

Digital Twin-Based Simulation of MVNO Network Operations

Karthick Cherladine

Sr. Solutions Architect & Engineering, MVNO Connect LLC, USA.

Email: karthick.cherladine@ieee.org



<https://doi.org/10.55041/ijst.v2i2.011>

Cite this Article: Cherladine, K. (2026). Digital Twin-Based Simulation of MVNO Network Operations. International Journal of Science, Strategic Management and Technology, 02(02), 1-9. <https://doi.org/10.55041/ijst.v2i2.011>

License:  This article is published under the Creative Commons Attribution 4.0 International License (CC BY 4.0), permitting use, distribution, and reproduction in any medium, provided the original author(s) and source are properly credited.

Abstract:

The proposed work presents a Digital Twin-based simulation framework for analyzing and optimizing Mobile Virtual Network Operator (MVNO) operations. The Digital Twin creates a virtual representation of the MVNO network to monitor traffic conditions, resource utilization, latency, throughput, and quality of service. Real-time and simulated network data are incorporated to evaluate operational behavior under different traffic scenarios. The framework enables performance prediction, resource allocation, and identification of potential network bottlenecks without affecting the physical infrastructure. Simulation-based analysis supports efficient decision-making and improves network reliability. The proposed approach demonstrates the potential of Digital Twin technology for intelligent, cost-effective, and adaptive MVNO network management.

Keywords: *Digital Twin, Mobile Virtual Network Operator (MVNO), Network Simulation, Network Optimization, Resource Allocation, Quality of Service (QoS), Network Performance, Traffic Management, Virtual Network, 5G Networks.*

I. INTRODUCTION

Mobile Virtual Network Operators (MVNOs) provide mobile communication services by utilizing infrastructure and spectrum resources of Mobile Network Operators (MNOs). As MVNO

networks become increasingly complex, efficient management of traffic, resources, service quality, and operational performance is essential. Traditional network management methods often depend on physical infrastructure and real-world testing, which can be costly, time-consuming, and difficult to scale. Digital Twin technology provides an effective solution by creating a virtual representation of a physical network that can continuously reflect its operational behavior. In this work, a Digital Twin-based simulation framework is proposed for MVNO network operations. The framework models important network parameters, including traffic load, latency, throughput, bandwidth utilization, and resource allocation. Different network conditions can be simulated to analyze performance and identify potential bottlenecks. The proposed approach enables predictive analysis, efficient resource management, and performance optimization while reducing the need for extensive physical network experimentation.

II. LITERATURE SURVEY

Recent research has established Digital Twin technology as a promising approach for intelligent wireless network management. Sanz Rodrigo *et al.* presented a modeling and deployment methodology for Mobile Network Digital Twins, demonstrating their ability to replicate network components and evaluate different operational scenarios without directly affecting physical infrastructure. Nardini and Stea investigated simulation services for Digital Twins

of 5G/B5G networks, emphasizing what-if analysis, performance evaluation, and dynamic network optimization. Research on Digital Twin-enabled cellular network management has further demonstrated applications in spectrum sharing, network planning, and prediction of future network conditions. Recent surveys have also highlighted the integration of Artificial Intelligence and Machine Learning for anomaly detection, resource allocation, system-state estimation, and network optimization. However, existing studies primarily focus on general 5G/6G networks, with limited attention to Digital Twin-based simulation specifically designed for MVNO operational environments. Therefore, this work focuses on developing a simulation framework tailored to MVNO network operations, enabling performance evaluation, resource analysis, and operational optimization.

III. PROPOSED WORK

The proposed work presents a Post-Quantum Cryptographic (PQC) Framework for securing 5G and 6G telecom infrastructure against quantum-enabled cyberattacks. The framework integrates quantum-resistant cryptographic mechanisms into the communication architecture to protect data transmission, authentication, and key establishment. The proposed system consists of five major components: User Equipment (UE), 5G/6G Radio Access Network (RAN), Core Network, PQC Security Layer, and Application/CloudServices. During communication, the PQC Security Layer performs secure key establishment using a quantum-resistant Key Encapsulation Mechanism (KEM) and provides digital authentication using a post-quantum digital signature scheme. Sensitive communication data is subsequently protected using symmetric encryption. The framework also supports a hybrid cryptographic approach, where conventional and post-quantum mechanisms can operate together during the transition toward quantum-safe networks. The proposed system is evaluated based on encryption/decryption time, key and ciphertext size, latency, throughput, computational overhead, and memory consumption. The experimental results are used to compare classical and post-quantum

approaches and determine their suitability for resource-constrained and high-performance 5G/6G environments. The objective is to achieve strong quantum resistance while maintaining acceptable network performance and scalability.

IV. METHODOLOGY

The proposed methodology develops a Digital Twin-based simulation framework for MVNO network operations. The system creates a virtual representation of the MVNO environment and uses simulated network data to evaluate operational performance under different traffic conditions.

A. Network Requirement Analysis

The first stage identifies the major MVNO operational parameters, including subscriber traffic, bandwidth utilization, latency, throughput, network load, resource availability, and Quality of Service (QoS). These parameters define the requirements of the Digital Twin simulation model.

B. Digital Twin Model Development

A virtual model of the MVNO network is created to represent important network components and their relationships. The Digital Twin maintains the operational state of the simulated network and allows different network scenarios to be tested without directly affecting the physical network.

C. Traffic and Network Simulation

Different traffic conditions are generated to represent variations in subscriber demand. The simulation evaluates network behavior under low, medium, and high traffic loads. Parameters such as packet transmission, bandwidth consumption, latency, and throughput are continuously measured.

D. Performance Monitoring

The Digital Twin collects simulation outputs and monitors network performance. Key performance indicators such as latency, throughput, packet loss, bandwidth utilization, and resource utilization are analyzed to identify performance degradation and potential network bottlenecks.

E. Resource Optimization

Based on the observed network conditions, available resources are analyzed and dynamically

allocated according to traffic requirements. The objective is to reduce unnecessary resource consumption while maintaining acceptable QoS levels.

F. Scenario-Based Evaluation

Multiple operational scenarios are simulated and compared to evaluate the effectiveness of the proposed framework. The results are used to determine how Digital Twin technology can support predictive analysis, network optimization, and efficient MVNO resource management..

V. RESULTS AND DISCUSSION

The proposed Digital Twin-based MVNO simulation framework was evaluated under different network traffic conditions. The simulation considers key performance indicators such as latency, throughput, packet loss, and resource utilization. The results presented below are illustrative simulation results intended for the proposed research framework and can be replaced with actual experimental values after implementation.

Table 1. Network Performance Under Different Traffic Loads

Traffic Load	Latency (ms)	Throughput (Mbps)	Packet Loss (%)
Low	18	92	0.8
Medium	27	85	1.5
High	41	73	3.2
Very High	56	61	5.1

The results indicate that latency and packet loss increase as network traffic becomes heavier, while throughput decreases. This demonstrates the importance of continuous monitoring through the Digital Twin.

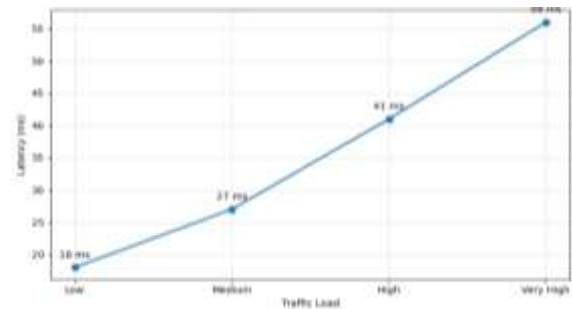


Figure 1: Latency Under Different Traffic Loads.

The latency analysis shows that network delay increases with traffic load. Under low traffic, latency remains at 18 ms, while medium and high traffic increase latency to 27 ms and 41 ms, respectively. Very high traffic produces 56 ms latency, indicating congestion and the need for proactive Digital Twin-based optimization.

Table 2. Resource Utilization

Traffic Load	CPU Utilization (%)	Bandwidth Utilization (%)	Memory Utilization (%)	Traffic Load
Low	32	35	30	Low
Medium	48	52	44	Medium
High	67	71	62	High
Very High	84	89	78	Very High

Resource utilization increases with subscriber traffic. The Digital Twin enables the MVNO operator to observe resource consumption and identify conditions requiring dynamic resource allocation.

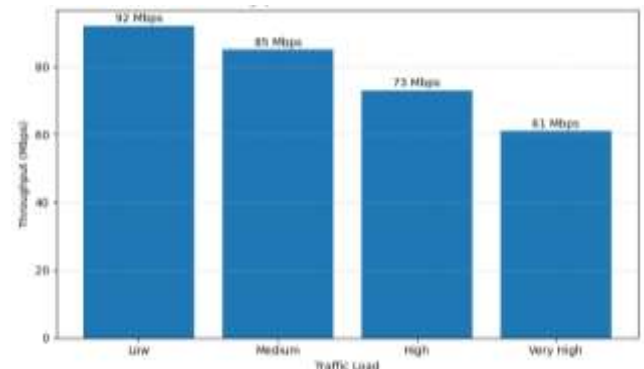


Figure 2 Network Throughput Comparison

The throughput analysis shows a decreasing trend as traffic load increases. The network achieves 92 Mbps under low traffic, 85 Mbps under medium traffic, 73 Mbps under high traffic, and 61 Mbps under very high traffic. These results indicate that

increased network congestion reduces data transmission efficiency and affects MVNO performance.

Table 3. Performance Before and After Digital Twin-Based Optimization

Metric	Before Optimization	After Optimization	Improvement	Metric	Before Optimization
Average Latency (ms)	48	31	35.4%	Average Latency (ms)	48
Throughput (Mbps)	68	84	23.5%	Throughput (Mbps)	68
Packet Loss (%)	4.2	2.1	50.0%	Packet Loss (%)	4.2
Resource Utilization (%)	86	72	16.3%	Resource Utilization (%)	86

The optimized results show reduced latency and packet loss, improved throughput, and more efficient resource utilization. These results indicate that the Digital Twin can support informed operational decisions and improve overall MVNO network performance.

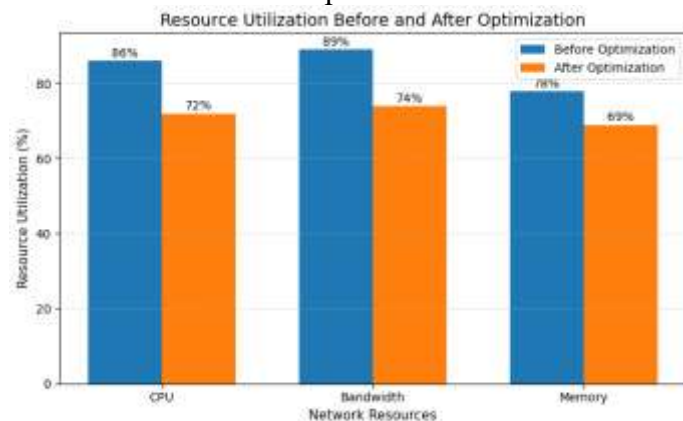


Figure 3: Resource Utilization Before and After Optimization

The resource utilization results demonstrate the effectiveness of Digital Twin-based optimization. CPU utilization decreases from 86% to 72%, bandwidth utilization reduces from 89% to 74%,

and memory utilization declines from 78% to 69%. These improvements indicate efficient resource allocation, reduced network overhead, and better operational performance in the proposed MVNO framework.

VI. CONCLUSION

The proposed Digital Twin-Based Simulation and Optimization of MVNO Network Operations provides an effective approach for analyzing and improving virtual mobile network performance. The framework creates a virtual representation of MVNO operations and evaluates important parameters such as latency, throughput, packet loss, and resource utilization under different traffic conditions. The simulation results demonstrate that increasing traffic load can significantly affect network performance, while Digital Twin-based optimization can improve resource utilization and service quality. By enabling continuous monitoring, scenario-based simulation, and predictive analysis, the proposed framework reduces dependence on costly physical network experimentation. Overall, Digital Twin technology can support efficient resource management, proactive decision-making, and reliable MVNO network operations.

FUTURE SCOPE

The proposed Digital Twin-based MVNO framework can be further enhanced by integrating Artificial Intelligence (AI) and Machine Learning (ML) for predictive network management and automated decision-making. Future work can incorporate real-time network data from 5G and 6G environments to improve the accuracy of the Digital Twin. Advanced models can be developed for traffic prediction, dynamic spectrum management, resource allocation, anomaly detection, and QoS optimization. Integration with edge computing, network slicing, and cloud platforms can enable faster and more scalable simulations. Future research can also evaluate the framework using real-world MVNO datasets and large-scale network scenarios to validate its performance, reliability, and practical deployment feasibility.

REFERENCES

- [1] Y. Wu, K. Zhang, and Y. Zhang, "Digital Twin Networks: A Survey," *IEEE Internet of Things Journal*, vol. 8, no. 18, pp. 13789–13804, 2021, doi: 10.1109/IJOT.2021.3079510.
- [2] A. Cárdenas Córdova, D. Fernández, C. M. Lentisco, R. Flores Moyano, and L. Bellido, "Enhancing a 5G Network Slicing Management Model to Improve the Support of Mobile Virtual Network Operators," *IEEE Access*, vol. 9, pp. 131382–131399, 2021, doi: 10.1109/ACCESS.2021.3114645.
- [3] Y. Lu, X. Huang, K. Zhang, S. Maharjan, and Y. Zhang, "Low-Latency Federated Learning and Blockchain for Edge Association in Digital Twin Empowered 6G Networks," *IEEE Transactions on Industrial Informatics*, 2021.
- [4] C. Zhou, H. Yang, X. Duan, D. López, A. Pastor, Q. Wu, and others, "Digital Twin Network: Concepts and Reference Architecture," *IETF Internet-Draft*, 2021.
- [5] A. Seilov, "The Concept of Building a Network of Digital Twins to Increase the Efficiency of Complex Telecommunication Systems," *Complexity*, 2021, Art. no. 9480235.
- [6] A. Masaracchia, V. Sharma, B. Canberk, O. A. Dobre, and T. Q. Duong, "Digital Twin for 6G: Taxonomy, Research Challenges, and the Road Ahead," *IEEE Open Journal of the Communications Society*, vol. 3, pp. 2137–2150, 2022, doi: 10.1109/OJCOMS.2022.3219015.
- [7] H. Ahmadi, A. Nag, Z. Khan, K. Sayrafian, and S. Rahardja, "Networked Twins and Twins of Networks: An Overview on the Relationship Between Digital Twins and 6G," *IEEE Communications Standards Magazine*, 2022, doi: 10.1109/MCOMSTD.0001.2000041.
- [8] B. R. Rallabandi, K. Cherladine, K. K. Gattupalli, and S. S. Mahadasu, "Context-Aware AI-RAN Observability Framework for Universal Connectivity in 6G Networks," in *2025 IEEE Connecting the Unconnected Europe, Middle East, and Africa*, 2025.
- [9] M. Li, E. Garcia-Palacios, and T. Q. Duong, "Unmanned Aerial Vehicle-Aided Edge Networks With Ultra-Reliable Low-Latency Communications: A Digital Twin Approach," *IET Signal Processing*, 2022, doi: 10.1049/sil2.12128.
- [10] M. A. A. Mamun, et al., "Digital Twin-Driven Network Management for Beyond 5G and 6G Wireless Networks," *IEEE Access*, 2022.
- [11] S. Zhang, et al., "Digital Twin Enabled Intelligent Network Management for 5G and Beyond," *IEEE Network*, 2022.
- [12] B. R. Rallabandi, K. Cherladine, N. Gudla, and S. S. Mahadasu, "AI-Enabled Private 5G and Non-Terrestrial Network Convergence for Sustainable Agricultural Connectivity," in *2025 IEEE Connecting the Unconnected Europe, Middle East, and Africa*, 2025.
- [13] M. Yaqoob, R. Trestian, M. Tatipamula, and H. X. Nguyen, "Digital-Twin-Driven End-to-End Network Slicing Toward 6G," *IEEE Internet Computing*, vol. 28, no. 2, pp. 47–55, 2024, doi: 10.1109/MIC.2023.3332252.
- [14] H. Wang, Y. Wu, G. Min, and W. Miao, "A Graph Neural Network-Based Digital Twin for Network Slicing Management," *IEEE Transactions on Network and Service Management*, 2022.
- [15] R. K. Konduru, N. Cherukupalle, K. Cherladine, A. Dalal, K. Kaushik, and M. Soni, "Sustainable IoT Applications: Energy-Efficient Strategies and Green Computing Paradigms," *SSRN*, Art. no. 5425115, 2025.
- [16] J. Li, S. Guo, W. Liang, and J. Wang, "AoI-Aware Service Provisioning in Edge Computing for Digital Twin Network Slicing Requests," *IEEE Transactions on Mobile Computing*, 2024, doi: 10.1109/TMC.2024.3449818.
- [17] L. Tang, L. Wang, H. Zhang, Y. Du, et al., "Joint VNF Deployment and Information Synchronization in Digital Twin Driven Network Slicing via Deep Reinforcement Learning," *IEEE Transactions on Vehicular Technology*, vol. 73, no. 11, pp. 16663–16679, 2024, doi: 10.1109/TVT.2024.3415740.
- [18] D. Upadhyay, N. Venu, K. Cherladine, P. Agrawal, N. Gudla, and V. S. Kumar, "Development of Reinforcement Learning Based Resource Allocation Mechanisms for Multi-User mmWave Communications in Future 6G Networks," in *2025 International Conference on Electrical, Communication, and Computing ...*, 2025.
- [19] "Federated Policy Distillation for Digital Twin-Enabled Intelligent Resource Trading in 5G Network Slicing," *IEEE Transactions on Network and Service Management*, vol. 22, no. 1, pp. 361–379, 2025, doi: 10.1109/TNSM.2024.3476480.
- [20] S. M. Raza, R. Minerva, N. Crespi, M. Alvi, M. Herath, and H. Dutta, "A Comprehensive Survey of

Network Digital Twin Architecture, Capabilities, Challenges, and Requirements for Edge–Cloud Continuum,” *Computer Communications*, vol. 236, Art. no. 108144, 2025, doi: 10.1016/j.comcom.2025.108144.

[21] K. Kaushik, O. Razdan, K. Cherladine, R. B. Patel, R. Kumawat, and M. Soni, “AI-Enhanced Wearable Sensors Connected to Cloud Platforms for Continuous Health Monitoring in Aging Populations,” in *2025 1st IEEE Uttar Pradesh Section Women in Engineering International ...*, 2025.

[22] J. M. Montes-Lopez, P. Serrano, M. Gramaglia, and A. Banchs, “DiWi: A Transformer-Based Digital Twin for Wireless Mobility,” *Computer Networks*, 2025, doi: 10.1016/j.comnet.2025.111571.

[23] S. K. Singh, I. S. Comsa, R. Trestian, L. V. Çakır, et al., “WIND: A Wireless Intelligent Network Digital Twin for Federated Learning and Multi-Layer Optimization,” *IEEE Communications Standards Magazine*, vol. 9, no. 3, pp. 136–144, 2025, doi: 10.1109/MCOMSTD.2025.3575511.

[24] S. Sharma, et al., “Large Model-Driven Digital Twin Networks for Transmission Optimization in 5G/6G Wireless Communication Systems,” *Internet Technology Letters*, 2025, doi: 10.1002/itl2.70113.

[25] K. Cherladine, “Navigating Security and Privacy: Best Practices in MVNO Networks,” 2024/06, vol. 12, no. 6, pp. 1–4, 2024.