Guest Editorial Special Issue on Green Open Radio Access Networks: Architecture, Challenges, Opportunities, and Use Cases

NEXT-GENERATION cellular networks will need to support RAN deployments at an unprecedented scale for supporting heterogeneous and complex use cases. Managing and optimizing these new network systems require solutions that by opening the Radio Access Network (RAN) expose data and analytics and enable advanced, data- driven optimization, closed-loop control and automation. To this aim, the Open RAN paradigm has recently emerged as an enabler of (i) openness in the RAN, with standardized interfaces that allow integration of RAN controllers and multi-vendor equipment; (ii) RAN virtualization, with RAN functionalities implemented in software and running on white box hardware; and (iii) RAN's ability to program intelligence control through closed-loop systems. Therefore, the Open RAN allows an ecosystem where multi-vendor capabilities can be practically deployed, along with interoperable software features, and autonomous services. To fully realize the ecosystem, it is important to understand the underpinnings of multi-vendor functionality, open interfaces, and the workflows enabled by Open RAN. The scope of this Special Issue is to highlight key research problems along with solid technical solutions for the development and testing of networks based on the Open RAN vision, for the adoption of open APIs, interfaces, integration of AI and ML workflows, coexistence with proprietary virtual RAN (vRAN) alternatives, developing performance measurement metrics, and dealing with vertical and horizontal flexibility in the context of Open RAN deployments. Furthermore, the Special Issue will also focus on the Open RAN standards and architecture for the evolution of 5G to 6G, and Open RAN-based intelligent techniques for service orchestration, resource allocation and management, and use-cases.

Zeydan et al. [A1] explore the integration of Blockchain Network (BCN)-based Self-Sovereign Identity (SSI) into Open Radio Access Networks (O-RAN) to improve security and identity management in the post-quantum era. Some aspects such as replacing classic cryptographic algorithms with quantum-resistant alternatives and optimizing mathematical operations with the Toom-Cook multiplication method are discussed in detail. The role of BCN-SSI with Post-Quantum Cryptography (PQC) is emphasized to ensure robust authentication and data integrity and to address potential quantum threats for resource sharing scenarios within the O-RAN ecosystem.

The study by Qiao et al. [A2] proposes a method that introduces a Neural Aggregation Bandwidth Optimization (NABO) scheduler for O-RAN, combining bandwidth prediction with scheduling policy optimization. This improves the bandwidth aggregation approximately 51% and 30% over existing benchmarks, respectively.

The study by Simiscuka et al. [A3] presents a 360-ADAPT, which is a DASH-based adaptation solution on an Open-RAN architecture for 360° opera and increased quality remote experiences. Results indicate that 360-ADAPT achieves higher perceived quality levels than alternative solutions both in QoS and QoE metrics.

The research by Khan et al. [A4] proposes a security solution specifically designed to protect L-band Digital Aeronautical Communications System (LDACS) handovers. Their solution uses a mutual authentication and key agreement mechanism tailored for LDACS, ensuring robust security for all types of handovers. Author's approach utilizes post-quantum cryptography to protect aviation communication systems against potential post-quantum threats, such as unauthorized access to flight data, interception of communication, and spoofing of aircraft identity.

The study by Zhang et al. [A5] proposes a diFferential pRivacyaware gEnErative aDversarial netwOrk-assisted resource scheduling algorithM (FREEDOM). FREEDOM leverages a deep Q-learning network (DQN) to learn the resource scheduling strategy via differential privacy awareness, and improves optimization and convergence performances with the assistance of generative adversarial network (GAN).

The study by Zhu et al. [A6] proposes a STAR-RIS-assisted secure simultaneous wireless information and power transfer (SWIPT) system is investigated. Results have proved the effectiveness of the deployment of STAR-RIS and robustness of the proposed algorithm, meanwhile, STAR-RIS can be a promising candidate to complement the construction of O-RAN.

The study by Wadud et al. [A7] discusses an overview of various types of conflicts that may occur in Open RAN, with a particular focus on intra-component conflict mitigation among

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Extended Applications (xApps) in the Near Real Time RAN Intelligent Controller (Near-RT-RIC).

The study by Ndikumana et al. [A8] proposes renewable energy powered Open RAN-based architecture for 5G fixed wireless access (FWA) serving low-density and rural areas (LDRAs) using three-level closed-loops. Open RAN is a new 5G RAN architecture allowing Open Central Unit and Open Distributed Unit to be distributed in virtualized environment. Author also proposed reinforcement learning and successive convex approximation to solve the formulated problems.

The study by He et al. [A9] proposes a four-layer Mobile Edge Computing (MEC) architecture that connects user devices to the core network using RAN. Authors also proposed a MEC server location algorithm to optimize communication distance, and a Q-learning algorithm for selection and resource allocation. Experimental results demonstrate significant energy savings compared to baseline algorithms.

The study by Taneja et al. [A10] proposes an efficient approach for improving the efficiency of RAN by proposing an active-IRS aided framework. The multiple active IRSs assist the user communication by amplifying the incident signals before transmission.

The proposed work by Khan et al. [A11] presents a machine learning-based intelligent system whose primary goal is load balancing using Artificial Neural Networks (ANN) with Particle Swam Optimization-enabled meta heuristic optimization mechanisms for telecommunication industry requests, like product compatibility.

Li et al. [A12] analyze the meta heuristic optimized deep random neural networks (MH-DRNN) based anomaly detection process. The study uses the UNSW-NB15 dataset information to evaluate the system's efficiency.

Tao et al. [A13] propose a novel digital twin function virtualization (DTFV) architecture based on Open Radio Access Networks (ORAN) is proposed. Experimental results shows that the scheme achieves 8.48% higher service response profit and 6.8% lower VDT synchronization delay over the best baseline scheme.

Akram et al. [A14] propose seamless integration of digital twin technology with blockchain to establish a robust trust management system in the IoDT context. This approach addresses the critical vulnerabilities associated with unsecured wireless networks in IoDT, such as data integrity issues and susceptibility to cyber threats.

The research work presented by Zho et al. [A15] proposes an in-network architecture for privacy-preserving methods by leveraging programmable switches to improve resource efficiency (i.e., CPU cycles, network bandwidth, and privacy budgets). The key idea of NetDP is to accommodate and exploit cryptographic operators to reduce resource consumption rather than repetitively and exhaustively suppressing the impact of these methods.

The research work presented by Salameh et al. [A16] presents a secure and jamming-resistant green channel assignment algorithm designed for indoor uplink communication in MIMO- and CR-enabled O-RAN-supported UAV networks.

Hazarika et al. [A17] explore the examination of a three-tier hierarchical O-RAN slicing model, created to address the unique challenges of vehicular networks. The top-level follow 3GPP standards like ultra-reliable and low-latency communications (URLLC), enhanced mobile broadband (eMBB), and massive machine-type communications (mMTC).

Jaiswal et al. [A18] explore the use of UAVs for charging IoT nodes in critical situations.Methodology optimizes charging via RFET zones, K-means clustering, and modified ACO to cluster nodes by proximity and energy demands. Experiments show enhanced charging performance, energy efficiency, and deadline compliance. Li et al. [A19] explore the O-RAN-enabled UAV-assisted network design improves wireless coverage by integrating UAVs with terrestrial networks. Improve network energy efficiency by combining radio unit (RU) association, aerial radio unit (ARU) deployment, and resource allocation. Proposal efficacy is verified using comprehensive simulation results.

Wu et al. [A20] present the HSADR scheme based on ORAN with cryptographic operations, which maintains the security and privacy of data generated by all participants. This FL security scheme employs cloud–edge–client architecture, which is accepted for the ORAN.

APPENDIX: RELATED ARTICLES

[A1] E. Zeydan, L. Blanco, J. Mangues-Bafalluy, S. S. Arslan, and Y. Turk, "Post-quantum blockchain-based decentralized identity management for resource sharing in open radio access networks," *IEEE Trans. Green Commun. Netw.*, vol. 8, no. 3, pp. 895–909, Sep. 2024, doi: 10.1109/TGCN.2024.3432689.

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[A9] Q. He et al., "Joint data offloading and energy-efficient secure MEC resource allocation method for IoT device data in RAN communication," *IEEE Trans. Green Commun. Netw.*, vol. 8, no. 3, pp. 1008–1017, Sep. 2024, doi: 10.1109/TGCN.2024.3379960.

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