Energy-Aware Multi-Domain Orchestration Architecture for Sustainable 6G Networks

Berk Buzcu*[§], Laura Finarelli*[§], Engin Zeydan[†], Jorge Baranda[†],
Nikolaos Tzanis[‡], Stamatiou Nikolaos[‡], Nikolaos Kanakaris[‡], Gianluca Rizzo*
* Connected Experience Lab, HES-SO Valais/Wallis, Sierre, Switzerland
[†]Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Castelldefels, Spain
[‡]Department of Research, Technology & Development, Independent Power Transmission Operator (IPTO), Athens, Greece
[§]Telecommunication Networks group, Technical University of Berlin, Germany
Email: {berk.buzcu, laura.finarelli, gianluca.rizzo}@hevs.ch,
{engin.zeydan, jorge.baranda}@cttc.es, nikostza@gmail.com, {n.stamatiou, n.kanakaris}@admie.gr

Abstract*—Future 6G systems must operate as intelligent, sustainable, and self-optimizing infrastructures that integrate heterogeneous communication and power domains. We present an energy-aware, multi-domain orchestration architecture for 6G networks, built on a hierarchical control model comprising an Inter-Domain Management and Orchestration (IDMO) layer, domain-level Management and Orchestration (DMO) entities, and Infrastructure Domain Managers (IDMs), interconnected through a Service-Based Management Architecture. Furthermor, the architecture incorporates Virtual Power Plants (VPPs) and an inter-domain Energy Management System (EMS) that jointly interface (physically and logically) with the network infrastructure while respecting the operational autonomy of local grids. In this model, the VPP exposes unified, virtualized interfaces for energy providers and domain-embedded sources at network elements (e.g., photovoltaics and storage) for network-level coordination without interfering with local grid control. The inter-domain Energy Management System (EMS) ingests standardized, multi-domain energy telemetry and forecasts (e.g., generation potential, carbon, and consumption intensity) and applies predictive modeling to produce locality-aware reports for the IDMO. Guided by this intelligence, the IDMO coordinates cross-domain service decomposition, placement, and reconfiguration. Each DMO can locally promote IDMs whose energy mix satisfies sustainability and performance targets. We aim to validate the approach in a cross-domain proof-of-concept spanning two sites: a baseline site and a sustainable site, to demonstrate that our proposed architecture allows to balance orchestration latency and energy savings.

***Index Terms*—6G networks, multi-domain orchestration, energy-aware network management, AI-native automation.**

I. INTRODUCTION

The advent of Sixth Generation (6G) networks offers unprecedented opportunities for intelligent, energy-efficient, and sustainable connectivity across heterogeneous infrastructures [1]. Unlike traditional single-domain management paradigms, future 6G systems are expected to integrate terrestrial and non-terrestrial segments [2], cloud-edge resources [3], and vertical-specific infrastructures into a unified, service-oriented ecosystem [4]. This paradigm shift necessitates orchestration frameworks capable of managing cross-domain complexity while embedding energy awareness and sustainability at their core.

Building on the foundations laid in 5G, research on network management and orchestration has significantly evolved from the initial concepts of Network Function Virtualization (NFV) and Software-Defined Networking (SDN) introduced in the 5G era [5]. These technologies established the foundations for flexible and programmable infrastructures, but their orchestration scope largely remained confined to single administrative domains. In contrast, 6G networks aim to integrate multiple heterogeneous domains, spanning different technologies, ownership models, and geographic locations, under a unified, Artificial Intelligence (AI)-driven orchestration layer capable of dynamic service decomposition and cross-domain optimization [1]. This includes distributing Radio Access Network (RAN) and mobile core functions across different points of presence (PoP), co-located with vertical applications to meet stringent latency and throughput requirements, while also incorporating non-terrestrial capabilities such as satellite access for ubiquitous coverage.

Several initiatives have addressed the challenges of multi-domain orchestration and single-domain automation. The ETSI Zero-touch Service Management (ZSM) framework [6] defines intent-based, closed-loop automation for service management across multiple domains, and more specifically, within the field of mobile networks, the O-RAN Alliance [7] specifies the near-real-time and non-real-time RAN Intelligent Controllers (RICs) to enhance AI-based optimization at the RAN layer. At a broader system level, the 3GPP Service-Based Management Bus (SBMA) [8] considers ETSI ZSM principles to perform multi-domain management, modular service exposure, and data-driven control across multiple network functions. However, these frameworks lack explicit mechanisms to incorporate energy sustainability as a decision parameter for the deployment and end-to-end mobile network configuration. Furthermore, our architecture envisions virtual entities and actors (the Inter-Domain Management and Or-

---

This work is supported by UNITY-6G project, co-funded from European Union's Horizon Europe Smart Networks and Services Joint Undertaking (SNS JU) research and innovation programme under the Grant Agreement No 101192650 and from the Swiss State Secretariat for Education, Research and Innovation (SERI).

chestration (IDMO), Domain Management and Orchestration (DMO)s, and Infrastructure Domain Manager (IDM)s) rather than simple network functions.

Recent studies have introduced *green orchestration* concepts by integrating energy consumption models and carbon awareness into placement or scheduling decisions [9]. Approaches such as renewable-aware virtual network function placement [10] and energy-efficient service chaining [11] highlight the potential of sustainability-driven orchestration. Yet, these models often operate at the resource management level without coordination among multiple orchestration layers or domains. From the perspective of AI-native management, projects such as Hexa-X [12], ADROIT6G [13], and UNITY-6G [14] have highlighted the need for hierarchical orchestration architectures capable of integrating semantic monitoring, intent translation, and digital twin feedback. These studies align with the increasing interest in coupling AI/ML pipelines with orchestration logic to achieve self-optimising and self-sustaining 6G infrastructures. However, the holistic integration of energy intelligence, such as Virtual Power Plant (VPP) telemetry, into inter-domain orchestration decision loops remains largely unexplored.

To bridge this gap, our framework introduces energy-aware, multi-criteria decision logic within the IDMO–DMO hierarchy, embedding sustainability as a native component of both service instantiation and runtime adaptation. Unlike prior approaches that treat energy efficiency as a post-deployment optimization task, our architecture leverages real-time energy data from distributed VPP systems to enable sustainability-aware placement, scaling, and migration decisions across federated domains. This design is expected to contribute to the realization of self-governing, carbon-conscious 6G infrastructures. Specifically, a single, monolithic orchestrator cannot handle (i) heterogeneity and scale across administrative/technology domains, (ii) policy constraints that require local autonomy, and (iii) end-to-end energy objectives that demand global coordination of local trade-offs. To address these challenges, UNITY-6G project [14] proposes an architecture that incorporates two key layers: the IDMO and DMO. The IDMO operates as a global intelligence plane orchestrating multiple administrative and technological domains. It functions as a master orchestrator that coordinates and manages end-to-end (E2E) network composition by negotiating deployment policies and integrating inputs from the individual domain managers (i) and (iii). Each domain, in turn, is managed locally by its respective DMO, which is responsible for orchestration and management within its domain boundaries, handling resource allocation, lifecycle management, policy enforcement, and operational control over infrastructure resources and deployed network services (ii).

In this paper, we present our distributed future networks architecture incorporating the IDMO-DMO structure (See Section II), how energy-awareness integrates into the architecture with the assistance of inter-domain EMS and Virtual Powerplants (Section III), and the road map to the implementation of a multi-domain, energy-aware orchestration framework (Section IV).

II. BACKGROUND: INTER-DOMAIN ORCHESTRATION ARCHITECTURE

Future wireless networks are expected to be heterogeneous, multi-vendor, and multi-domain ecosystems, integrating diverse access technologies (e.g., 5G, 6G, Wi-Fi) and complex service chains spanning from the edge to the central cloud. The proposed architecture uses a hierarchical and modular design, providing the structural properties needed to manage the complexity and scale of future wireless network service orchestration. It implements a distributed orchestration paradigm across multiple administrative and technological domains. Fig. 1 shows the overall structure and interrelations among the relevant architectural components.

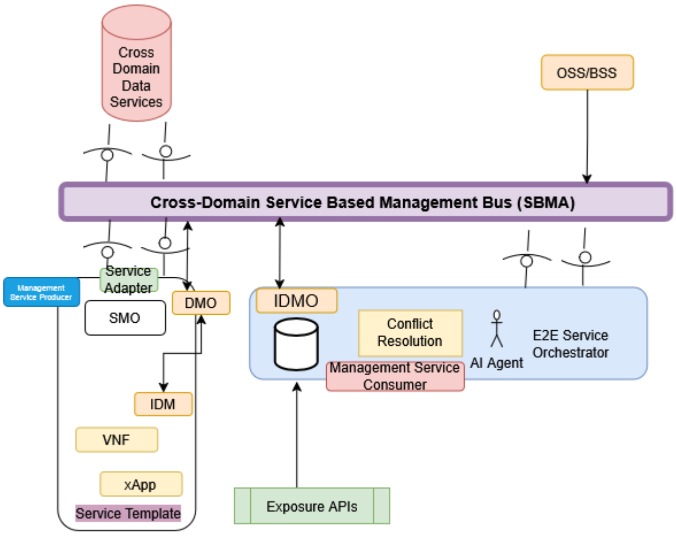

Fig. 1. Cross-domain orchestration architecture for end-to-end 6G service deployment.

IDMO is the top-level orchestrator that coordinates different domains to establish end-to-end (E2E) mobile networks. The IDMO is the global orchestrator responsible for decomposing E2E service requests into domain-specific components (RAN, Transport, Core Network, AI Data Orchestration) and assigning them to appropriate DMO entities. The IDMO decomposes each request into smaller tasks (e.g., for the RAN part, transport part, and mobile core) and selects the appropriate domains (DMOs) in each domain to create the E2E view. IDMO executes a multi-criteria decision-making process that evaluates all potential domain candidates according to:

- *Service capability availability*: verifying that the domain can host the required network functions;
- *Resource sufficiency*; ensuring that CPU, memory, and storage resources are available;
- *Latency and coverage suitability*: matching deployment location with target service area.

DMO is the middle-orchestrator that receives *domain-specific service components* from the IDMO and directly interacts with its associated IDMs to manage the lifecycle of the Network Services (NSs). These NSs are composed of virtualised/containerised networks functions (Virtual Network Function (VNF)s/Cloud Native Function (CNF)s) that implement the assigned service component. Each DMO (e.g., DMO/CORE, DMO/RAN, DMO/Transport, DMO/Data Orch) orchestrates the realization of its assigned component inside its domain. It deploys and configures VNFs/CNFs in selected Points of Presence (PoPs), manages intra-domain resource optimization, monitors domain KPIs such as CPU load and link latency, and reports status and metrics to the IDMO via the SBMA. *IDMs* are managers that directly oversee the infrastructure (e.g., servers, Kubernetes clusters, or virtualized PoPs) where network functions are hosted. Within a single domain, there can be multiple IDMs. For example, in the RAN segment, PoPs are often distributed to ensure coverage and meet strict latency constraints (e.g., for the fronthaul interface). Each IDM is responsible for deploying, monitoring, and managing the CNFs/VNFs requested by its parent DMO. All orchestration layers communicate via the *cross-domain service-based management bus* (SBMA). This component serves as a *lightweight communication and service discovery middleware*, inspired by the 3GPP service-based architecture [8]. The SBMA enables event-driven exchanges between the IDMO, the DMOs, and other supporting components such as analytics engines and policy managers.

The overall architecture forms a vertically integrated control hierarchy that unifies orchestration, analytics, and sustainability management. The IDMO provides global coordination and multi-domain decision-making; the DMOs execute local orchestration and energy-aware management; the IDMs implement infrastructure-level control. Once the optimal mapping is determined, the IDMO decomposes the service into domain-specific components and dispatches orchestration intents through the SBMA to the corresponding DMOs. Each DMO translates the received intent into actionable deployment instructions for its managed IDMs. The IDMs then instantiate the assigned VNFs or CNFs (e.g., gNB-DU/CU, UPF, or AMF) within their local Points of Presence (PoPs), using container orchestration platforms such as Kubernetes. After successful deployment, the IDMs report the operational status and endpoint identifiers to their DMOs, which aggregate this information and notify the IDMO of domain readiness. Finally, the IDMO performs cross-domain configuration tasks, such as interconnecting network segments, establishing VPNs, and enforcing end-to-end policies, thus completing the service instantiation process. The resulting E2E slice is provisioned to optimally balance performance, resource efficiency, and sustainability. In the following section, we examine how we plan to integrate energy awareness into the IDMO architecture.

III. PROPOSED APPROACH: ENERGY-AWARE ORCHESTRATION

The operation of the proposed energy-aware multi-domain orchestration framework can be divided into two main phases: (*i*) the *provisioning and placement phase*, during which the system instantiates an end-to-end (E2E) mobile service across heterogeneous domains, and (*ii*) the *runtime adaptation phase*, where continuous monitoring and optimization ensure sustained performance and energy efficiency. Both phases rely on hierarchical collaboration among the IDMO, DMOs, IDMs, and the inter-domain EMS through the SBMA. To achieve energy-aware orchestration, the UNITY-6G framework integrates an inter-domain EMS. This system aggregates information from distributed power providers, including renewable generation, battery energy storage, and other energy assets, and enables real-time monitoring and reporting of these resources. This information fed back into the decision-making process of orchestrator, enabling it to dynamically evaluate the available energy mix within each domain or site. As a result, the orchestrator can prioritize greener locations when placing or migrating virtualized network functions, supporting sustainability goals while balancing performance or Service Level Agreements (SLAs).

Figure 2 illustrates the proposed hierarchical "system-of-systems" architecture. At the local level, each domain includes a VPP. The VPP acts as an aggregation entity, monitoring and managing the collective energy status of all IDMs, such as relevant Distributed Energy Resources (DERs), storage systems, or flexible loads. The VPP collects real-time energy-related telemetry from the domain's infrastructure, which is then consolidated to create a unified representation of the domain's state (e.g., net load profiles and local generation capacity/greenness). This VPP-level status report is then transmitted to the superordinate inter-domain EMS. The inter-domain EMS operates at a higher hierarchical level and is responsible for optimal coordination of the coupled domains. A core capability of this EMS is advanced forecasting, which uses both real-time data streams from the VPPs and extensive historical datasets. This enables the EMS to generate probabilistic or deterministic forecasts of key parameters, such as inter-domain power exchanges, net load, and generation availability. The processed and forecasted information is further aggregated and placed into a standardized data structure. This formatting is essential for interoperability and is designed to be ingested by the IDMO, providing a coherent overview of the entire network. Ultimately, the IDMO does not need to consider the energy status of the network, as all intelligence gathering is delegated to the Inter-domain EMS system, where the IDMO only ingests the information it needs at the time of decision making.

Meanwhile, the DMOs promote or deprioritize IDMs based on the energy mix advertised by local VPPs. VPPs already monitor local energy information for each IDM along with their resource abstractions to support this. DMOs then deploy VNFs in points of presence powered by renewable sources when feasible. This is particularly relevant

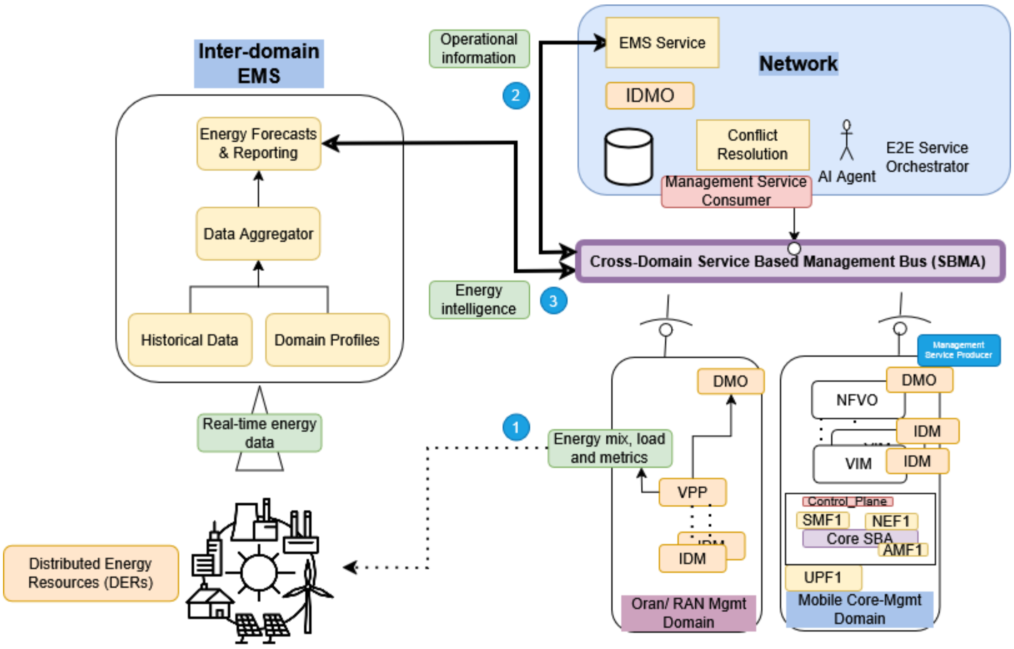

Fig. 2. Proposed energy-aware unified architecture for 6G networks.

for distributed RAN domains, where a gNB VNF may be instantiated at a greener site while respecting latency constraints. IDMs regularly report their energy mix, resource load, and latency metrics to the DMO for localized, energy-aware decisions. Once the end-to-end request is established, local energy efficiency operations, such as turning RUs and related processing VNFs like CU on or off during nighttime while ensuring coverage, are managed by the running tuples: monitoring, analytics, decision engines, and the actuator. The actuator then issues orders to the DMO, which may inform the IDMO of changes. These tuples must be orchestrated on demand if requested for a specific entity, since the expected infrastructure could host multiple services. For example, a ”Mobile Core Domain” could run several mobile core instances for different requesters. The domains are interconnected through VPN tunnels that carry both control and data traffic. For example, a site or domain with a regular power supply can connect to another site or domain using sustainable energy sources via an encrypted VPN over the Internet. The SBMA ensures consistent orchestration, lifecycle management, and policy synchronization between the IDMO and the distributed DMOs.

The provisioning workflow enables the automated instantiation of a network that is not only compliant with Quality-of-Service (QoS) requirements but also optimized for carbon footprint and energy efficiency. This process is triggered when the IDMO receives a high-level E2E service request or intent. The workflow proceeds through four distinct stages: *Intent Translation*, *Candidate Discovery*, *Multi-Criteria Optimization*, and *Distributed Instantiation*. The core of the workflow is the placement engine within the IDMO. It matches resource advertisements from the DMOs with energy profiles from the EMS. The engine uses a Multi-Criteria Decision Analysis (MCDA) algorithm to rank candidate domains based on a weighted cost function. This approach enables the IDMO to make trade-offs, such as choosing a core network domain in a distant location (with higher latency) if it is currently powered by surplus solar energy, as long as the total latency remains within the network's tolerance margin.

IV. VALIDATION FRAMEWORK

To effectively validate the proposed energy-aware orchestration framework, we propose designing and implementing a Proof of Concept (PoC) across two federated, geographically distributed domains. This setup is intended to demonstrate interoperability and test the feasibility of sustainability-aware orchestration policies coordinated by the centralized IDMO layer.

A. Proposed PoC Architecture

Figure 3 illustrates the proposed architecture consists of two distinct domains that cooperate under a unified orchestration framework, representing different provider capabilities and energy profiles:

- *Domain A (Sustainability-Focused):* This domain (represented by the blue area on the left in the figure) includes a VPP to supply green energy, such as from solar or hydro sources, to data center resources that primarily host core network functions.
- *Domain B (Baseline/Performance-Focused):* This domain (right, yellow area) includes Transport, RAN, and data management infrastructures, representing a typical deployment powered by the standard electric grid.

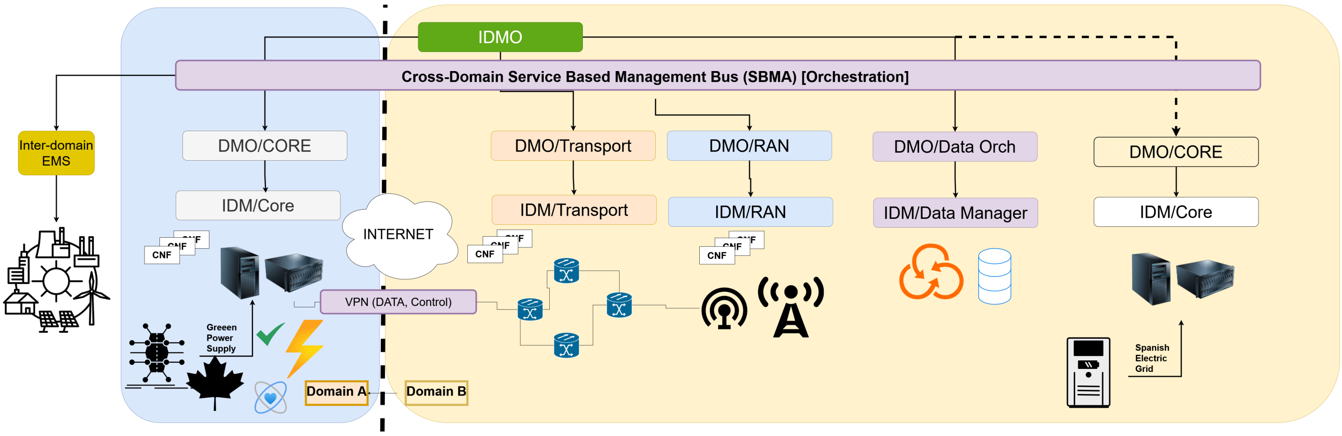

Fig. 3. Cross-domain orchestration architecture for energy-aware end-to-end 6G service deployment.

At the top level, the IDMO serves as the global orchestrator. It is responsible for decomposing high-level service requests into domain-specific components (e.g., RAN, Transport, Core) and dispatching them through the Cross-Domain SBMA, which provides a unified orchestration and policy interface.

B. Prototype Implementation Details

Each domain hosts its own DMO instance, deployed as a lightweight microservice suite that exposes RESTful APIs for intra-domain orchestration. The DMOs communicates with the IDMO through secure VPN tunnels and use a publish–subscribe interface for telemetry exchange and intent delivery. Within each domain, IDMs manages the underlying compute using container orchestration platforms such as *Kubernetes* or *OpenStack*. The IDMs are instrumented with agents for metrics collection and exposes energy and performance telemetry. Network functions (e.g., gNB-Distributed Unit (DU)/Centralized Unit (CU), User Plane Function (UPF), Access and Mobility management Function (AMF), or transport VNFs) are deployed as containerized workloads packaged with Helm charts. To incorporate energy awareness, each domain interfaces with a local *VPP* which aggregates information from its renewable sources and the local grid then these metrics are published to the local DMO and propagated by the inter-domain EMS to the IDMO via the SBMA, providing real-time telemetry on: (i) The current percentage of renewable energy in its mix, (ii) Carbon intensity (gCO$_2$/kWh), (iii) Available reserve power. In addition to these metrics, each domain can expose an index value that quantifies the locally available green energy using real-time SCADA-derived power flows together with the national (or inter-domain) renewable energy mix. This index provides a normalized, site-specific indicator of how favorable current conditions are for low-carbon computation, as it not only reflects the local renewable energy surplus but also ranks it against the other domains and the overall system-wide green index. A low index value signals heavy import of non-renewable energy into the domain, while a high value indicates a strong local surplus of renewable energy, enabling the orchestrator to prioritize workloads at domains with higher renewable availability.

C. System Workflow and Interaction

The proposed PoC architecture functions through a hierarchical interaction among the IDMO, the DMO entities, and their IDMs. A VPP and the Inter-domain EMS provides real-time energy metrics to enable sustainability-aware orchestration. The workflow, as shown in Fig. 4 (from components within Fig. 1), proceeds in six main stages:

1) *Service Request Reception:* The IDMO receives a high-level E2E service instantiation request specifying the required network functions, performance indicators (such as latency), and sustainability preferences.
2) *Service Decomposition and Domain Selection:* The IDMO decomposes the E2E service into functional components (RAN, Transport, Core, etc.). Based on resource advertisements received via the Cross-Domain SBMA, the IDMO selects appropriate domains using multi-criteria logic that balances performance and sustainability:
    a) *Service capability availability* - whether a domain advertises the capability to instantiate the required VNFs.
    b) *Resource availability* - based on compute, memory, and storage capacities.
    c) *Coverage and latency constraints* - ensuring placement meets radio and transport delay requirements.
    d) *Sustainability and Energy Mix* - using energy intelligence from the VPP to prioritize greener domains (e.g., Domain A) when other performance conditions are met.
3) *Domain-Level Orchestration:* The selected DMOs (e.g., in Domain A or B) receive service components from the IDMO and translate them into domain-specific deployments, instructing their local IDMs to instantiate the required CNFs or VNFs.
4) *Energy Intelligence from EMS:* The EMS aggregates energy data from distributed sources (VPPs) and provides this information to the IDMO. This enables the IDMO to make informed placement decisions, such as deploying

high-load compute functions in domains currently powered by renewable sources.

5) *Runtime Monitoring and Energy-Aware Optimization:* Once instantiated, the services run under continuous supervision by Monitoring, Analytics, Decision, and Actuation (MADA) tuples. When conditions change (e.g., low traffic, reduced renewable availability in Domain A), the Decision Engine triggers adaptation actions, such as:
   - Scaling down low-load RUs or CUs in the RAN domain.
   - Migrating VNFs to a domain with a greener energy mix.
   - Adjusting resource allocations to minimize carbon footprint while maintaining the SLA.
6) *Feedback and Closed-Loop Control:* Adaptation decisions are executed by the respective DMOs. Each DMO then notifies the IDMO of the status change, ensuring that the IDMO maintains an accurate global E2E view of resource and energy states.

Through this workflow, the IDMO can effectively orchestrate sustainable services across federated infrastructures. Figure 4 shows the proposed provisioning and placement messages for this E2E energy-aware placement.

D. Functional Validation Strategy

We propose a validation strategy focused on three main scenarios: (*i*) end-to-end service instantiation across distributed domains, (*ii*) dynamic adaptation to changing network and energy conditions, and (*iii*) evaluation of the outcomes of energy-aware decisions. For each test, the IDMO receives a high-level service intent (e.g., instantiate a 5G Core slice and RAN coverage). The IDMO decomposes this request and selects domains using multi-criteria logic. Orchestration is considered successful when both DMOs report domain readiness and inter-domain connectivity is established. During runtime, controlled experiments can simulate varying traffic and energy conditions. For example, traffic load variations can be generated using synthetic user emulators, while renewable energy levels in the VPP can be adjusted to represent day–night cycles. When the renewable share falls below a threshold, the IDMO is expected to automatically initiate VNF migrations to the alternative domain if it offers a greener profile. Similarly, under low-traffic conditions, Radio Units (RUs) are temporarily powered down to minimize energy consumption.

E. Performance Evaluation Metrics

To quantify the framework's effectiveness, the following key performance indicators (Key Performance Indicators (KPIs)) should be monitored throughout the experiments: *(i) Orchestration latency:* Time elapsed between intent submission and successful E2E service activation. *(ii) Resource utilization:* Average CPU, memory, and storage usage across PoPs before and after adaptation. *(iii) Energy efficiency:* Power consumption reduction achieved through EMS-driven optimization actions. *(vi) Carbon footprint:* Estimated emissions (gCO_2/kWh) associated with each service deployment. *(v) Service continuity:* Packet loss and latency variations during migration or scaling operations. These metrics could then be automatically collected via the Prometheus monitoring stack and visualized through Grafana dashboards, providing real-time insight into both technical and sustainability performance.

V. CONCLUSION AND FUTURE WORK

This paper has presented an energy-aware, multi-domain orchestration framework for sustainable 6G network operation. The architecture introduces a hierarchical management model comprising the IDMO, DMO, and IDM layers, augmented by integrated VPPs and an inter-domain EMS. This combination enables cross-domain coordination of network functions and dynamic alignment of service placement with renewable energy availability. Through a proof-of-concept implementation spanning two real infrastructures, the performance-aware and sustainability-aware domains, the framework aim to demonstrate that energy intelligence can be seamlessly embedded into orchestration workflows without compromising service performance or interoperability. By integrating energy management, orchestration intelligence, and multi-domain automation, the proposed framework advances the development of self-optimizing, environmentally responsible 6G networks. It represents a concrete step towards unifying communication and power infrastructures, enabling future digital ecosystems that are not only connected and intelligent but also sustainable by design.

Future research will extend this work in three complementary directions. First, the integration of *AI-native decision engines* will be explored to improve prediction accuracy and adaptability, enabling anticipatory orchestration that responds proactively to variations in traffic, energy supply, and service demand in a unified simulation environment. Second, *trust and accountability mechanisms* will be embedded through decentralised verification and provenance tracking, ensuring that energy and resource claims exchanged between domains remain transparent and verifiable. Finally, *interoperability and standardization* efforts will focus on aligning the proposed architecture with ongoing activities in ETSI ZSM, 3GPP, and O-RAN Alliance frameworks, paving the way for widespread deployment of sustainable, carbon-conscious 6G orchestration systems.

REFERENCES

[1] H. F. Alhashimi, M. N. Hindia, K. Dimyati, E. B. Hanafi, N. Safie, F. Qamar, K. Azrin, and Q. N. Nguyen, "A Survey on Resource Management for 6G Heterogeneous Networks: Current Research, Future Trends, and Challenges," *Electronics*, vol. 12, no. 3, 2023. [Online]. Available: https://www.mdpi.com/2079-9292/12/3/647.

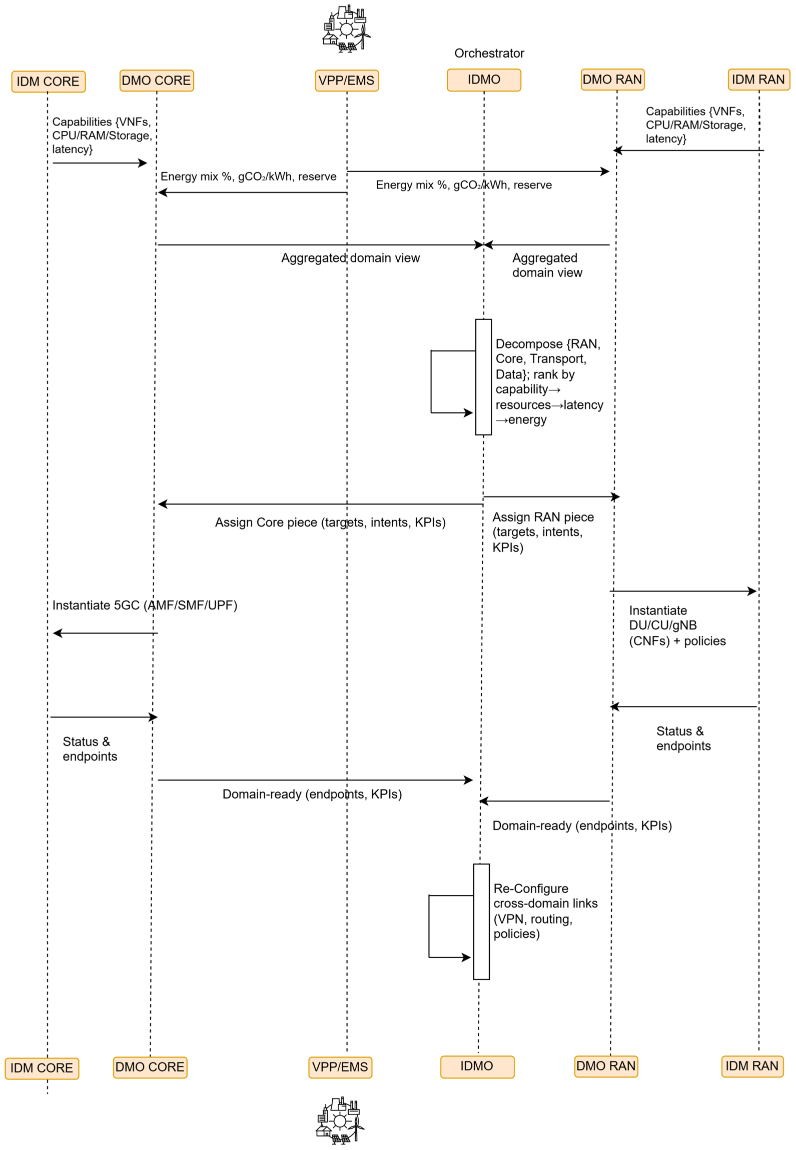

Fig. 4. Workflow and Provisioning/placement messages for energy-aware e2e 6G service deployment.

[2] F. Wang, S. Zhang, H. Yang, and T. Q. Quek, “Non-Terrestrial Networking for 6G: Evolution, Opportunities, and Future Directions,” *Engineering*, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2095809925002917.

[3] SNS JU 6G Architecture Working Group, “Towards 6G Architecture: Key Concepts, Challenges, and Building Blocks,” Smart Networks and Services Joint Undertaking (SNS JU), White Paper, 2024, 6G Architecture Working Group white paper on key concepts and enablers for 6G.

[4] K. Trichias, A. Kaloxylos, and C. Willcock, “6G Global Landscape: A Comparative Analysis of 6G Targets and Technological Trends,” in *2024 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, 2024, pp. 1–6.

[5] E. Zeydan, L. Blanco, S. Batewela, P. Ranaweera, and M. Liyanage, “Advances in Network Orchestration for Security, Scalability, and Sustainability,” in *2025 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, 2025, pp. 399–404.

[6] C. Benzaıd and T. Taleb, “AI-Driven Zero Touch Network and Service Management in 5G and Beyond: Challenges and Research Directions,” *IEEE Network*, vol. 34, no. 2, pp. 186–194, 2020.

[7] M. Polese, L. Bonati, S. D’Oro, S. Basagni, and T. Melodia, “Understanding O-RAN: Architecture, Interfaces, Algorithms, Security, and Research Challenges,” *IEEE Communications Surveys & Tutorials*, vol. 25, no. 2, pp. 1376–1411, 2023.

[8] Nokia Bell Labs, "The 3GPP-defined Service Based Management Architecture: A rich toolbox for 5G network and service automation solutions," Nokia Bell Labs, White Paper, 2020, Technical brief based on 3GPP Release 16.

[9] M. Floridia, D. Laganà, C. Mastroianni, M. Meo, and D. Renga, "Load Management with Predictions of Solar Energy Production for Cloud Data Centers," in *ICASSP 2020 - 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2020, pp. 8986–8990.

[10] J. Liang, S. Huang, Y. Qiu, L. Liu, F. Aziz, and M. Chen, "Sustainable Virtual Network Function Placement and Traffic Routing for Green Mobile Edge Networks," *IEEE Transactions on Green Communications and Networking*, vol. 8, no. 4, pp. 1450–1465, 2024.

[11] R. Lin, L. He, S. Luo, and M. Zukerman, "Energy-Aware Service Function Chaining Embedding in NFV Networks," *IEEE Transactions on Services Computing*, vol. 16, no. 2, pp. 1158–1171, 2023.

[12] M. A. Uusitalo, H. Farhadi, M. Boldi, M. Ericson, G. Fettweis, B. M. Khorsandi, I. L. Pavón, M. Mueck, A. Nimr, A. Pärssinen, B. Richerzhagen, P. Rugeland, D. Sabella, and H. Wymeersch, "Toward 6G — Hexa-X Project's Key Findings," *IEEE Communications Magazine*, vol. 63, no. 5, pp. 142–148, 2025.

[13] C. Christophorou, I. Ioannou, V. Vassiliou, L. Christofi, J. S. Vardakas, E. E. Seder, C. F. Chiasserini, M. Iordache, C. B. Issaid, I. Markopoulos, G. Franzese, T. Järvet, and C. Verikoukis, *ADROIT6G DAI-driven Open and Programmable Architecture for 6G Networks*, 2024. arXiv: `2403.05277 [cs.NI]`. [Online]. Available: https://arxiv.org/abs/2403.05277.

[14] L. Blanco, S. Via, C. J. Vaca-Rubio, E. Zeydan, L. M. C. Murillo, G. Kedar, G. R. Antonio, A. Antonopoulos, J. Haxhibeqiri, V. Maglogiannis, D. Naudts, J. Hoebeke, T. de Cola, L. G. Giordano, G. Fontanesi, S. Spantideas, H. Koumaras, M. Neri, A. Vesco, C. Amatetti, N. C. T. Quijada, M. Dryjański, N. Kanakaris, C. Pamminger, M. Pagin, and F. Ivanovic, "UNITY-6G: UNified archITecture for Open RANenabled Distributed, Scalable and SustainabilitYenhanced 6G Networks," in *2025 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, 2025, pp. 440–445.