# Edge-Aware Optimization for AI-Driven Anomaly Detection in Smart City Wireless Networks

D.G.S.M. Kumarasiri
(MS24041416)

A THESIS
SUBMITTED TO
SRI LANKA INSTITUTE OF INFORMATION TECHNOLOGY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE IN INFORMATION TECHNOLOGY

December 2025

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Prof. Dilshan De Silva

Approved for MSc. Research Project:

MSc in IT Programme Co-ordinator, SLIIT

Approved for MSc:

Head of Graduate Studies, FoC, SLIIT

# DECLARATION

This is to certify that the work is entirely my own and not of any other person, unless explicitly acknowledged (including citation of published and unpublished sources). The work has not previously been submitted in any form to the Sri Lanka Institute of Information Technology or to any other institution for assessment for any other purpose.

Sign: …………………..
Sachini Kumarasiri

Date: …12.12. 2025……..

# ABSTRACT

## Edge-Aware Optimization for AI-Driven Anomaly Detection in Smart City Wireless Networks

D. G. S. M Kumarasiri
MSc. in Information Technology
**Supervisor:** Prof. Dilshan De Silva
November 2025

The rapid growth of smart cities has led to increased reliance on wireless networks and IoT devices, raising critical security concerns, particularly regarding anomaly detection. Traditional methods fall short in dynamic and resource constrained environments due to their limited adaptability and high computational demands. This paper presents a comprehensive review of AI-driven approaches to anomaly detection in smart city wireless networks, focusing on real-time adaptability and edge-aware optimization. It evaluates state of the art techniques such as federated learning, lightweight deep learning models, and hybrid AI frameworks that balance detection accuracy with efficiency. Public datasets like CICIDS 2017 and IoT-23 are discussed in detail for their role in training and evaluating these systems. Despite significant progress, existing models struggle with scalability, high false positive rates, and limited deployment readiness for edge devices. The paper proposes a conceptual framework to address these gaps and lays a foundation for future research in secure, scalable smart city networks. Additionally, this study incorporates architectural visualization and proposes feasible real-time deployment through edge-based simulators, addressing gaps in prior implementations and privacy safeguards.

# ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor, Professor Dilshan De Silva, for his continuous guidance, encouragement, and constructive feedback throughout the course of this research. His expertise and support have been invaluable in shaping this study and motivating me to overcome challenges along the way.

I extend my appreciation to the faculty members of the Sri Lanka Institute of Information Technology (SLIIT) for providing the academic foundation, resources, and supportive environment that made this work possible. I am also grateful to my colleagues and friends for their insightful discussions, collaboration, and moral support during this journey.

A special word of thanks goes to my family, whose patience, love, and sacrifices have been my greatest strength. In particular, I am deeply indebted to my husband, whose constant encouragement, understanding, and belief in my abilities inspired me to persevere and complete this work.

Finally, I acknowledge all the researchers and practitioners whose work provided the foundation for my study. Any shortcomings in this thesis remain entirely my own responsibility.

# TABLE OF CONTENTS

DECLARATION ........ ii
ABSTRACT ........ iii
ACKNOWLEDGEMENT ........ iv
TABLE OF CONTENTS ........ v
List of Tables ........ x
Table of Figures ........ xi
Chapter 1 Introduction ........ 1
1.1. Background on Smart Cities ........ 1
1.2. Wireless Network Vulnerabilities ........ 2
1.3. Problem Statement ........ 3
1.4. Research Objectives ........ 4
1.5. Scope of the Study ........ 5
1.6. Research Questions ........ 5
1.7. Contributions of the Study ........ 6
Chapter 2 Literature Review ........ 7
2.1. AI-Driven Anomaly Detection ........ 7
2.1.1. Supervised Models ........ 7
2.1.2. supervised and One-Class Models ........ 8
2.2. Hybrid, Semi-, and Self-Supervised Approaches ........ 9
2.2.1. Feature Engineering and Preprocessing ........ 10
2.2.2. Evaluation Metrics ........ 10
2.2.3. Explainability ........ 10
2.3. Edge Computing in Smart Cities ........ 11
2.3.1. The Edge Paradigm ........ 11
2.3.2. Benefits of Edge Computing ........ 11
2.3.3. Challenges of Edge Computing ........ 12
2.3.4. Case Studies in Edge Deployments ........ 12
2.3.5. Edge Optimization Techniques ........ 13
2.4. Federated Learning for Anomaly Detection ........ 13
2.4.1. Federated Paradigm ........ 13
2.4.2. Benefits of FL in Smart Cities ........ 14
2.4.3. Challenges of FL ........ 14
2.4.4. FL Variants and Enhancements ........ 14
2.4.5. Security Threats in FL ........ 15
2.4.6. Case Studies in FL for Anomaly Detection ........ 15

2.5. Comparative Analysis ........ 15
2.5.1. Models vs. Datasets ........ 16
2.5.2. Performance Metrics ........ 17
2.5.3. Deployment Models ........ 18
2.6. Gaps and Open Challenges ........ 18
2.6.1. Real-Time Adaptability ........ 18
2.6.2. Synthesis and Implications ........ 19
Chapter 3 Methodology ........ 21
3.1. Research Design: Mixed-Method Approach ........ 21
3.1.1. Qualitative Component ........ 21
3.1.2. Quantitative Component ........ 21
3.2. Simulation-Based Methodology ........ 22
3.3. Rationale for Methodology ........ 22
3.4. Datasets ........ 22
3.4.1. CICIDS2017 Dataset ........ 23
3.4.2. IoT-23 Dataset ........ 23
3.4.3. Edge-IoTset Dataset ........ 24
3.4.4. Dataset Preprocessing ........ 24
3.5. Baseline Models ........ 25
3.5.1. K-Nearest Neighbors (KNN) in MATLAB ........ 25
3.5.2. Convolutional Neural Networks (CNN) ........ 25
3.5.3. Long Short-Term Memory Networks (LSTM) ........ 26
3.5.4. Autoencoders (AE) ........ 26
3.5.5. Baseline Comparison Strategy ........ 27
3.6. Proposed Approach: Hybrid CNN–LSTM with Federated Averaging ........ 27
3.6.1. Rationale for Hybrid CNN–LSTM ........ 27
3.6.2. Architecture ........ 27
3.6.3. Federated Averaging (FedAvg) ........ 27
3.6.4. Handling Non-IID Data ........ 28
3.7. Edge-Aware Optimization ........ 28
3.7.1. Model Pruning ........ 28
3.7.2. Quantization ........ 28
3.7.3. Knowledge Distillation ........ 28
3.7.4. Adaptive Offloading ........ 29
3.8. Evaluation Metrics ........ 29
3.9. Ethical and Reproducibility Considerations ........ 29
3.9.1. Ethical Issues ........ 29

3.9.2. Reproducibility ..... 30
3.10. Summary of Methodology ..... 30
Chapter 4 Implementation ..... 31
4.1. Completed Implementation ..... 31
4.1.1 Dataset Preparation ..... 31
4.2. Dataset Preparation ..... 32
4.2.1. Dataset Selection ..... 32
4.2.2. Preprocessing Pipeline ..... 33
4.3. Model Architecture ..... 33
4.3.1. Baseline Models ..... 33
4.3.2. Hybid CNN + LSTM Architecture ..... 34
4.4. Federated Learning Implementation ..... 35
4.4.1. Rationale ..... 35
4.4.2. FL Setup ..... 35
4.4.3. Training Procedure ..... 35
4.5. Edge-Aware Optimization ..... 36
4.5.1. Motivation ..... 36
4.5.2. Techniques Applied ..... 36
4.5.3. Implementation ..... 36
4.5.4. Latency Evaluation ..... 37
4.6. Visualization and Dashboard Design ..... 37
4.6.1. Purpose ..... 37
4.6.2. Artifacts Generated ..... 37
4.6.3. Displayed Metrics ..... 38
4.7. Simulation Prototype Design ..... 38
4.7.1. Objective ..... 38
4.7.2. Prototype Architecture ..... 39
4.7.3. Prototype Execution ..... 41
4.8. Summary of Implementation ..... 43
Chapter 5 Results ..... 44
5.1. Experimental Environment ..... 44
5.2. Baseline Model Evaluation ..... 45
5.2.1. Performance on CICIDS2017 ..... 45
5.2.2. Performance on IoT-23 ..... 45
5.3. Hybrid CNN-LSTM Model Results ..... 45
5.3.1. Learning Dynamics ..... 46
5.3.2. Confusion Matrix Analysis ..... 46

5.4. Federated Learning Results ........ 46
5.4.1. Overview ........ 46
5.4.2. Discussion ........ 47
5.5. Edge-Aware Optimization Results ........ 47
5.5.1. Model Compression and Latency ........ 47
5.5.2. Impact on Accuracy ........ 47
5.6. Visualization and Dashboard Outputs ........ 48
5.7. Simulation Prototype Results ........ 49
5.7.1. Experimental Setup ........ 49
5.7.2. Observed Behaviour ........ 49
5.7.1. Interpretation ........ 49
5.8. Comparative Discussion ........ 49
5.8.1. Against Existing Research ........ 49
5.9. Research Question Validation ........ 51
5.10. Key Insights ........ 51
5.11. Summary ........ 51
Chapter 6 Simulation Framework and Evaluation design ........ 53
6.1. Objectives of the Simulation ........ 53
6.2. Framework Architecture ........ 54
6.3 Simulation Workflow ........ 54
6.4. Simulation Parameters ........ 55
6.6 Integration with NS-3 ........ 56
6.6.1 NS-3 Environment ........ 56
6.6.2 Implementation Steps ........ 56
6.6 Integration with OMNeT++ ........ 57
6.8 Metrics for Evaluation ........ 57
6.8.1 ML-Level Metrics ........ 57
6.8.2 Network-Level Metrics ........ 57
6.9 Expected Results and Validation Strategy ........ 58
6.10. Visualization of Simulation Results ........ 58
6.11. Challenges and Mitigation ........ 59
6.12 Ethical and Security Considerations ........ 59
6.13 Summary ........ 59
Chapter 7 Conclusion and Future Work ........ 61
7.1. Summary of Research Achievements ........ 61
7.1.1. Dataset Preparation and Baseline Evaluation ........ 61
7.1.2. Development of Hybrid CNN–LSTM Model ........ 62

7.1.3. Federated Learning Integration ........ 62
7.1.4. Edge-Aware Optimization ........ 62
7.1.5. Visualization and Dashboard ........ 62
7.1.6. Smart-City Simulation Prototype ........ 62
7.3. Research Contributions ........ 63
7.4. Reflection on Research Objectives ........ 64
7.5. Limitations of the Study ........ 64
7.6. Future Work ........ 65
7.6.1. Large-Scale Federated Learning ........ 65
7.6.2. Full Smart-City Simulation ........ 65
7.6.3. Edge Deployment and Benchmarking ........ 65
7.6.4. Adaptive FL with Reinforcement Learning ........ 66
7.6.5. Integration with Cloud–Edge Orchestration ........ 66
7.7 Conclusion ........ 66
Chapter 6 References ........ 67
Appendix ........ 70
a. Omnetpp.ini ........ 70
b. SmartCirtCompare.ned ........ 79
c. SmartCityModules.cc ........ 80

# List of Tables

Table 1 Model Vs Datasets ........ 16
Table 2 Performance Metrics ........ 17
Table 3 Deployment Models ........ 18
Table 4 Dataset Selection ........ 32
Table 5 Sampling ........ 33
Table 6 Parameter Selection ........ 35
Table 7 Results Summary ........ 36
Table 8 Artifacts ........ 37
Table 9 Latency Comparison ........ 37
Table 10 Metrics ........ 38
Table 11 Achievement ........ 43
Table 12 Specification ........ 44
Table 14 Performance on CICIDS2017 ........ 45
Table 15 Performance on IoT-23 ........ 45
Table 16 Hybrid CNN-LSTM Accuracy and F1 Scores ........ 46
Table 17 Federated Learning Results ........ 46
Table 18 Model Size and Latency Before and After Optimization ........ 47
Table 19 Accuracy Loss ........ 48
Table 20 Sample Dashboard Metrics ........ 48
Table 21 Experimental Setup ........ 49
Table 22 Discussion ........ 50
Table 23 Research Question Validation ........ 51
Table 24 Smart-City Simulation Framework Architecture ........ 54
Table 25 Simulation Parameters ........ 55
Table 26 Integration with OMNeT++ ........ 57
Table 27 Validation ........ 58
Table 28 Challenges and Mitigation ........ 59
Table 29 Contributions of the Research ........ 63
Table 30 Supporting Evidence ........ 64

# Table of Figures

Figure 1 Smart City Overview ........................................................................................................ 2
Figure 2 Implementation Workflow ........................................................................................... 31
Figure 3 Hybrid_CNN_LSTM..................................................................................................... 34
Figure 4 Federated Learning ....................................................................................................... 35
Figure 5 Edge Optimization......................................................................................................... 36
Figure 6 Dashboard Layout ......................................................................................................... 38
Figure 7  Baseline and proposed networks. ................................................................................. 38
Figure 8 Overall system architecture of the proposed edge-aware federated learning framework............. 39
Figure 9 Internal structure of the proposed edge-aware federated learning network................................. 41
Figure 10 Internal structure of the proposed edge-aware federated learning network................................ 42