust automations. Furthermore, it is expected that 6G is expected to not only focus on performance-oriented argumentation, but to also include value-oriented future-looking debates on the requirements and validation indicators [3].

The proposed concepts in this article aim at describing innovative concepts of a 6G system architecture, which unify and disintegrate the entire 6G Control Plane communication, fully disintegrate the 6G Core Network, start fusing upper layer Application Programming Interfaces (APIs) for Radio Access and Core Networks, and natively integrating Service Routing, Telemetry, Orchestration and Artificial Intelligence as an SBA-Native Platform-as-a-Service (PaaS) offering to Enterprise Services. The article describes SBA-Native as the underlying enabling set of functionalities and sees SBA-Native intrinsic to 6G without permitting any deviation. Built upon Cloud-Native principles and the adoption of microservice-based software design patterns for services, SBA-Native provides modern and future-proof architectural definitions and specifications, which are fine-tuned towards the requirements of telco operators and verticals, enabling a never seen flexibility and scalability of a mobile communication system. While 5G has brought many advances to enable QoS-constraint (high throughput, low latency) applications, SBA-Native will allow a significant increase of consumer devices to utilise the 6th generation of 3GPP's mobile telecommunication system in order to natively consume a wider range of services. The resulting 6G ecosystem is composed of the capability to tailor the required functionalities.

The remainder of the article is structured as follows: Section II describes the system architecture of Access and Core Networks as the baseline for the propositions in this article. Section III then provides a list of technical Key Value Indicator

(KVI) for 6G beyond the current list of Key Performance Indicators (KPIs) and non-technical KVIs. This is followed by Section IV which lists a range of high-level SBA-Native concepts. The paper is concluded with Section V.

II. Current 5G System Architecture

The baseline architecture for SBA-Native is 3GPP's technical specifications 38.401 for Next Generation (NG)-RANs [4] and 23.501 for CNs [5]. Fig. 1 depicts a joint drawing of both 5G system architectures and categorises their components into the domains *Radio Access Network*, *Core Network* and *Data Network*, following 3GPP terminology. Furthermore, the RAN domain also illustrates the O-RAN components non-realtime and near-realtime RAN Intelligent Controller (RIC). Fig. 1 is complemented with the ability to utilise non-3GPP Access Networks (ANs), e.g. Wi-Fi or any Ethernet-based Local Area Network (LAN).

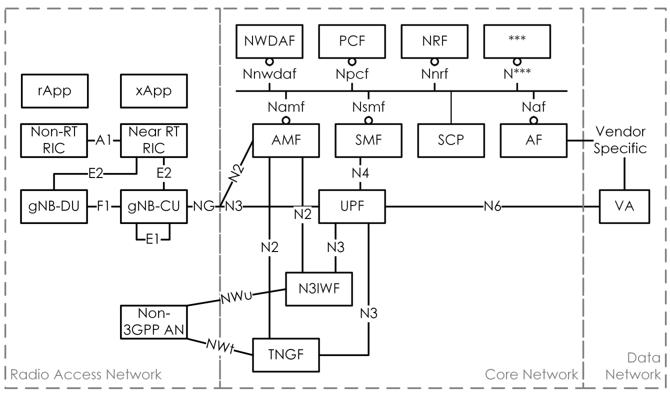

Fig. 1. Combined Radio Access Network and Core Network System Architecture.

What becomes apparent in the joint architecture figure is the clear separation of RAN and CN. This split is historically motivated and is deeply rooted in the structure of 3GPP as a standardisation body. As a consequence, it can be seen that SBA principles, manifest in Service-based Interfaces (SBIs), can only observed in the CN with the interfaces carrying 5G Core Network Function (NF) names, such as Namf or Nsmf. Any interface denoted by N followed by an integer number are "legacy" interfaces between two specific architectural components (across all three domains in Fig. 1). Furthermore, the CN has already received a component for inter-NF communication, the SCP. While the RAN misses such architectural component entirely, the clear boundaries in interfaces and components between RAN and CN does not even allow an extension of capabilities from one domain to the other. Another important aspect in relation the clear split between RAN and CN is the potential duplication of functionality. For instance, there is an increasing demand for telemetry (data collection and analytics) for AI/ML-driven functions in all areas of the system. As the CN already has the Network Data Analytics Function (NWDAF) for this propose and the x/rApps in the RAN often utilising proprietary solutions, a joint architectural solution would be of great benefit.

III. Identified 6G Requirements, Key Value Indicators and Examples

This section presents the 6G requirements identified by the authors, which will see a positive impact by SBA-Native concepts described in Section IV. Table I lists the requirements over a selection of KVIs as a two-dimensional binary matrix. The content of the table is described in further detail in dedicated sections hereafter. It should be noted that the attempt to define 6G requirements and link them to KVIs follows the common understanding of the global telecommunication research community to not only focus on performance-oriented argumentation, but to also include value-oriented and future looking debates on the requirements for 6G [3]. However, the authors of this paper go beyond the proposed KVIs "sustainability, inclusiveness and trustworthiness" in [3]. A more fine-grained set of KVIs is proposed and adjectives are chosen instead of nouns. In order to comprehend the matrix table, a first definition of each KVI is provided.

- **green** To contribute to the "it's now, or never" climate call for action by the United Nations (UN) [6], it is at the heart of 6G to introduce requirements to target environmental friendly operations of the telco domain.
- **smart** It has been acknowledged that future systems (computer networks), in particular access networks, that form part of the internet are going to become more complex [2]. To cope with this increase of complexity, it is understood that systems must be come more intelligent using more advanced AI/ML-driven algorithms.
- **reconfigurable** With the adoption of Software-defined Networks (SDN) and Network Function Virtualisation (NFV) concepts in 4G and 5G, it has become a good practice to offer the ability to reconfigure resources after they have been instantiated.
- **programmable** The adoption of SBA in 5G demonstrates the importance of programmable interfaces. Thus, any 6G requirement should be carefully assessed against its need for programmable method and procedures through modern APIs.
- **inclusive** The trend in 5G to bring vertical stakeholder into the conversation has demonstrated the necessity to allow externals gaining access to 5G. In 6G, all requirements should be carefully checked against the general value in making a technological concepts accessible to external components in the wider 6G ecosystem and verticals in particular.
- **reliable** The Service-Level Agreements (SLAs) required in mobile telecommunication network have many more 9s compared to cloud solutions. This created trust and adoption to use 3/4/5G as the daily communication technology for the vast majority of many. Thus, any 6G requirement shall be assessed what its value is when it comes to reliability.
- **efficient** With the ever growing traffic per user per month and user (active device) numbers, it becomes inevitably important to discuss any 6G requirement in relation to its

key value towards efficiency.

The following sub-sections provide the list of identified 6G requirements relevant to SBA-Native. Each sub-section provides an explanation of the requirement, a short discussion on the key value for 6G and an example.

A. Service Routing-Enabled Communications

The internet and its protocol suite has changed the way societies communicate by ignoring country borders and distance. However, it has been understood that the best effort design of the internet, as a concatenation of computer networks, has served its general purpose for exchanging non-Quality of Service (QoS) sensitive information, but has reached its possibilities. To enable QoS-sensitive services and to cope with the amount of traffic generated by these modern services, the general client-server paradigm, design to perfection by cloud solutions, has seen adoption in the access computer networks by introducing cloud concepts at the edge, allowing to bring the service closer to where it is requested. As a result, the services are instantiated and scaled based on demand at the edge, which requires a much higher flexibility in routing traffic between endpoints. In particular in extreme scenarios, where the instances of service endpoints are changing in real time based on demand, the IP protocol suite and design principles do not offer the capabilities for fast and dynamic service routing. Thus, 6G shall provide alternative solutions in access networks that can coexist alongside a standard IP protocol stack.

The key value in doing so shall result in the ability to offer greener networking capabilities when needed. This can be achieved through smart decision making algorithms that not only take into account network load to meet required QoS and Quality of Experience (QoE), but also the cost of routing a packet to a specific instance. Once the routing decisions can be programmatically configured to which constraints it shall take into account.

B. Native Support for Heterogeneous Access Networks

With the wide range of devices attached to different public and private networks, future mobile networks should have the ability to accommodate all types of heterogeneous (3GPP and non-3GPP) ANs and allow UEs to utilise them sequentially or simultaneously. As currently all ANs have different requirements and attachment procedures to attach to a mobile telecommunication system, flexible, efficient and reliable communication procedures, interfaces, and protocols are required that are manifest in a standardised system architecture.

As an example, during attachment procedures of UEs to trusted non-3GPP networks, the UE communicates with the CN via a dedicated Trusted Non-3GPP Access Network (TNAN) with its own internal procedures. In the case of untrusted non-3GPP networks, such as public WIFI network, the CN is only accessible through the non-3GPP Interworking Function (NI3WF). Each network type uses different interfaces and procedures to access the CN. Future mobile networks should unify procedures in an SBA fashion to enable the flexibility, reliability and programmability across 3GPP and non-3GPP ANs.

C. Native Support for Artificial Intelligence

Artificial Intelligence can be used to improve performance and adaptability in wireless networks. Realising its value, standardisation work is ongoing to define a framework to leverage upon data and Artificial Intelligence (AI) techniques in the context of important use cases, to improve related KPIs [7]–[10]. This is however, an over-the-top approach in deployment to the current 5G system. It relies on data aggregation for model training either to databases that the CN has access to (the NWDAF [11]), or to specific network nodes and for a particular target optimisation. Data can be collected from UE, AN and CN functions. Several problems can be identified with this approach. The data aggregation process has an high energetic cost due to transmissions over the air interface, if the UE is the data endpoint, and can create traffic bottlenecks in the backhaul network due to the high volumes of data that are typically required to train Machine Learning (ML) models. Furthermore, the target optimisation always relates to a particular user, environment, use case or function. This may lead to an improvement in performance, but always limited to a specific aspect or KPI, without a broader end-to-end (E2E) view of the entire system.

E2E data services and AI support is a requirement in the proposed SBA-native architecture and the design provides high availability of both to the entire system. This approach achieves higher E2E cognition levels, i.e. the system's state and context. By increasing cognition, much broader optimisations can be targeted, as e.g. by taking into account multiple elements in the infrastructure. As an example, the User Plane Function (UPF)'s packet routing and forwarding functionalities require awareness of both the UE's mobility, traffic requirements, and AN radio resource management and planning information for improved performance.

The SBA-Native architecture also facilitates the deployment of intelligence, by being capable of seamlessly integrating federated and distributed learning approaches, easing computation requirements, eliminating the need of data aggregation and reducing the intelligence distribution overhead. Metadata is centralised at the telemetry component, providing E2E cognition without the burden of data transfer. Elements of the infrastructure and enterprise can quickly update models making real-time and near real-time optimisations feasible in a seamless way.

D. Energy Efficiency

As energy consumption and carbon footprint are among key issues in future mobile networks [12]. However, it becomes apparent that with a continuous increase in traffic globally, networks will inevitably require more energy in total to handle the data storm. Thus, the objective for system architecture efforts to target greener networking shall lie in the efficient usage of available energy, allowing more UEs perceiving higher QoS benchmarks while not consuming more energy

TABLE I
6G REQUIREMENTS AND THEIR KEY VALUE INDICATORS

Requirement	Key Value Indicator						
	green	smart	reconfigurable	programmable	inclusive	reliable	efficient
Service Routing-Enabled Communications	•	•		•	•	•	•
Heterogeneous Access Networks			•	•	•		
AI-as-a-Service	•		•	•		•	•
Energy Consumption	•	•	•				•
Ubiquitous Service Continuity		•	•	•	•	•	

across all system components. Such effort must also be tightly linked with aspects of service reliability on control and user plane.

For instance, when comparing the 4G Evolved Packet Core (EPC) with the 5G Core (5GC), there is a significant increase in the number of NFs that form the core, driven by the architectural design choice to adopt an SBA which disintegrates the 4G EPC NFs into more components, but with with lower functionality each. While this follows cloud principles and the realisation of a 5GC using a microservice-based software architecture, it significantly increased the signalling within the control plane in terms of messages. The additional energy needed for such flexibility should be offset with the efficiency it allows to achieve, e.g. by only deploying a subset of all possible NF based on the needs of the operator.

E. Ubiquitous Service Continuity

Service reliability needs to be a fundamental 6G characteristic. Many user services and applications demand QoS fulfilment, while others require user perceived QoE only. To achieve a reliable 6G network, ubiquitous coverage is a fundamental requirement across a range of different AN technologies. Assuming the infrastructure is able to provide it, QoS and QoE fulfilment continuity become computing and scheduling management problems, difficult to solve due to constant environment, user(s) and system changes. In case of sub-optimal coverage, cognitive radio functions can modify coverage via AN self-configuration adjustments. However, these are very difficult to achieve under the current 5G architecture.

Current QoE standardisation work include definition of use cases, requirements and measurement configuration, triggering, and reporting aspects [11], [13], with a focus on streaming, Virtual Reality (VR) and Multimedia Broadcast/Multicast Service (MBMS) services. QoE enhancements rely therefore on measurement evaluation for a specific application, and the evaluation method needs to be triggered from the network. As a direct consequence, increased signalling is needed to perform the evaluation and only a subset of selected users and applications are evaluated. Moreover, this is a reactive process. Resource adjustment actions are taken after measurement evaluation, which makes it difficult to guarantee the reactive action will seamlessly serve time sensitive applications.

As opposed to QoE, QoS has a well defined framework [5]. Both UE and UPF mark, respectively, Uplink (UL) and Downlink (DL) packets with a QoS Flow Identifier (QFI), following CN given QoS rules. The QFI marker is then used by the AN to define its scheduling policy and mapping to connection radio resources. While this framework provides some flexibility for application specific resource allocation, it still cannot totally make an efficient use of radio resources. The CN QoS rules provide the AN means to anticipate an estimate of resource usage but the real traffic requirements are user and application usage dependant, and are different for both UL and DL. However, in the event of traffic demand fluctuations, new QoS rules are required and this can only be achieved by configuration, increasing again signalling.

IV. SBA-NATIVE PROPOSITION

At the heart of SBA-Native lies the proposition of a unified offering to the so called Enterprise Services, specifically focusing on the telco domain and its needs. Fig. 2 illustrates this proposition where three dedicated layers are depicted: Infrastructure, SBA-Native Platform, Enterprise Services. Each layer is separated through programmable and open APIs, allowing the upper layer to control resources offered by the lower layer. All APIs are considered to support multi-tenancy scenarios and offer a service-centric control, e.g. Create, Read, Update, Delete (CRUD) or Representational State Transfer (REST).

As illustrated, the Enterprise Service layer bundles Vertical Services (IT software, vertical applications), 6G Cores, x/rApps and services on Consumer Devices (e.g. UE in the traditional telecommunication). The functionalities illustrated by the underlying platform are then enforced onto the Enterprise Service layer as a cloud-native proposition. The SBA-Native Platform layer is composed of the four components Service Routing, Orchestration, Telemetry and Artificial Intelligence. Note that these functionalities are offered in a programmable and unified fashion to Enterprise Services.

The *Routing* component of the SBA platform implements the SCP, which is only an optional component since Release 16. Furthermore, 3GPP merely specifies the SCP as a (web-) proxy in the likes of a Kubernetes cluster, which offers rather limited routing capabilities (only within the cluster). The Routing component in the SBA platform layer goes beyond such proposition and adds service routing capabilities for HTTP-based Enterprise Services in a transparent fashion. The underlying technology, Name-Based Routing (NBR) [14], mentioned in 3GPP's 23.501 [5] as one of the three deployment options uses Information-Centric Networking (ICN) principles instead of the standard DNS/IP-based communication procedures to offer service routing capabilities. Thus, it does not rely on DNS and can switch the packet exchange between consumer and producer within a matter of milliseconds without impacting the HTTP endpoints.

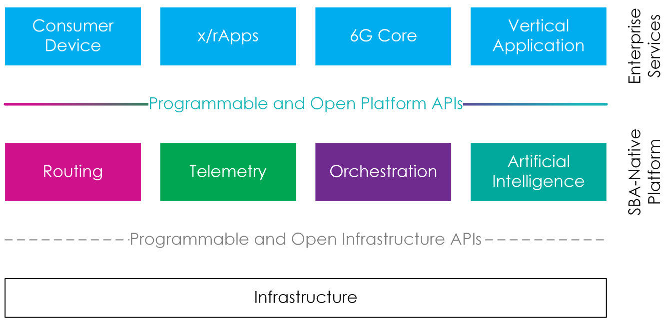

Fig. 2. Envisaged End-to-End System Architecture for 6G Access and Core Networks.

The *Orchestration* component implements a location-aware and telco-centric Service Chain provisioning and lifecycle control framework, called Service Function Virtualisation (SFV) [15]. SFV is agnostic to the virtualisation technology used on the compute host and even supports Android APKs or bare metal deployments. This is achieved by leaving it to developers and compute host owners to decide which (virtualisation) technology to expose to the SFV orchestration layer. SFV comes with a set of descriptors describing the Service Chain in its requirements (provisioning) and policies (lifecycle control). The underlying information model departs from what existing technologies can offer for Virtual NFs (VNFs) (Open Source MANO (OSM) with OpenStack, i.e Heat Orchestration Templates or TOSCA) or Cloud-Native Network Functions (CNFs) (Kubernetes/OpenShift, i.e. Helm charts or Ansible). Instead, it has been designed from scratch with location-awareness in mind and piggybacking on well-defined interfaces for various virtualisation technologies, e.g. KVM (virsh [16]), LXC (LXD) [17] or Docker (Docker Compose) [18].

The *Telemetry* component offers flexible data ingestion, cataloguing and searching of data from across all layers (infrastructure, platform and service) in a unified fashion supporting distributed structured, unstructured or time-series databases. This results in a single point of (logical) contact for any logic to retrieve data or analytics to improve the functionality of Enterprise Services. For instance, instead of the NWDAF as part of the 5GC (into which only 5GC NFs report data into), the Telemetry component has a wider scope in terms of data sources and offers the ability to aggregate and accept policies for threshold-based notifications (if desired).

The *Artificial Intelligence* component offers AI-as-a-Service to Enterprise Services for both algorithm training and inference purposes. This component offers easy access to on-premises GPU resources and allows this to be scaled out to off premise cloud services (e.g. Azure or AWS). The AI component will provide containers with preinstalled deep learning libraries and frameworks, which simplifies some of the common challenges seen around software versioning and backwards compatibility. It's possible that the models trained by different Enterprise Services use different deep learning frameworks and libraries.

The Infrastructure layer offers programmable and open APIs to utilise compute, storage and networking resources. More precisely, the SBA platform is a set of fully softwarised components which can be deployed as Virtual Machines or Containers using OpenStack or OpenShift, respectively. While the telemetry and orchestration components have no further API requirements towards the infrastructure, the Routing component demands an SDN-enabled switching fabric (if any network topology is present in the infrastructure). The Routing component supports OpenFlow 1.3 and above compliant SDN switches as well as the SDN controllers Floodlight, OpenDaylight and ONOS (if provided by the infrastructure).

V. Conclusive Statements

This paper presented arguments towards an SBA-Native system architecture for future mobile telecommunication networks. Such system is based upon the assumption of a unified 3GPP Access and Core Network in relation to routing, telemetry, orchestration and AI capabilities for services required to control the user plane. Such services can reside on consumer devices, in the RAN, CN or in Data Networks (DNs) as vertical applications.

Furthermore, this article presented 6G requirements an SBA-Native system architecture can impact on and mapped them to KVIs as a means of potential verification. As argued in the paper, technical KVI should be taken into account when validating a requirement, which goes beyond many efforts within the European community focusing on societal and economical KVIs only.

As arguments are often valid within a certain scope only where boundaries are defined by time and/or space, the arguments presented in this article shall serve as a baseline to define 6G and its key difference to its predecessor. As such, the list of requirements, KVIs and the actual proposition of SBA-Native may raise unprecedented challenges when debating about potential standardisation and realisation efforts. Thus, the authors are well aware that their work on and around SBA-Native must lead to more tangible results allowing to tackle the KVIs listed herein.

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