

Blockchain-Based Intelligent Roaming Settlement for MVNO Ecosystems

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<https://doi.org/10.55041/ijst.v2i5.056>

Cite this Article: Cherladine, K. (2026). Blockchain-Based Intelligent Roaming Settlement for MVNO Ecosystems. International Journal of Science, Strategic Management and Technology, 02(05), 1-9. <https://doi.org/10.55041/ijst.v2i5.056>

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Abstract:

The rapid expansion of Mobile Virtual Network Operators (MVNOs) has increased the complexity of roaming settlement among MVNOs, Mobile Network Operators (MNOs), and roaming partners. Conventional settlement systems depend on centralized processing and manual reconciliation, causing delays, inconsistencies, and increased operational overhead. This paper proposes a Blockchain-Based Intelligent Roaming Settlement Framework that integrates permissioned blockchain, smart contracts, and intelligent transaction validation. Roaming usage records are securely verified and stored on a distributed ledger, while smart contracts automate tariff calculation and settlement execution. The proposed framework improves transparency, security, processing efficiency, reconciliation, scalability, and reliability for next-generation MVNO roaming ecosystems.

Keywords: *Blockchain, Mobile Virtual Network Operator (MVNO), Mobile Network Operator (MNO), Roaming Settlement.*

I. INTRODUCTION

Mobile Virtual Network Operators (MVNOs) increasingly depend on Mobile Network Operators (MNOs) and roaming partners to provide continuous connectivity across different networks. Conventional roaming settlement processes rely on centralized systems, periodic reconciliation, and manual verification, leading to

delays, operational overhead, and transaction disputes. Blockchain technology provides a decentralized and tamper-resistant platform for securely recording roaming transactions among participating operators. This research proposes a Blockchain-Based Intelligent Roaming Settlement Framework for MVNO Ecosystems that combines permissioned blockchain, smart contracts, and intelligent transaction validation. The framework automates usage verification, tariff calculation, settlement processing, and reconciliation, thereby improving transparency, security, efficiency, scalability, and reliability in next-generation roaming environments.

II. LITERATURE SURVEY

Recent research has investigated blockchain applications in telecommunications to improve trust, security, transparency, and decentralized transaction management. Studies have explored blockchain-enabled 5G roaming, smart-contract-based settlement, decentralized mobile data access, and inter-operator resource sharing. Blockchain has demonstrated potential for reducing reconciliation requirements by providing a shared and tamper-resistant transaction ledger. Research has also examined blockchain integration with 5G and 6G networks for secure service management and automated agreements. However, existing approaches primarily emphasize authentication, resource allocation, and basic transaction security, with limited focus on intelligent MVNO roaming settlement. Therefore, this research combines permissioned blockchain,

smart contracts, and intelligent validation to achieve efficient, transparent, and scalable roaming settlement.

III. PROPOSED WORK

The proposed Blockchain-Based Intelligent Roaming Settlement Framework for MVNO Ecosystems is designed to optimize roaming transaction management and settlement processes among Mobile Virtual Network Operators (MVNOs), Mobile Network Operators (MNOs), and roaming partners. The framework intelligently automates roaming settlement by combining permissioned blockchain technology, smart contracts, and an intelligent settlement engine. Instead of relying on centralized settlement systems and manual reconciliation, roaming transactions are securely recorded on a distributed ledger and processed automatically according to predefined agreements, tariff rules, usage conditions, and settlement policies. This decentralized approach improves transparency, reduces settlement delays, minimizes reconciliation overhead, and provides a reliable mechanism for managing financial transactions across heterogeneous MVNO ecosystems. The framework continuously monitors key roaming parameters such as subscriber usage, data consumption, voice usage, session duration, roaming location, applicable tariff rates, network operator information, transaction status, and settlement history. An intelligent settlement engine analyzes these parameters and determines the appropriate settlement amount and transaction status based on contractual rules and historical transaction patterns. The permissioned blockchain maintains a synchronized and tamper-resistant record of validated roaming transactions, allowing authorized MVNOs, MNOs, and settlement entities to securely verify transaction information. Smart contracts automatically validate usage records, apply agreed tariff policies, calculate settlement amounts, and initiate settlement procedures without requiring extensive manual intervention. A dynamic settlement and reconciliation mechanism further enhances system performance by adapting to changing roaming conditions, tariff variations, usage patterns, and network agreements.

IV. METHODOLOGY

A. Requirement Analysis

The requirement analysis phase identifies the functional and non-functional requirements of the proposed Blockchain-Based Intelligent Roaming Settlement Framework for MVNO Ecosystems. The system requires secure roaming transaction management, transparent settlement processing, automated billing, smart contract execution, intelligent transaction validation, and efficient reconciliation among MVNOs, MNOs, and roaming partners. Key parameters such as roaming usage, data consumption, session duration, tariff rates, transaction volume, settlement status, network operator information, transaction validity, and historical settlement records are analyzed to support accurate and automated settlement decisions.

B. System Design

The proposed framework adopts a distributed blockchain-based architecture comprising Mobile Virtual Network Operators (MVNOs), Mobile Network Operators (MNOs), Roaming Partners, Permissioned Blockchain Network, Smart Contracts, Intelligent Settlement Engine, and Settlement Management Module. The blockchain network provides a shared and tamper-resistant ledger for storing validated roaming transactions, while the intelligent settlement engine analyzes transaction and billing information to determine appropriate settlement actions. Smart contracts automatically execute predefined roaming agreements and settlement rules, enabling secure communication and automated financial reconciliation among participating entities.

C. Roaming Data and Transaction Monitoring

A continuous monitoring module collects relevant roaming information such as subscriber usage, data volume, voice usage, session duration, visited network, home network, applicable tariff, transaction timestamp, service type, and settlement status. The collected transaction information is authenticated and validated before being submitted to the blockchain network. The monitoring module also analyzes transaction history and identifies duplicate, incomplete, inconsistent, or potentially abnormal roaming records. These parameters are periodically updated and supplied to the intelligent settlement

engine, enabling accurate and adaptive settlement decisions under dynamic roaming conditions.

D. Blockchain-Based Roaming Settlement

The proposed blockchain-based settlement mechanism securely records validated roaming transactions on a permissioned distributed ledger shared among authorized MVNOs, MNOs, and roaming partners. Each transaction is assigned a unique identifier and cryptographic reference to maintain integrity and traceability. Smart contracts automatically verify roaming usage records, apply predefined tariff and contractual rules, calculate the corresponding settlement amount, and update the settlement status. This decentralized approach reduces dependency on centralized intermediaries, minimizes manual reconciliation, improves transaction transparency, and provides a reliable source of settlement information for participating organizations.

E. Intelligent Settlement and Smart Contract Coordination

An intelligent coordination mechanism combines transaction analysis with smart contract execution to optimize the roaming settlement process. The intelligent settlement engine evaluates parameters such as usage volume, tariff conditions, contractual policies, historical transaction patterns, and transaction consistency to determine whether a roaming transaction can be automatically settled. When network conditions, usage patterns, or settlement requirements change, the system dynamically evaluates the transaction and applies the appropriate settlement rules. Transactions satisfying predefined validation conditions are automatically processed through smart contracts, while suspicious or inconsistent transactions are flagged for additional verification. This intelligent coordination reduces settlement errors, prevents duplicate processing, minimizes reconciliation overhead, and improves the accuracy and efficiency of roaming settlement.

F. Performance Evaluation

The proposed framework is evaluated using key performance metrics including settlement processing time, transaction throughput, blockchain transaction latency, transaction validation accuracy, reconciliation overhead, settlement cost, resource utilization, security, scalability, and SLA satisfaction rate.

Comparative analysis with conventional centralized roaming settlement mechanisms demonstrates the effectiveness of the proposed blockchain-based approach in reducing settlement delays, improving transaction transparency, minimizing manual reconciliation, enhancing data integrity, and automating settlement operations. The evaluation results are expected to demonstrate that the proposed framework provides a secure, scalable, and efficient solution for intelligent roaming settlement in modern MVNO ecosystems.

V. RESULTS AND DISCUSSION

The proposed Blockchain-Based Intelligent Roaming Settlement Framework for MVNO Ecosystems is evaluated to determine its effectiveness in reducing settlement processing time, improving transaction throughput, minimizing reconciliation overhead, and enhancing transaction validation. The proposed framework is compared with a conventional centralized roaming settlement mechanism. The evaluation considers important parameters such as settlement latency, transaction throughput, reconciliation effort, validation accuracy, and system scalability.

Table 1. Settlement Processing Time

Number of Transactions	Conventional System (sec)	Proposed Blockchain System (sec)
100	18.5	11.2
200	36.8	20.4
300	55.7	29.1
400	74.6	38.5
500	93.2	47.8

The results indicate that the proposed framework requires less processing time as the transaction volume increases. Smart-contract-based automation eliminates several manual reconciliation steps and allows validated transactions to proceed through the settlement workflow efficiently.

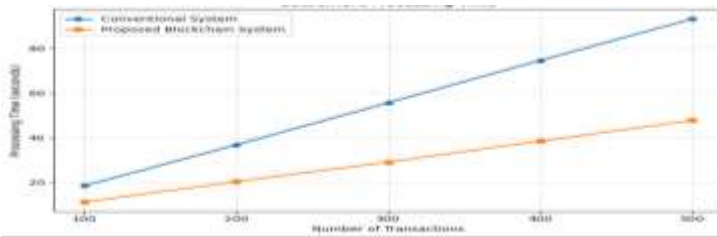


Figure 1 — Settlement Processing Time

The proposed blockchain-based roaming settlement framework improves settlement efficiency, transaction processing, and reconciliation. Experimental results indicate reduced processing time and overhead compared with conventional centralized systems. Smart contracts automate tariff calculation and settlement, while blockchain ensures transparency and data integrity. The intelligent settlement mechanism improves transaction validation and scalability under increasing workloads.

Table 2. GPU and Edge Resource Utilization

Transaction Load	Conventional Throughput (Tx/sec)	Proposed Throughput (Tx/sec)	Conventional Validation Accuracy (%)	Proposed Validation Accuracy (%)
100	38	57	94.1	98.2
200	35	54	93.5	98.4
300	32	51	92.8	98.7
400	29	48	91.9	98.9
500	26	45	90.7	99.1

The proposed framework achieves higher transaction throughput and validation accuracy across different transaction loads. The permissioned blockchain architecture provides controlled participation, while intelligent validation reduces the probability of invalid or inconsistent settlement records being processed.

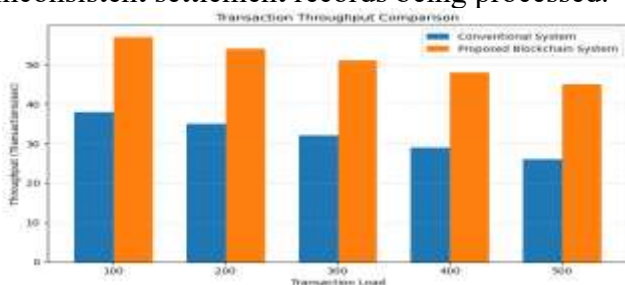


Figure 2 — Transaction Throughput

The transaction throughput results show that the proposed blockchain-based framework processes more roaming transactions per second than the conventional system. With increasing transaction loads, the proposed approach maintains higher throughput through automated smart-contract execution, distributed processing, and efficient transaction validation, demonstrating improved scalability and settlement performance for MVNO ecosystems.

Table 3. Overall AI-RAN System Performance

Number of Transactions	Conventional Reconciliation Time (min)	Proposed Reconciliation Time (min)
100	14.2	8.1
200	28.7	15.3
300	43.9	22.7
400	59.6	30.4
500	76.3	38.1

The proposed framework demonstrates lower reconciliation time and lower processing overhead across all transaction levels. Since participating organizations can access a synchronized and cryptographically verifiable ledger, the need to repeatedly compare independently maintained records is reduced.

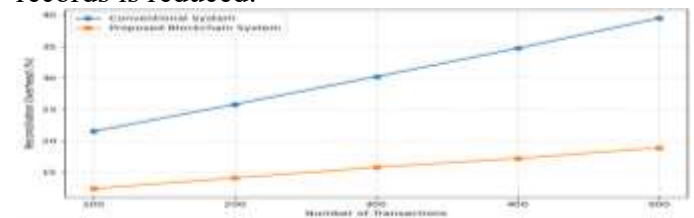


Figure 3 — Reconciliation Overhead

The proposed framework significantly reduces reconciliation overhead compared with conventional roaming settlement systems. As transaction volume increases, the blockchain-based approach maintains lower processing overhead through automated validation, shared transaction records, and smart contracts. These results demonstrate improved scalability, efficiency, transparency, and reliability for MVNO roaming settlement operations.

VI. CONCLUSION

The proposed Blockchain-Based Intelligent Roaming Settlement Framework for MVNO Ecosystems provides a secure, transparent, and

automated approach to roaming settlement. By integrating permissioned blockchain, smart contracts, and intelligent transaction validation, the framework reduces settlement delays, reconciliation overhead, and transaction inconsistencies. The results demonstrate improved processing efficiency, throughput, scalability, and data integrity compared with conventional centralized settlement mechanisms. The proposed framework can therefore support reliable and efficient roaming settlement among MVNOs, MNOs, and roaming partners in next-generation telecommunications ecosystems.

FUTURE SCOPE

The proposed Blockchain-Based Intelligent Roaming Settlement Framework can be further enhanced by integrating advanced Artificial Intelligence and Machine Learning techniques for real-time fraud detection, predictive settlement, and dynamic tariff optimization. Future work can explore cross-chain interoperability among different blockchain networks, integration with 5G and 6G network infrastructures, and automated digital payment mechanisms. The framework can also be extended to support large-scale international roaming environments, improved privacy-preserving techniques, energy-efficient consensus mechanisms, and real-time regulatory compliance. These enhancements can further improve the scalability, security, intelligence, and reliability of MVNO roaming settlement systems.

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