6Green: Green Technologies for 5/6G Service-Based Architectures

R. Bolla[*‡], R. Bruschi[‡], F. Davoli[*‡], C. Lombardo[*], Beatrice Siccardi[*‡]

[‡] DITEN - University of Genoa - Genoa, Italy

[*] CNIT – S2N National Lab - Genoa, Italy

***Abstract*— While the fifth generation (5G) of mobile networks is seen as a key enabler to new digital technologies, empowering different verticals and enabling new business models, the intrinsic distributed and pervasive nature of 5G/6G is expected to cause a significant usage and deployment increase of computing resources, increasing the associated infrastructure Operational Expenditure (OpEx) and Capital Expenditure (CapEx), and, consequently, their carbon footprint and energy requirements. In order to avoid such a curse, this paper outlines the objectives of 6Green, a European project; it proposes the definition of a green ecosystem in which all the stakeholders are incentivized to decrease their energy consumption. The paper, in more detail, proposes three innovations and the corresponding methodologies necessary to realize such an ecosystem. Finally, the expected impact is reported.**

Keywords—5/6G, Green Networking, Artificial Intelligence.

I. Introduction

The fifth generation (5G) of mobile networks is a key enabler to support the introduction of digital technologies in multiple sectors, empowering different verticals and enabling new business models. Thanks to native capabilities of 5G networks, especially network slicing [1] and edge computing [2], vertical applications with high performance requirements are supported.

Recent studies show that the intrinsic distributed and pervasive nature of 5G/6G and edge computing are going to cause a significant usage and deployment increase of computing resources, increasing the associated infrastructure Operational Expenditure (OpEx) and Capital Expenditure (CapEx), and, consequently, their carbon footprint and energy requirements [3]-[5]. The numbers are foreseen to be much higher than in today's cloud scenarios. In further detail, [6] points out that energy consumption constitutes between 20 and 40% of network OpEx of Mobile Network Operators (MNOs) which are major energy consumers. Moreover, the growth of edge computing will further affect the infrastructure and its impact on energy consumption, leading to an edge-cloud continuum composed of a large number of public/private micro/small/medium data centers. Within this context, it is important to avoid any potential energy waste by following any changes, for instance, in UE mobility and workload peaks across the continuum in an almost real-time and automatic fashion, and to provide a suitable amount of resources only when and where really needed.

In order to fasten and foster the sustainable rise of a new mass-market of novel vertical applications with challenging, heterogeneous, and time-varying requirements, an innovative, full value-chain ecosystem is required to make all the 6G stakeholders becoming integral part of a win-win business model, common to the best green economy practices, by promoting behaviors (e.g., consuming resources as-a-Service) that reduce the power consumed in the infrastructure through incentives.

To this end, the 6Green Project, funded under the SNS R&I Work Programme and starting in January 2023, aims to conceive, design, and realize an innovative service-based and holistic ecosystem, able to extend "the communication infrastructure into a sustainable, interconnected, greener end-to-end inter-compute system, supporting all types of services and interconnected networks" and promote energy efficiency across the whole 5/6G value-chain.

This ambitious goal will be achieved by introducing fully automated orchestration tools able to sense relevant Key Performance Indicators (KPIs) and events, decide when to trigger elasticity- and agility-driven (proactive) operations, and efficiently perform them by coordinating all the involved architectural building blocks. As a consequence, the evolution of the 6G Service-Based Architecture (SBA) will see the introduction of new features for supporting of such tools, for example by collecting events and analytics streams from both the infrastructure and the vertical applications. Moreover, Artificial Intelligence (AI) [7] is expected to play a key role in this evolution.

This paper introduces the 6Green project and outlines the most relevant principles to be embraced for the development of a green 6G ecosystem and introduces the solutions that we propose.

The remainder of the paper is organized as follows. Section II presents the ground-breaking innovations we propose for a new green technology, while Section III focuses on the technical activities necessary to reach them. The impact we expect from 6Green is reported in Section IV and conclusions are drawn in Section V.

II. Ground-breaking Innovations

In this section, the ground-breaking innovations proposed in the 6Green Project are introduced. In particular, they will enable, on the one side, the smooth and rapid reconfiguration of the ecosystem towards more energy- and carbon-efficient configurations (i.e., Edge Agility and Green Elasticity); on the other side, they will allow to assess the indirect energy/carbon footprint induced by any stakeholder on the infrastructure, consequently allowing more responsible and sustainable practices.

Moreover, it is worth mentioning that the following innovations stem from our experience in several European projects [8]-[10] and that they will be compliant with ETSI ENI (Experiential Networked Intelligence) specification [11] for defining AI policies fed by the 6G enhancement of the SBA.

A. Edge Agility

The Edge Agility innovation is meant to provide smart, fast, and automated horizontal scalability to vertical applications and related slices across the 5/6G edge-cloud continuum. This feature will support to move applications/services (or part of them) at run-time in different geographical areas of the edge-cloud continuum, only when, where and for the time needed by (mobile) 6G end-users. As a result, this will allow to save energy by "scaling-to-zero" the network functions and the vertical applications when and where they are not needed.

In further detail, we propose an AI that enables the smart, fast, and automated relocation of vertical applications and related network slices across the geographically distributed 6G edge-cloud continuum based on user (e.g., mobility) or infrastructure-driven (e.g., availability of renewable energy) events. The relocations should be transparent to the users through suitable procedures based on cloud-native service-mesh routing that exploit the "stateless" nature of cloud-native microservices. Moreover, 6Green will support two types of Edge Agility operations: reactive and proactive. The former ones are triggered by asynchronous events (e.g., sudden User Equipment (EU) handover), while the latter ones exploit forecasting techniques aimed at foreseeing, for instance, the traffic of the end-users or the seasonal patterns of renewable energy availability. In Figure 1 an example of a reactive Edge Agility operation triggered by the movement of a user is shown.

Finally, the Edge Agility innovation should be able to take relocation decisions and enforce them at two levels (at the network and at the vertical applications). Therefore, this solution will be not only a paradigm internal to the 6G SBA, but suitably exposed to the 6G Application Function (AF) to fully and bidirectionally coordinate/synchronize network- and application-level orchestration.

B. *Green Elasticity*

Green Elasticity aims to dynamically and adaptively provide energy-aware, hardware-assisted acceleration to network functions and vertical applications to enable smart vertical scalability across the three domains of 6G environments: from the vertical domain, through the network (slice), down to the infrastructure. Green Elasticity refers to the capability of scaling performance by opportunistically trading-off (and mixing) diverse resources, as for example computing resources for low-latency storage or network slices, to enable smart vertical scalability across the three domains of 6G environments: from the vertical domain, through the network (slice), down to the infrastructure. An example of the Green Elasticity innovation through the offloading of microservice business logic and network tasks at sidecar level is shown in Figure 2.

The hardware acceleration can significantly lower processing latency with respect to pure software artefacts, and can be applied for network tasks (e.g., P4 programmable hardware, smart Network Interface Cards – NICs – with hardware support for extended Berkley Packet Filters – eBPFs) and business logic (e.g., Graphical processing Units – GPU, Field-Programmable Gate Arrays - FPGAs). However, since Hardware acceleration engines usually exhibit low power-consumption dependency against their usage, and significant energy savings can only be achieved by putting the engines into standby low power modes, the Green Elasticity innovation becomes energetically/environmentally advantageous, with respect to pure software processing, only when applied to large volume of the time-varying workloads. Thus, Green Elasticity is a crucial mean for dynamically distributing the time-varying, end-to-end latency budgets of vertical applications across the domains, while holistically optimizing the trade-off between the energy/carbon footprint and the performance of network and application artefacts.

Moreover, as for Edge Agility, through this innovation, elasticity operations will be no longer constrained to a single domain, but they will rather propagate to the other domains (i.e., through proper interfaces between the SBA and the AF). This will allow jointly adapting/consolidating the service meshes of vertical applications and network slices to optimally exploit the available computing/networking resources.

C. *Energy-aware Backpressure*

The Energy-aware Backpressure innovation consists in a set of cross-domain observability mechanisms and analytics to evaluate the energy and the carbon footprint that a vertical application, a slice, or the overall 6G network is inducing onto the edge-cloud infrastructure.

In detail, the edge-cloud infrastructure is composed of physical computing/networking/acceleration devices that consume energy depending on their workload, corresponding to the aggregation of workloads of the hosted artefacts (i.e., network functions and vertical application components). To reach a holistic green ecosystem and to make all the stakeholders aware of the footprint they induce, we aim to suitably process, infer, and expose this information at both the 6G SBA and vertical application (and their network slices) levels. Hardware-level energy consumption metrics will be collected by explicitly considering renewable energy

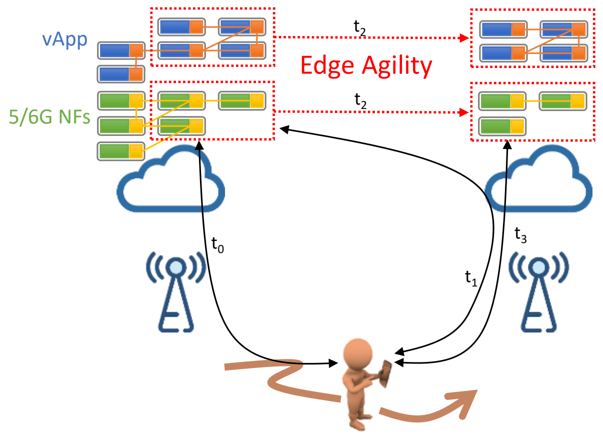

Figure 1. Example of Edge Agility reactive operations, triggered by a user on the move.

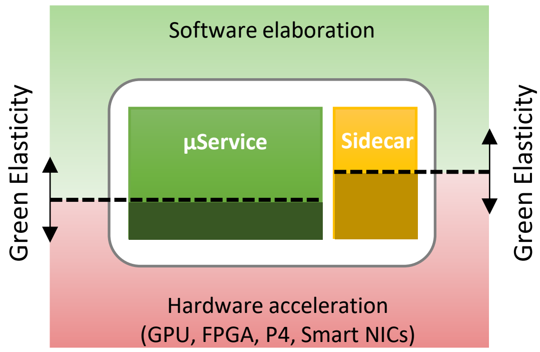

Figure 2. Example of Green Elasticity through the offloading of microservice business logic and network tasks at sidecar level.

contribution and will be divided/mapped onto each hosted tenant through adaptive AI-driven analytics.

Moreover, it is worth noting that backpressure metrics will be jointly consumed by optimization (AI) engines operating in all the stakeholder domains through a win-win cooperation. Finally, through the Energy-aware Backpressure, all the involved stakeholders will be made aware of their energy consumption.

III. METHODOLOGIES

The activities that will be undertaken within 6Green to achieve the innovations described in Section II aim to involve the whole architecture from the infrastructure level up to the vertical industry one. The interactions among the aforementioned levels is attributed to an energy-driven "backpressure" that is meant to carry information on OpEx and energy-aware metrics extracted from the infrastructure (i.e., the estimate of the induced resource usage footprint, suggestions on how scalably reconfiguring microservices/sidecars to meet the requested performance, while enabling the infrastructure to act in a green and (OpEx) sustainable fashion) and relevant events or data (e.g., handover events of specific UEs, geographical densities of a set of UEs, etc.) to drive Green Elasticity and Edge Agility in a reactive or proactive fashion.

A. *Green Enabling Technologies for Cloud-Native Services*

Starting from the bottom of the architecture, the innovations mentioned in Section II will require the introduction of greener technologies in in 5/6G cloud-native infrastructures and service meshes.

First of all, focusing on the Green Elasticity innovation, our main goal will be to optimize the execution environment of microservices and their mesh interconnectivity and network-related functions, to make them intrinsically more elastic and agile in heterogeneous serverless environments. To this purpose, latest-generation Graphics Processing Units (GPUs), software-defined networking (SDN) and network software artefacts, like P4-enabled network interface cards (NICs) and switches will be exposed to microservices and sidecars as programmable offloading engines. Throughout this objective, attention will be focused also on the seamless nature that these operations should have.

Then, regarding the "Energy-aware Backpressure" to 6G stakeholders acting on virtual layers, 6Green will focus on the non-trivial task of mapping the energy consumption arising from the main hardware components of servers (i.e., CPUs, memory, disks, network I/O) to the hosted containers/pods. To accomplish this task, 6Green will design and develop reference resource usage footprint and energy consumption models for containers and pods to estimate the induced energy consumption. These models will represent only the software operating dynamics and workload of the single considered container/pod, as it would act in a completely isolated fashion with respect to all the other containers/pods (from other stakeholders). In order to obtain the aforementioned analytics, CPU hardware monitoring tools, such as the Intel Running Average Power Limit (RAPL) framework [12], will be adopted.

Finally, monitoring data will be suitably exposed to the 6G platform and Vertical Application Orchestrators (through the SBA Application Function - AF) and used to obtain energy-aware KPIs. These KPIs will be then exploited to support run-time policies and long-term optimizations for adaptive power management in serverless environments.

Such optimizations have to be performed in a hierarchical fashion, since they stem from a suitable sharing and consolidation of resources among all the containers in a server, and proper settings of each hosted container to efficiently exploit the assigned resources. The software artefact to provide feedback suggestions on the green policies to be used will be realized through lightweight and latest generation artificial intelligence and machine learning algorithms.

B. *The 6Green Service-Based Architecture*

The evolution of the 5/6G SBA towards the 6Green innovations will allow to exploit the new capabilities and the backpressure originated by the infrastructure, to realize extremely efficient 6G network slices, and to autonomically drive their lifecycle management according to vertical applications' run-time requirements and feedback.

To this end, large effort will be devoted to the innovative extensions of both the 5G SBA architecture and single NFs, managing the lifecycle of deployed software components and reserved resources in the 5/6G continuum, and abstracting them to the vertical stakeholders or, more precisely, to VAOs (by means of the AF). The extensions will be targeted to suitably consider and map the aforementioned Energy-aware Backpressure KPIs across the various domain layers (i.e., per platform, per slice, per application), by reinforcing awareness of the platform to optimize the placement and the configuration of microservices across the continuum in order to correctly serve moving UEs, to exploit the availability of renewable energy sources, to meet the workload according to the dynamic requirements expressed by the stakeholders, etc. For instance, focusing on the observability, monitoring, and analytics framework, the Management Data Analytics Function (MDAF) and the Network Data Analytics Function (NWDAF) will be extended to infer energy-aware backpressure metrics against classical management ones to estimate the current and the future carbon/energy footprint induced to the computing and offloading resources in the edge-cloud continuum.

Moreover, specific effort will be devoted to the design of efficient mechanisms for reaction/proaction to events sensed from the cloud-native bare-metal infrastructure, the vertical applications and the UEs (e.g., mobility patterns per type of slice, PDU session requests, etc.), which might trigger fast migrations of (run-time session data of) application and slices according to the Edge Agility paradigm.

C. *Vertical Application Orchestration within the 5/6G Green Economy*

Finally, the definition of a set of green business/use models and Decarbonization Layer Agreements is required to optimize, with the support of the 6Green SBA, direct and induced carbon and energy footprints for all the stakeholders, and of the consequent algorithms, policies, and mechanisms that the Vertical Application Orchestrator has to integrate in order to fully integrate with and to take advantage from the 6Green ecosystem.

Green economy is the holistic and distributed intelligence driving the interaction/interoperability among the stakeholders acting at any layers and, consequently, it will heavily impact on the operational effectiveness of the entire

6G ecosystem. As a matter of fact, if not properly integrated according to their main technological/business relevance, Green Elasticity and Edge Agility may be used sparingly or even left disabled. For these reasons, the 6Green business models will rely on, reinforce, and somehow go beyond, the "as-a-Service" paradigm, which provides easily predictable "flat" costs to dynamically enable/rent services, slices, and resources when needed, and to release them when they are no longer required.

In further detail, economic incentives will be defined and provided to motivate upper stakeholders to acquire and use resources as-a-Service, which would improve energy-savings/OpEx reductions for the underlying stakeholders. Moreover, the same agreements between Telecom Operators and Vertical Stakeholders will be extended and made more flexible and dynamic. For example, 6Green will enable to include carbon footprint and energy consumption and/or requirements induced to the network as integral metrics of business agreements to be minimized or to be kept within a capping threshold.

IV. Impact

6Green will massively contribute to sustainability aspects as crucial challenge for European and global society. The project will not only reduce the carbon footprint of the 5/6G continuum, but it will provide vertical stakeholders with the possibility to significantly reduce their own Green House Gas (GHG) emissions. Moreover, 6Green outcomes are meant to contribute to European policies, standards, and regulations and in particular to the Green Deal, Artificial Intelligence, Data and Cloud Computing.

The 6Green approach and the nature of the addressed 5/6G evolution have been conceived to establish strategic alliances with vertical sectors to build and offer win-win, zero-carbon, powerful and persuasive Business to Business (B2B) and Business to Consumer (B2C) propositions with enhanced environmental responsibility. This will directly contribute to the joint economic growth and the creation of new zero-carbon value chains of Telecom Industries and Vertical Sectors relying on 5/6G and strengthen European industrial competitiveness. In detail, stakeholders whose virtual resources/services are not traditionally linked to the power consumption they cause will be made aware of their individual footprint; furthermore, they will be incentivized to adopt energy-conscious and environmental-responsible behaviours through green business models and the subscription of a Decarbonization Service Agreement (DSA).

Eventually, the ultimate and challenging impact targeted by the 6Green project is to reduce the carbon footprint of 5/6G networks of more than 10 times with respect to Business-As-Usual (BAU) scenarios.

V. Conclusions

The distributed and pervasive nature of 6G technologies, that stems from the growth of edge computing, will certainly cause a significant increase in usage and deployment of computing resources and consequently of their carbon footprint and energy requirements. In this context, the need to address energy efficiency is apparent in order to provide 6G technologies at affordable costs both in terms of economic and environmental costs.

In this respect, the paper presents the 6Green Project, recently approved within the SNS R&I Work Programme, whose aim is to propose a new green ecosystem in which all stakeholders are incentivized to reduce energy consumption. In particular, we propose three ground-breaking innovations that we believe should be key parts in the definition of the new generation of mobile networks (6G), and the corresponding technical activities that should be carried out in order to achieve them.

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