

ITUJournal

FREE | FAST | FOR ALL

*Future and evolving
technologies*

Volume 7, Issue 2, June 2026



ISSN: 2616-8375



The ITU Journal on Future and Evolving Technologies (ITU J-FET) is an international journal providing complete coverage of all communications and networking paradigms, free of charge for both readers and authors.

The ITU Journal considers yet-to-be-published papers addressing fundamental and applied research. It shares new techniques and concepts, analyses and tutorials, as well as learning from experiments and physical and simulated testbeds. It also discusses the implications of the latest research results for policy and regulation, legal frameworks, the economy and society. This publication builds bridges between disciplines, connects theory with application, and stimulates international dialogue. Its interdisciplinary approach reflects ITU's comprehensive field of interest and explores the convergence of ICT with other disciplines.

The ITU Journal welcomes submissions at any time, and on any topic within its scope.

Publication rights

© International Telecommunication Union, 2026

Some rights reserved. This work is available under the CC BY-NC-ND 3.0 IGO license:

<https://creativecommons.org/licenses/by-nc-nd/3.0/igo/>.

SUGGESTED CITATION:

ITU Journal on Future and Evolving Technologies, Volume 7, Issue 2, June 2026

COMMERCIAL USE:

Requests for commercial use and licensing should be addressed to ITU Sales at: sales@itu.int.

THIRD PARTY MATERIALS: If the user wishes to reuse material from the published articles that is attributed to a third party, such as tables, figures or images, it is the user's responsibility to determine whether permission is needed for that reuse and to obtain permission from the copyright holder. The risk of claims resulting from infringement of any third-party-owned component in the work rests solely with the user.

GENERAL DISCLAIMERS: The designations employed and the presentation of the material in the published articles do not imply the expression of any opinion whatsoever on the part of ITU concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by ITU in preference to others of a similar nature that are not mentioned.

ADDITIONAL INFORMATION

Please visit the ITU J-FET website at:

<https://www.itu.int/en/journal/j-fet/Pages/default.aspx>.

Inquiries should be addressed to Alessia Magliarditi at: journal@itu.int.

Special issue on “Network orchestration and management for 6G and beyond”

Editorial

The path towards 6G is shaped as much by new radio capabilities as by operational complexity. Terrestrial and non-terrestrial domains are converging, and the compute continuum now stretches from devices through the edge to the cloud and even to satellites in orbit. Meanwhile, emerging services impose strict targets on throughput, latency, reliability and energy consumption. At this scale and heterogeneity, traditional, largely manual management paradigms no longer suffice. The community is therefore moving towards fully-automated, AI-native and zero-touch agentic operations, in which networks understand high-level intents, reason about their own state and acting upon it autonomously.

The special issue on “Network orchestration and management for 6G and beyond” brings together nine papers that capture this transition. They span the sustainability requirements that 6G must meet, intent-driven and agentic orchestration, closed-loop automation in the radio access, transport and core networks, the integration of satellite and terrestrial domains, the evolution of digital twins into cognitive twins, privacy-preserving security for network slices, and energy-aware reconfiguration of optical transport networks. Together they reflect the four tracks of the call for papers: AI-native automation and zero-touch management; resource orchestration and network slicing; security, resilience and trust; and the management of novel networking paradigms and architectures.

Scanning the issue

This special issue highlights research contributions across six key themes:

I. Setting the scene: sustainability requirements for 6G

Any discussion of how 6G networks should be orchestrated and managed must start with what 6G is expected to deliver, and at what environmental, social and economic cost. The opening paper of this issue provides this context through the findings of Europe’s 6G flagship Hexa-X-II project.

- **Towards environmentally, socially and economically sustainable 6G – Key findings from the European Flagship Hexa-X-II**

Authors: Mikko Uusitalo, Patrik Rugeland, Mauro Renato Boldi, Mårten Ericson, Jeroen Famaey, Sylvaine Kerboeuf, Diego Lopez, Ignacio Labrador Pavón, Nurul Huda Mahmood, Ahmad Nimr, Stefan Wendt

The European 6G Flagship Hexa-X-II project ran from January 2023 to June 2025 and created momentum around 6G through 44 member organizations covering the entire value chain. This paper summarizes the project’s key findings: the requirements for a sustainable, inclusive and trustworthy 6G, the end-to-end system view and architecture with their validation, enhanced connectivity, network sensing, and compute and AI for novel digital services, as well as efficient network realization and management. While the contributions that follow focus primarily on automation, performance and efficiency, this opening paper is a reminder of the wider goals these capabilities ultimately serve: a 6G that is also environmentally, socially and economically sustainable.

II. Intent-driven and agentic orchestration

Intents, high-level objectives that the network must translate into concrete actions, are emerging as the primary interface between users and autonomous networks. Two papers in this issue examine how agentic AI (autonomous AI agents that perceive, plan, and act) can close the gap between such objectives and executable network operations.

- **Agentic, intent-driven end-to-end service orchestration with test-driven quality assurance for 6G networks**

Authors: Christos Tranoris, Kostis Trantzas

This paper couples deterministic end-to-end service orchestration with proactive, test-driven quality assurance. In an intent co-creation process, specialized agents iteratively refine incomplete user intents into a user-confirmed intent contract, which is then translated into machine-executable actions aligned with TM Forum product and service models. A strict separation between cognition and actuation is enforced: Agents reason and plan, while execution is left to a deterministic service orchestrator. Inspired by test-driven development; quality assurance is built in from the start, with Service Level Objective/Agreement (SLO/A) validation tests being derived before provisioning and progressively satisfied as orchestration proceeds. The framework's feasibility is demonstrated through a connectivity service use case.

- **Towards zero-touch autonomy: A vision and agentic GenAI architecture for intent-based self-configuration**

Authors: Yosra Njah, Wael Jaafar, Rami Langar, Bassant Selim, Mohamed Cheriet

This work positions Intent-Based Networking (IBN) as the core of self-configuration, upon which higher-order self-X capabilities such as self-optimization, self-healing and self-protection are built. It identifies persistent challenges across the intent lifecycle, namely intent-policy translation, conflict-free activation and closed-loop assurance in multi-domain, multi-stakeholder environments, and argues that current IBN implementations lack the cognitive reasoning required for the 6G era. The authors then derive an agentic GenAI-driven IBN reference architecture in which specialized LLM agents orchestrate intent fulfilment through retrieval-augmented generation with sufficiency checking and knowledge graphs, demonstrated in a 6G O-RAN pipeline through an Industry 5.0 use case.

III. Closing the loop: AI-native automation in the RAN and the core

Zero-touch operation ultimately depends on closed loops that connect data collection, analytics and automated control. Two papers in this issue build such loops at different points of the network: in the Open RAN intelligent controller and in the mobile network core.

- **ML-driven network orchestrator for 6G O-RAN: Resolving multi-xApp conflicts in near-RT RIC**

Authors: Can Kurtulan, Onur Kalinagac, Erdinc Ozdemir, Burak Gorkemli, Gokhan Karakus, Semih Aktas, Mehmet Basaran

In the O-RAN architecture, the near real-time RAN intelligent controller hosts third-party xApps for radio resource management, and xApps from different vendors can issue overlapping control commands and compete for resources, possibly degrading network performance. This paper proposes an ML-driven network orchestrator for conflict detection and resolution in multi-xApp 6G O-RAN environments, autonomously identifying steering conflicts and executing resolution strategies in real time. Experimental results show that the orchestrator mitigates the degradation caused by xApp collisions and maintains high-fidelity service delivery even under dense traffic, contributing a scalable and resilient orchestration logic for autonomous RAN operations.

- **Towards zero-touch network orchestration: An NWDAF-centered standards-compliant closed-loop approach**

Authors: Fatemeh Shafiei Ardestani, Noura Limam, Raouf Boutaba

Moving to the core network, this paper presents a standards-compliant framework that elevates the 3GPP Network Data Analytics Function (NWDAF) from an analytics service to an active component in runtime orchestration. It integrates real-time user-plane observability through a novel UPF event exposure service implementation, modular analytics engines with ML lifecycle management, and automated policy enforcement through control-plane functions, forming a complete data analytics action pipeline. Implemented on an open-source 5G core and evaluated under realistic workloads, the framework collects fine-grained telemetry with minimal overhead, and two use cases, anomaly detection with automated mitigation and congestion-aware QoS adaptation, demonstrate that standards-aligned NWDAF can serve as a practical foundation for zero-touch automation.

IV. Orchestrating heterogeneous domains: AI-driven satellite-terrestrial integration

The integration of terrestrial and non-terrestrial networks is a cornerstone of the 6G vision, yet orchestrating AI workloads across these heterogeneous domains remains an open challenge. One paper in this issue addresses this challenge end to end, from architecture to testbeds and standardization.

- **AI-driven orchestration for integrated satellite-terrestrial 6G networks: Architecture, handover management, and testbed evaluation**

Authors: Murat Parlakisik, Ertan Ozturk, Nazlı Güney

Drawing on a systematic analysis of the 3GPP ubiquitous connectivity and AI-NTN convergence use cases, this paper extends four components of the authors' AI-native design with NTN-specific capabilities: an NTN-enhanced NWDAF ingesting satellite telemetry and ephemeris data, a space-edge computing tier enabling onboard satellite AI inference, a cross-domain AI agent for intent-driven orchestration across terrestrial and satellite operator boundaries, and a knowledge exposure feature publishing constellation topology and coverage predictions. A handover management framework addressing four transition types with backhaul-aware path selection, a comparative evaluation of eight NTN testbeds, and a mapping to 3GPP releases 19–21 with five identified specification gaps complete the contribution.

V. From digital twins to cognitive twins

Managing 6G systems will also require new representational paradigms. One paper in this issue argues that digital twins, as we know them, are not enough.

- **Beyond digital twins: The rise of cognitive twins in 6G and beyond wireless systems**

Authors: Ian F. Akyildiz, Tuğçe Bilen

Digital twins are a key enabler for monitoring, simulation and optimization, yet they remain limited to state replication and prediction. This paper introduces the cognitive twin, a new system paradigm that extends state synchronization with structured cognitive capabilities, including perception, memory, causal reasoning and interaction, supporting a transition from data-driven monitoring to understanding-driven operation. A four-layer reference architecture distributes cognitive processes across device, edge and cloud domains, and a central insight is that communication changes roles: wireless systems must synchronize cognitive state under heterogeneous latency, bandwidth and reliability constraints. The paper shows how 6G capabilities such as integrated sensing and communication, semantic communication and the edge-cloud continuum provide the necessary substrate, and it presents a roadmap toward practical realization.

VI. Secure and energy-efficient network infrastructure

Security, resilience and sustainability are paramount for the deployment and societal acceptance of 6G. The final two papers of this issue address, respectively, privacy-preserving attack detection across network slices and the energy footprint of the optical transport networks that will carry 6G traffic.

- **FLAccShield: Federated learning with accuracy-weighted aggregation for DDoS detection**

Authors: Md Mahibul Hasan, Aymen Ben Said, Karamveer Singh Sidhu, Nashid Shahriar, Sajal Saha

Network slices expand the attack surface and are increasingly exposed to Distributed Denial-of-Service (DDoS) attacks, while their strict privacy requirements rule out conventional centralized ML-based intrusion detection. FLAccShield is a federated learning-based, privacy-preserving intrusion detection framework for DDoS detection in 5G/6G networks, built on collaboration between multiple slices with accuracy-weighted aggregation. Rigorously evaluated in supervised and unsupervised settings under diverse data distributions, it achieves consistently higher detection performance than state-of-the-art federated learning methods, demonstrating robustness, efficiency and privacy preservation in complex next generation mobile network environments.

- **Traffic-aware network reconfiguration for energy-efficient IPoWDM networks with ZR/ZR+ pluggable optics**

Authors: Qiaolun Zhang, Nisanur Camuzcu, Xiaoyang Guo, Jiaheng Xiong, Ruikun Wang, Tianqu Luo, Mëmëdhe Ibrahim, Massimo Tornatore

With AI workloads, cloud services and data centre interconnect driving optical traffic growth, this paper studies traffic-aware reconfiguration strategies at the IP and optical layers for optical transport networks in which compact, energy-efficient pluggable transceivers (ZR/ZR+) replace traditional dedicated long-haul transmission equipment. Using realistic topologies and traffic traces, they show that while ZR/ZR+ pluggables consume less power at peak load than traditional equipment, they benefit far less from dynamic reconfiguration, a key insight for energy-aware 6G backhaul design.

Looking ahead

Read together, these nine papers trace a consistent trajectory: network orchestration and management are evolving from reactive, human-driven processes into intent-driven, cognitive and increasingly autonomous operations, with sustainability and trust as first-class requirements rather than afterthoughts. They also show how closely this evolution is tied to ongoing standardization, with contributions building on and extending work in 3GPP, ETSI, TM Forum and O-RAN. Open questions remain, notably conflict management among autonomous decision makers and the energy footprint of intelligence itself, and we expect these to shape the research agenda well beyond this issue. What is notably missing today are operational-scale validations of agentic systems and standardized benchmarks for evaluating AI-native orchestration.

We thank all authors for their contributions, and we are grateful to the reviewers, whose careful and timely feedback was essential to the quality of this special issue. We also thank the Editor-in-Chief and the ITU Journal team for their support throughout the process. We hope readers find in this issue both a snapshot of the state of the art and an invitation to help define the future of autonomous network operations.

The Guest Editors

[Burak Gorkemli](#), OdineLabs, Turkey (Leading Guest Editor)

[Raouf Boutaba](#), University of Waterloo, Canada

[Ahan Kak](#), Nokia Bell Labs, USA

[Rolf Stadler](#), KTH Royal Institute of Technology, Sweden

EDITORIAL BOARD

Editor-in-Chief

Ian F. Akyildiz, *Truva Inc., USA*

Special issue on “Network orchestration and management for 6G and beyond”

Leading Guest Editor

Burak Gorkemli, *OdineLabs, Turkey*

Guest Editors

Raouf Boutaba, *University of Waterloo, Canada*

Ahan Kak, *Nokia Bell Labs, USA*

Rolf Stadler, *KTH Royal Institute of Technology, Sweden*

Reviewers

Ian F. Akyildiz, *Truva Inc., USA*

Tuğçe Bilen, *Istanbul Technical University, Turkey*

Raouf Boutaba, *University of Waterloo, Canada*

Orhan Dagdeviren, *Ege Universitesi Muhendislik, Turkey*

Burak Gorkemli, *OdineLabs, Turkey*

Nazlı Güney, *TC İstanbul Rumeli Üniversitesi, Turkey*

Kim Hammar, *University of Melbourne, Australia*

Wael Jaafer, *Ecole de Technologies Supérieures, Canada*

Ahan Kak, *Nokia Bell Labs, USA*

Cem Kaya, *Odine Solutions, Turkey*

Jakob Nyberg, *KTH Royal Institute of Technology, Sweden*

Ertan Ozturk, *University of North Dakota, USA*

Nashid Shahriar, *University of Regina, Canada*

Rolf Stadler, *KTH Royal Institute of Technology, Sweden*

Yang Xiao, *University of Waterloo, Canada*

Regular papers

Editors

Albert Lysko, *Council for Industrial and Scientific Research, South Africa*

Athanasios D. Panagopoulos, *National Technical University of Athens, Greece*

Reviewers

Philippa Biggs, *International Telecommunication Union, Switzerland*

Youlia Lozanova, *International Telecommunication Union, Switzerland*

Ardhendu Sekhar Patra, *Sidho-Kanho-Birsha University, India*

The full list of the ITU J-FET Editors is available at <https://www.itu.int/en/journal/j-fet/Pages/editorial-board.aspx>.

ITU Journal Team

Alessia Magliarditi, *ITU Journal Manager*

Erica Campilongo, *Publishing Editor*

Maria Eugenia Otero, *ITU Journal Assistant*

TABLE OF CONTENTS

	Page
Regular paper	
Evaluation of OFDM and OTFS under high-Doppler 6G midband channels <i>Sabbir Ahmed, Hirley Alves, Ari Pouttu</i>	85
Papers of the special issue on “Network orchestration and management for 6G and beyond”	
Towards environmentally, socially and economically sustainable 6G – Key findings from the European Flagship Hexa-X-II <i>Mikko A. Uusitalo, Patrik Rugeland, Mauro R. Boldi, Mårten Ericson, Jeroen Famaey, Sylvaine Kerboeuf, Diego Lopez, Ignacio Labrador Pavón, Nurul Huda Mahmood, Ahmad Nimr, Stefan Wendt</i>	100
Agentic, intent-driven end-to-end service orchestration with test-driven quality assurance for 6G networks <i>Christos Tranoris, Kostis Trantzas</i>	114
Towards zero-touch autonomy: A vision and agentic GenAI architecture for intent-based self-configuration <i>Yosra Njah, Wael Jaafar, Rami Langar, Bassant Selim, Mohamed Cheriet</i>	133
ML-driven network orchestrator for 6G O-RAN: Resolving multi-xApp conflicts in near-RT RIC <i>Can Kurtulan, Onur Kalinagac, Erdinc Ozdemir, Burak Gorkemli, Gokhan Karakus, Semih Aktas, Mehmet Basaran</i>	145
Towards zero-touch network orchestration: An NWDAF-centered standards-compliant closed-loop approach <i>Fatemeh Shafiei Ardestani, Noura Limam, Raouf Boutaba</i>	160
AI-driven orchestration for integrated satellite-terrestrial 6G networks: Architecture, handover management, and testbed evaluation <i>Murat Parlakisik, Ertan Ozturk, Nazlı Guney</i>	188
Beyond digital twins: The rise of cognitive twins in 6G and beyond wireless systems <i>Ian F. Akyildiz, Tuğçe Bilen</i>	213
FLAccShield: Federated learning with accuracy-weighted aggregation for DDoS detection <i>Md Mahibul Hasan, Aymen Ben Said, Karamveer Singh Sidhu, Nashid Shahriar, Sajal Saha</i> .	233
Traffic-aware network reconfiguration for energy-efficient IPoWDM networks with ZR/ZR+ pluggable optics <i>Qiaolun Zhang, Nisanur Camuzcu, Xiaoyang Guo, Jiaheng Xiong, Ruikun Wang, Tianqu Luo, Mëmëdhe Ibrahimi, Massimo Tornatore</i>	256
Regular paper	
UGC metaverse and network effects: Complementary interaction in the avatar market – A case study from VRChat <i>Yuto Kunitake</i>	272