6G Enablers for Zero-Carbon Network Slices and Vertical Edge Services

Raffaele Bolla, Roberto Bruschi, Chiara Lombardo, and Beatrice Siccardi

***Abstract*—6G of radio mobile networks should become an essential enabler for any vertical sector to meet sustainable growth targets of both the United Nations (UN) 2030 Agenda and the European Green Deal. 6G might lead to the dematerialization of (most of) any physical appliances, moving their smart parts to the network edge as virtual software instances. Such software instances can leverage on novel carbon-neutral schemes for computing and communication. Owing this vision, this letter aims to analyze how energy- and carbon-awareness can be introduced into the complex architecture of 6G, and how the diverse stakeholders in the 6G value-chain can benefit from this awareness.**

***Index Terms*—6G enablers, green networking, edge computing, carbon neutrality.**

I. INTRODUCTION

THE FIFTH-GENERATION (5G) of radio mobile networks and edge computing technologies are the two key enablers currently transforming the cloud into a flexible communication and inter-compute continuum, offering the possibility to introduce radically new applications in any vertical industrial domain.

Recent studies [1], [2], [3], [4] indicate that the intrinsic distributed and pervasive nature of 5G and edge computing are causing a noticeable 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. Such studies lay the foundation for questioning the sustainability of the upcoming 6G technology. Much higher numbers than in today's cloud scenarios are foreseen, which cannot be compensated only by better efficiency levels coming from an inertial evolution of the ecosystem.

Cloud computing datacenters are dimensioned against the aggregated workload of hosted applications publicly available on the Internet, while in 5/6G, edge facilities should be dimensioned against the workload produced by locally-connected mobile users and their (edge) applications. Therefore, the edge part of the 6G continuum cannot benefit from workload aggregation, and it will sensibly affect the sustainability of the ecosystem. To cope with this problem and to meet sustainable growth targets of both the United Nations (UN) 2030 Agenda [5] and the European Green Deal [6], the 6G continuum needs to rapidly evolve new foundation paradigms specifically addressing the energy and carbon footprints of the overall ecosystem.

Moreover, it is worth noting that the networking research community has been tackling the energy efficiency and carbon footprint issue for the past decades. As a matter of fact, solutions have been devised well before the concept of softwarization and virtualization [7].

The goal of this letter is to identify the main innovation aspects to forge 6G technologies as intrinsically green, and able to boost sustainability in any third-party vertical sectors (e.g., by enabling dematerialization of physical appliances or part of them, and supporting "softwarized" processes to run and communicate under carbon-neutral schemes).

To this end, this letter considers the highly-layered and multi-domain architecture interfacing diverse 6G stakeholders (from the ones acting at the infrastructure and network platform to vertical industries) and proposes a set of innovations. First of all, they will be key enablers for exposing energy- and carbon-related performance indexes across the whole ecosystem. Then, such indexes will be consumed in order to promote, through economic incentives, environmentally sustainable behaviors of all the stakeholders and to base the 6G edge-cloud continuum deployment on the actual utilization.

For example, vertical stakeholders might be enabled to extend their Service Level Agreements (SLAs) with mobile network operators to innovative Decarbonization Service Agreements (DSAs), where communication and edge resources might be assigned no more to rigidly achieve certain performance levels, but by guaranteeing a carbon footprint cap. Only in such a way, all the stakeholders will become integral parts of a win-win "green economy" business, holistically driving the 6G towards a renewed sustainability.

The remaining of this letter is organized as follows. Section II describes the current context and highlights its main issues, while Section III highlights the main features of the proposed ecosystem, and conclusions can be found in Section IV.

II. CONTEXT

Energy efficiency in radio mobile networks, and more in general in networking technologies, has been commonly interpreted as the ratio between the network capacity and its energy consumption. As such, in the network technology evolution up to 5G, generation after generation, increasing the energy efficiency ratio has been achieved with a significant raise of network capacities vs. a slight raise of energy requirements [8], [9], [10], [11].

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Although this ratio is an important aspect in evolving networking technologies, it cannot be used alone to assess or guarantee the real environmental sustainability of the 6G ecosystem.

Furthermore, increasing the capacity of the networks, mobile ones included, has always meant overprovisioning. In further detail, networks have always been dimensioned against their peak usage, resulting in a real utilization that is, most of the time, much lower than the capacity.

The need for the capacity to dynamically follow the actual utilization is now apparent.

In fact, even if 6G technologies may increase and extend the operational efficiency and reduce the carbon footprint of any third-party industry sectors (allowing vertical industries to customize/optimize their network slice and exploit edge computing paradigms), the overall 6G ecosystem sustainability may become more than a business/technological feasibility constraint.

As the network will scale, it is predicted that 5G base stations alone will consume about three times more energy with respect to 4G ones [12]. Moreover, as previously mentioned in Section I, 5/6G continuum's aggregation/multiplexing gain will be limited due to the geographically distributed workload.

The cloud as-a-Service business model itself can be seen as a barrier to the full environmental sustainability as targeted by the UN Agenda 2030 and by the European Green Deal. In the current 5G ecosystem, customized instances of 5G network slices are assigned to vertical applications interconnected to (mobile) devices and terminals. Edge computing closes the loop by hosting vertical applications into the 5G infrastructure, and directly attaching them to the network slice terminations in neighboring geographical facilities.

While this business model has shaped the market as we know it and paved the way to new classes of applications with unprecedented performance levels, stakeholders acting on virtual layers acquire/release resources in an almost independent fashion from both end-users' information flows and have little to no information regarding how their actions impact on resource utilization (i.e., in terms of network, computing and storage) and energy consumption to the physical infrastructures.

In order to see a significant change in the upcoming 6G ecosystem, environmental sustainability and energy efficiency should not be a business target of only Infrastructure Providers anymore, but should involve even the stakeholders relying on unlimited pools of virtual/abstract resources/services (e.g., a network slice, etc.), which are often not directly linkable to hardware entities with finite capacity and draining energy.

III. ENABLING STRATEGIES FOR A GREEN 6G

In order to overcome the energy issues highlighted in Section II, it is of paramount importance to design the 6G system and the overall edge-cloud continuum in a way to reach a full environmental sustainability, not bound to the network/computing capacity anymore, but rather to the real usage of resources.

In this regard, 5G's architecture itself, being cloud-native and service-based, presents an opportunity for 6G to seize. Furthermore, it is clear that the involvement of all key players is non-negotiable, and their involvement is conditional to the presence, on the one hand, of enabling technologies to collect and propagate the information regarding the induced consumption from the physical to the virtual layers, and, on the other hand, of green business models to incentivize energy-conscious behaviors.

This section presents the three features that compose the proposed ecosystem, whose architecture is shown in Fig. 1. The first feature concerns observability and is the key enabler for the other two which regard actuation. Finally, in both spheres, observability and actuation, Artificial Intelligence (AI) will play a key role.

A. Energy-Aware Backpressure

A set of cross-domain observability mechanisms and analytics are required 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: this concept can be described as "energy-aware backpressure."

The aforementioned analytics should involve not only the energy consumption, but also the carbon footprint in order to preferably make use of energy coming from renewable sources. In detail, the edge-cloud infrastructure is composed of computing/networking/acceleration devices consuming energy depending on their workload, corresponding to the aggregation of workloads of the hosted artefacts.

In current cloud environments, power consumption information is usually consumed only within the infrastructure domain to better consolidate virtual artefacts in the datacenter farm. As highlighted in Fig. 1 (see the light blue arrow), to reach a holistic green ecosystem and to make all the stakeholders aware of the footprint they induce, such information must be suitably processed, inferred, and exposed also at both the 6G network and vertical application levels.

Hardware-level energy consumption metrics should be collected by explicitly considering renewable energy contribution and will be jointly consumed by optimization (by means of AI) engines operating in all the stakeholder domains through a win-win cooperation.

To provide the "energy-aware backpressure" feature to 6G stakeholders acting on virtual layers, the energy consumption arising from the main hardware components of servers (i.e., CPUs, memory, disks, network I/O) must be mapped to the hosted containers/pods.

This is a non-trivial task: single server hardware components (e.g., a CPU core/thread) are not usually mapped against individual containers but rather shared among multiple virtual resources potentially owned by several tenants, and many hardware power management schemes are often designed to act on a group of components. This means that the real energy consumption of servers cannot be directly decomposed on a per-container basis, because it depends on the behavior of all the hosted containers, the overall power management configuration of the server, and how these containers are pinned to the available resources.

To cope with this problem, reference resource usage footprint and energy consumption models must be designed for containers and pods to estimate the induced energy consumption.

These models should 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). CPU

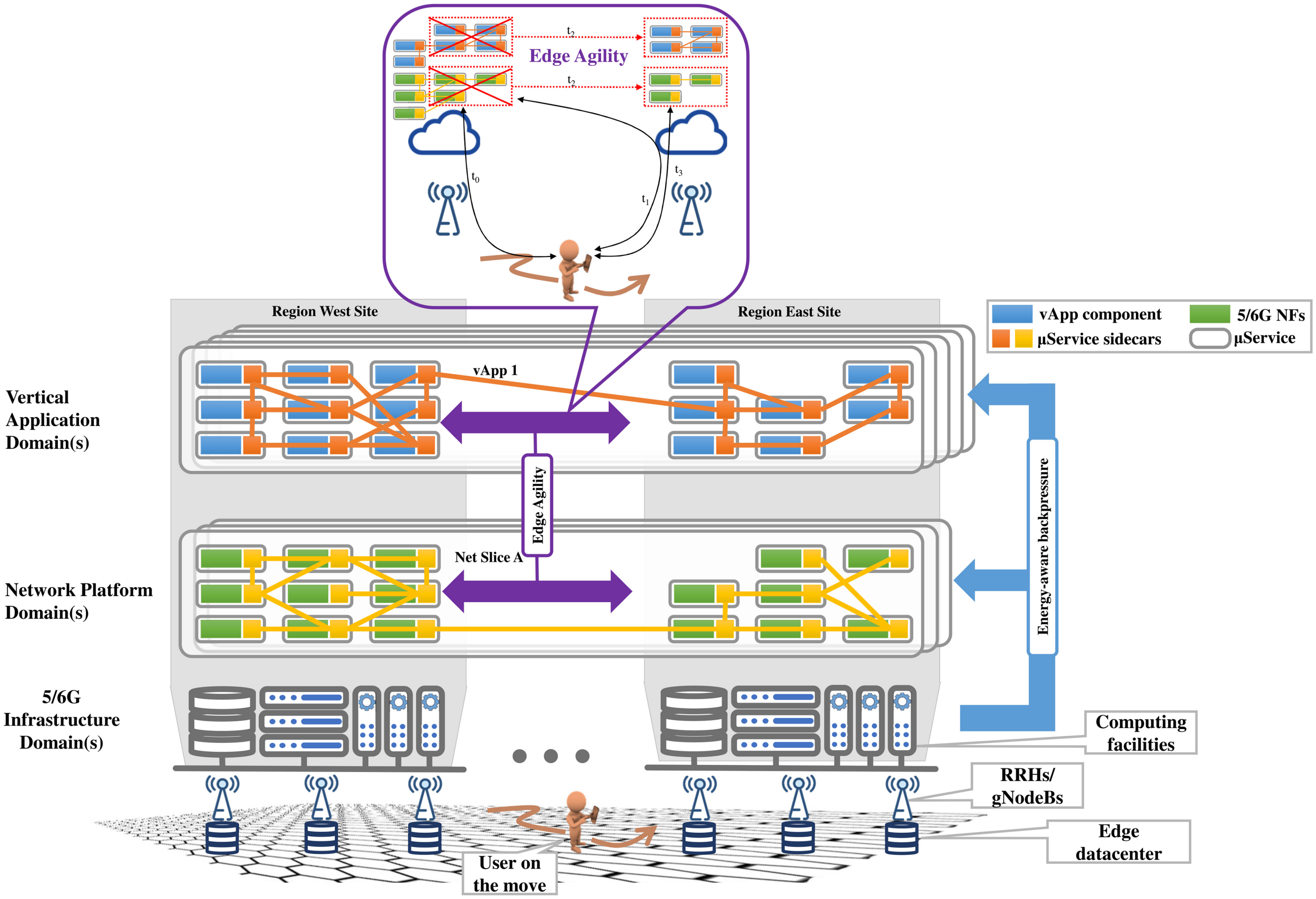

Fig. 1. The role of the "edge agility" (in purple) and the "energy-aware backpressure" (in light blue) features across the infrastructure, the network platform, and the vertical application cloud-native domains.

hardware monitoring tools, like the ones made available by the Intel Running Average Power Limit (RAPL) framework [13], must be used to feed the aforementioned analytics.

Moreover, in order to make the learning phase of software profiles shorter, a suitable set of tools for pre-analyzing energy-aware profiles of software containers is needed. Monitoring data should be then suitably exposed to the 6G platform and Vertical Application Orchestrators by extending/designing application and system probes and extra scheduling algorithms to provide monitoring data at different aggregation levels.

Finally, "energy-aware backpressure" should involve both the 6G Service-based Architecture (SBA) and the 6G Application Function (AF) to spread the awareness across all the stakeholders.

B. Green Economy

Given the collected and elaborated information on the induced energy consumption, "green economy" should drive the interaction/interoperability among the stakeholders acting at any layers and, consequently, it should heavily impact on the operational effectiveness of the entire 6G ecosystem.

In order to promote environmental-responsible behaviors, a set of business models should be designed to showcase the mutual benefits related to a win-win approach based on the optimization of energy consumption and carbon footprint - and the consequent reduction of OpEx from the infrastructure layer up to vertical industries - to all members of the ecosystem.

In further detail, economic incentives should be defined and provided to motivate upper stakeholders to acquire and use resources according to the current workload, which would improve energy-savings/OpEx reductions for the underlying stakeholders. To this purpose, the business/use models should consider both adaptive costs for the acquisition of new resources (e.g., by breaking down costs for the various SLA parameters), and economic incentives (to be cut from the previous costs) for their energy-efficient usage.

In the past, SLAs have typically included only strict performance related parameters (e.g., guaranteed bandwidth, maximum latency, etc.). Such agreements should be extended in order to include carbon footprint and energy consumption. Moreover, performance parameters, when possible, should assume variable values in order to obtain a "zero-carbon certificate" at the expense of performance.

By introducing these extensions, a fully-fledged DSA will become a reality. Finally, the previous concepts should also be focus topics for the standardization and regulation bodies (e.g., IETF, ETSI, etc.).

Moreover, "green economy" should also be involved in the journey towards carbon-neutrality of vertical sectors. Verticals, through 6G connectivity and edge computing, will be offered zero-carbon services that enable, on the one hand, the dematerialization of devices (e.g., Virtual Desktops) and, on the other hand, the decrease of transportation emissions (e.g., Augmented Reality Remote Assistance System).

The device dematerialization would significantly impact the Life Cycle Assessment (LCA) (i.e., the environmental impact due to the complete lifecycle of a physical good or a service) of such devices.

C. Edge Agility

The metrics provided by "energy-aware backpressure" should also be used to dynamically and adaptively horizontally scale the vertical applications and related slices across the 6G edge-cloud continuum, enabling the so-called "edge agility" feature.

This feature should allow to move applications/slices at runtime across the distributed edge-cloud continuum based on events or forecasts.

"Edge agility" is a natural extension of 5G, its foundation lays in the stateless essence of 5G Network Functions (NFs) which enables the seamless relocation of their run-time session data and software images within the network and computing continuum (i.e., retrieving the external state of the microservice(s) to be moved, injecting it to new instances running in the new edge facilities, and properly remapping the network interconnectivity and data locations, etc.). Such relocations should be based on events and forecasts concerning 6G (mobile) end-users (e.g., mobility, traffic intensity patterns, etc.) and the infrastructure (e.g., availability of renewable energy). For instance, Fig. 1 (in purple) shows a relocation due to the movement of the user.

Moreover, edge agility should significantly decrease the carbon footprint by "scaling to zero" the NFs and Vertical Applications when and where they are not needed.

However, the aforementioned functions/applications should always be reachable, and, in case of need, they should be reactivated; in order to achieve this goal, sensing and network presence should be provided by 6G. Such a goal can be achieved by applying the well-known concept of Network Connectivity Proxy (NCP) [14], [15]: a new or extended microservice should handle network presence on behalf of scaled to zero functions/applications, redirect the traffic to the nearest active instances and reactivate them when needed.

Finally, as well as the "energy-aware backpressure" feature, the relocation decisions should be enforced at two levels (at the network and at the vertical applications). Therefore, the "edge agility" feature should be not only a paradigm internal to the 6G SBA, but suitably exposed to the 6G AF to fully and bidirectionally coordinate/synchronize network- and application-level orchestration.

IV. CONCLUSION

This letter proposed the main innovations to not only shape 6G as intrinsically green, but also to enhance environmental sustainability in third-party vertical sectors. This letter introduced methodologies for providing the stakeholders acting at the virtual layers with the awareness of the consumption that their vertical applications and network services induce on the hardware underneath. This letter presented a coordinated set of mechanisms and frameworks for enabling data collection at infrastructure level and for propagating elaborated data to the other stakeholders.

Moreover, this letter also dealt with the usage of this information as driver of two actuation means.

The former concerns green business models able to incentivize stakeholders to adopt more energy-conscious behaviors and even promote the creation of new business agreements that include carbon footprint and energy consumption and/or requirements induced to the network as integral metrics. The latter regards the smart, dynamic horizontal scaling of services in order for them to be offered only when and where needed.

Finally, the critical analysis highlighted that it is crucial to measure the energy consumption of the added monitoring and AI mechanisms in order to avoid the paradox that energy-efficiency control/management mechanisms will drain more energy than the one that can be saved in the controlled system. In order to avoid such a curse, it is important to tune accordingly the sampling frequency and the depth of the energy-aware metrics.

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