

SELF-ORGANIZING NETWORKS: OPPORTUNITIES, CHALLENGES, AND APPLICATIONS

The network management automation problem in 5G systems has been gaining attention from standardization organizations and researchers. The current age of agile and dynamic cloud-based environments demands autonomous systems for managing network resources. Operators aim to optimize the network resources to achieve minimalism with efficiency. Autonomously in networks is the next leap of evolution that is capable of going beyond automation capabilities. With autonomy, it is not just making the network capable of managing resources but rather making the network learn and adapt itself with respect to the dynamic environment. Autonomous tasks in networks refer to self-healing, self-diagnosing, and self-provisioning. With the help of emerging technologies such as artificial intelligence (AI), Internet of Things (IoT), and Blockchain, autonomous tasks can be realized in current network systems.

To offer seamless automated end-to-end services, existing networks are made up of diverse heterogeneous devices that need to be integrated. Until very recently, the planning, implementation, and management of this mix of services has been a largely manual activity with some automated assistance. In short, no matter the degree of refinement, it is recognized that these services can no longer be managed using such approaches. The fresh demands need a transformation supported by integrating new technologies, such as virtualization, 6G, Blockchain, AI/ML/DL, etc., to attain a new level of automation and intelligence to manage the networks efficiently.

The study by Sohaib et al. [A1] analyzes Deep Reinforcement Learning (DRL) strategies for Radio Resource Management in ORAN to meet URLLC demands, focusing on the trade-offs between reliability, latency, and adaptability. The proposed TD3 with Thompson Sampling achieves over 99% reliability in 80% cases, outperforming baseline DRL methods.

The paper reviews key advancements in Range-Free Localization for self-organizing networks, focusing on distance estimation methods and location algorithms like DV-Hop and metaheuristics proposed by Xie et al. [A2]. It highlights simplified, hardware-independent localization and outlines current challenges and future research directions.

The manuscript by Singh et al. [A3] proposes a dynamic multi-objective resource allocation model to address QoS challenges in self-organizing networks within the Society of Things (SoT). The model improves delay, throughput, and energy efficiency, offering a scalable and reliable solution for dynamic, decentralized IoT environments.



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The paper by Ullah et al. [A4] presents a QoS-aware framework combining NOMA, DRL, RIS, and RF energy harvesting to enhance throughput and energy efficiency in Ambient IoT (A-IoT) networks. Simulations show significant performance gains, offering a path toward scalable, near-zero energy IoT systems.

The article proposes a dynamic task partitioning strategy in fog networks using self-organizing capabilities to optimize resource use and reduce overload. The approach presented by Saxena and Kumar [A5] achieves significant reductions in queue delay and length, enhancing performance for latency-sensitive IoT applications.

The article by Nguyen et al. [A6] explores the potential of Quantum Machine Learning (QML) for intelligent network functions while highlighting emerging security threats like quantum kernel poisoning and adversarial qubit attacks. It also discusses defense strategies and future research directions to secure QML-assisted applications.

The research by Naseer et al. [A7] presents a Deep Q-Learning (DQN)-based adaptive defense mechanism to counter DNS spoofing in self-organizing IoT networks. The model achieves 97.5% accuracy by continuously learning and detecting evolving threats, ensuring robust network security.

This study introduces by Jain et al. [A8] where a CHHO-CNN+LSTM hybrid model for intelligent network slicing in 6G, combining spatial-temporal learning with optimized hyperparameter tuning. Achieving 95.48% accuracy, it outperforms conventional methods in slice classification and enables adaptive, high-performance 6G networking.

The paper by Jiang et al. [A9] presents the first vision study on integrating quantum communication with self-organizing satellite networks to enhance security, reliability, and synchronization. It analyzes current advancements, challenges, and future opportunities for enabling trustworthy next-generation IoT connectivity.

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APPENDIX RELATED ARTICLES

- [A1] R. M. Sohaib et al., "Optimizing URLLC in open RAN: A deep reinforcement learning-based trade-off analysis," *IEEE Commun. Standards Mag.*, vol. 9, no. 3, pp. 33–39, Sep. 2025.
- [A2] W. Xie et al., "Advances and future directions in range-free localization techniques for self-organizing networks," *IEEE Commun. Standards Mag.*, vol. 9, no. 3, pp. 26–32, Sep. 2025.
- [A3] S. P. Singh et al., "A multi-objective QoS-driven dynamic resource allocation framework for self-organizing networks in society of things (SoT)," *IEEE Commun. Standards Mag.*, vol. 9, no. 3, pp. 7–14, Sep. 2025.
- [A4] S. A. Ullah et al., "DRL-enhanced QoS-aware NOMA for ambient IoT: Resource allocation optimization with RIS and RF energy harvesting diversity," *IEEE Commun. Standards Mag.*, vol. 9, no. 3, pp. 49–56, Sep. 2025.
- [A5] M. K. Saxena and S. Kumar, "Fog-enabled self-organizing networks for efficient task partitioning and resource allocation," *IEEE Commun. Standards Mag.*, vol. 9, no. 3, pp. 57–63, Sep. 2025.
- [A6] V.-L. Nguyen et al., "Quantum machine learning for 6G network intelligence and adversarial threats," *IEEE Commun. Standards Mag.*, vol. 9, no. 3, pp. 40–48, Sep. 2025.
- [A7] M. Naseer et al., "Adaptive IoT defense with deep Q-learning model for DNS spoofing prevention in self-organizing networks," *IEEE Commun. Standards Mag.*, vol. 9, no. 3, pp. 64–69, Sep. 2025.
- [A8] M. Jain et al., "Enhancing network slicing efficiency in 6G networks with a hybrid deep learning approach leveraging crisscross Harris hawks optimization," *IEEE Commun. Standards Mag.*, vol. 9, no. 3, pp. 70–77, Sep. 2025.
- [A9] W. Jiang et al., "Quantum communication in self-organizing satellite networks: Challenges and opportunities," *IEEE Commun. Standards Mag.*, vol. 9, no. 3, pp. 15–25, Sep. 2025.

BIOGRAPHIES

KAPAL DEV (Senior Member, IEEE) (kapal.dev@ieee.org) received the Ph.D. degree from the Politecnico di Milano, Italy, in 2019, under the prestigious fellowship of Erasmus Mundus funded by the European Commission. He is currently an Assistant Professor with the Department of Computer Science, Munster Technological University (MTU), Ireland. He has led workshops at top-tier conferences, such as ACM MobiCom, IEEE Globecom, and IEEE Blockchain, and his research on data and model security and privacy, agentic AI, and Industry 5.0 has produced over 100 publications in leading scientific venues. In addition, he has supervised more than 25 master's students. He is as an External Evaluator for high-profile funding bodies. He is among the top 45 scientists elected to the Global Young Academy (GYA) 2024 and has secured over €2.5 million in competitive funding as a Principal Investigator. He is a Professional Member of ACM, underlining his commitment to the global research community. He was recognized with numerous awards, including the IEEE ComSoc EMEA Outstanding Young Researcher in 2022 and the Tom Brazil Excellence in Research Award in 2023. He holds editorial roles as an associate editor as well as a guest editor in major IEEE, Elsevier Q1 journals and magazines, *Nature*, and other renowned publishers.

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