Blockchain-Enabled Edge AI Framework for Hyper-Localized Marine Ecosystem Monitoring

P.R.N.D. Jayalath[1], W.U. Withanachchi[2*]
[1]*Department of Language, Faculty of Management, Social Sciences and Humanities, General Sir John Kotelawala Defence University, Rathmalana, Sri Lanka.*
[2]*Department of Information Technology, Faculty of Computing, General Sir John Kotelawala Defence University, Rathmalana, Sri Lanka.*
[*]waruniwithanachchi@gmail.com

Coastal and marine ecosystems, particularly in the Indian Ocean region, are increasingly vulnerable to microplastic pollution, illegal, unreported, and unregulated (IUU) fishing, and climate-induced algal blooms. Existing monitoring systems are often fragmented, rely on delayed centralized processing, and lack trust in multi-stakeholder data environments, limiting their effectiveness for timely and localized decision-making. This study proposes a blockchain-enabled edge AI framework for hyper-localized marine ecosystem monitoring. The framework integrates multi-source data, including satellite imagery, IoT buoy sensors, unmanned aerial vehicles (UAVs), and crowd-sourced fisher-reported data. A decentralized ledger (Hyperledger Fabric) is utilized to ensure data provenance and integrity through cryptographic hashing and smart contracts. Edge computing nodes perform near real-time anomaly detection using graph neural networks (GNNs) and forecast algal bloom risks using Long Short-Term Memory (LSTM) models, while federated learning enables distributed model training without centralized data sharing. The system is designed to be implemented in three phases: simulation-based evaluation, prototype development, and pilot deployment in Sri Lankan coastal environments. Preliminary simulation-based analysis and expected performance outcomes indicate that the proposed framework can improve anomaly detection accuracy (target F1-score ≈ 0.90+) compared to conventional centralized models (≈ 0.70), while significantly reducing response latency from approximately 45 minutes to under 5 minutes. Additionally, the blockchain layer is expected to support secure, high-throughput data transactions (>100 transactions per second) with minimal risk of data tampering. These findings suggest that integrating edge AI with blockchain-based data provenance can enhance the reliability, responsiveness, and trustworthiness of marine monitoring systems. While the current results are derived from simulation and expected system behavior, the framework provides a scalable foundation for future real-world deployment in coastal regions such as Sri Lanka, supporting sustainable marine governance and environmental protection.

Keywords: *Edge AI, Blockchain-based data provenance, Marine ecosystem monitoring, Multi-source data, Simulation-based evaluation*