



UNDERGRADUATE THESIS

ACCURACY AND INFERENCE TIME OPTIMIZATION USING MULTI-OBJECTIVE XGBOOST ON THE NF-UNSW-NB15 DATASET

RACHMANANTA IBNU FAJAR

NPM 22081010175

THESIS ADVISORS

Prof. Dr. Basuki Rahmat, S.Si., MT., ITS-AI

Dr. Eng. Agussalim, MT.

**MINISTRY OF HIGHER EDUCATION, SCIENCE, AND TECHNOLOGY
UNIVERSITAS PEMBANGUNAN NASIONAL VETERAN JAWA TIMUR
FACULTY OF COMPUTER SCIENCE
INFORMATICS STUDY PROGRAM
SURABAYA
2026**

APPROVAL SHEET

ACCURACY AND INFERENCE TIME OPTIMIZATION USING MULTI-OBJECTIVE XGBOOST ON THE NF-UNSW-NB15 DATASET

By :
RACHMANANTA IBNU FAJAR
NPM. 22081010175

Has been defended before, and accepted by, the Board of Assessors of the Thesis Examination of the Informatics Study Program, Faculty of Computer Science, Universitas Pembangunan Nasional Veteran Jawa Timur, on June 23, 2026:

Approved,

Prof. Dr. Basuki Rahmat, S.Si., MT., ITS-AI
NIP. 19690723 202121 1 002



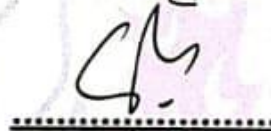
(Advisor I)

Dr. Eng. Agussalim, MT.
NIP. 19850811 201903 1 005



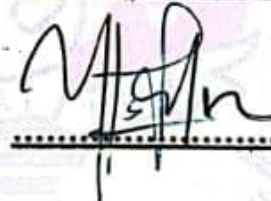
(Advisor II)

Eva Yulia Puspaningrum, S.Kom., M.Kom.
NIP. 19890705 202121 2 002



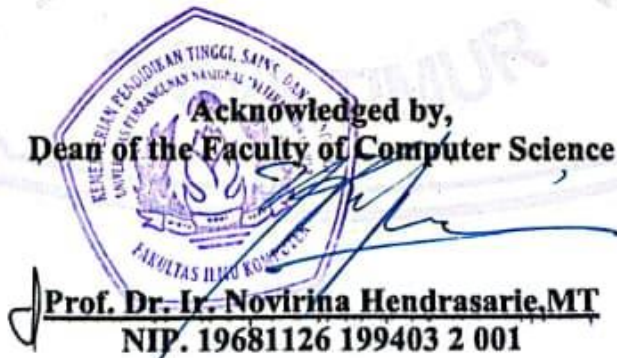
(Head Assessor)

Yisti Vita Via, S.ST., M.Kom.
NIP. 19860425 202121 2 001



(Assessor I)

Acknowledged by,
Dean of the Faculty of Computer Science



Prof. Dr. Ir. Novirina Hendrasari, MT
NIP. 19681126 199403 2 001

APPROVAL SHEET

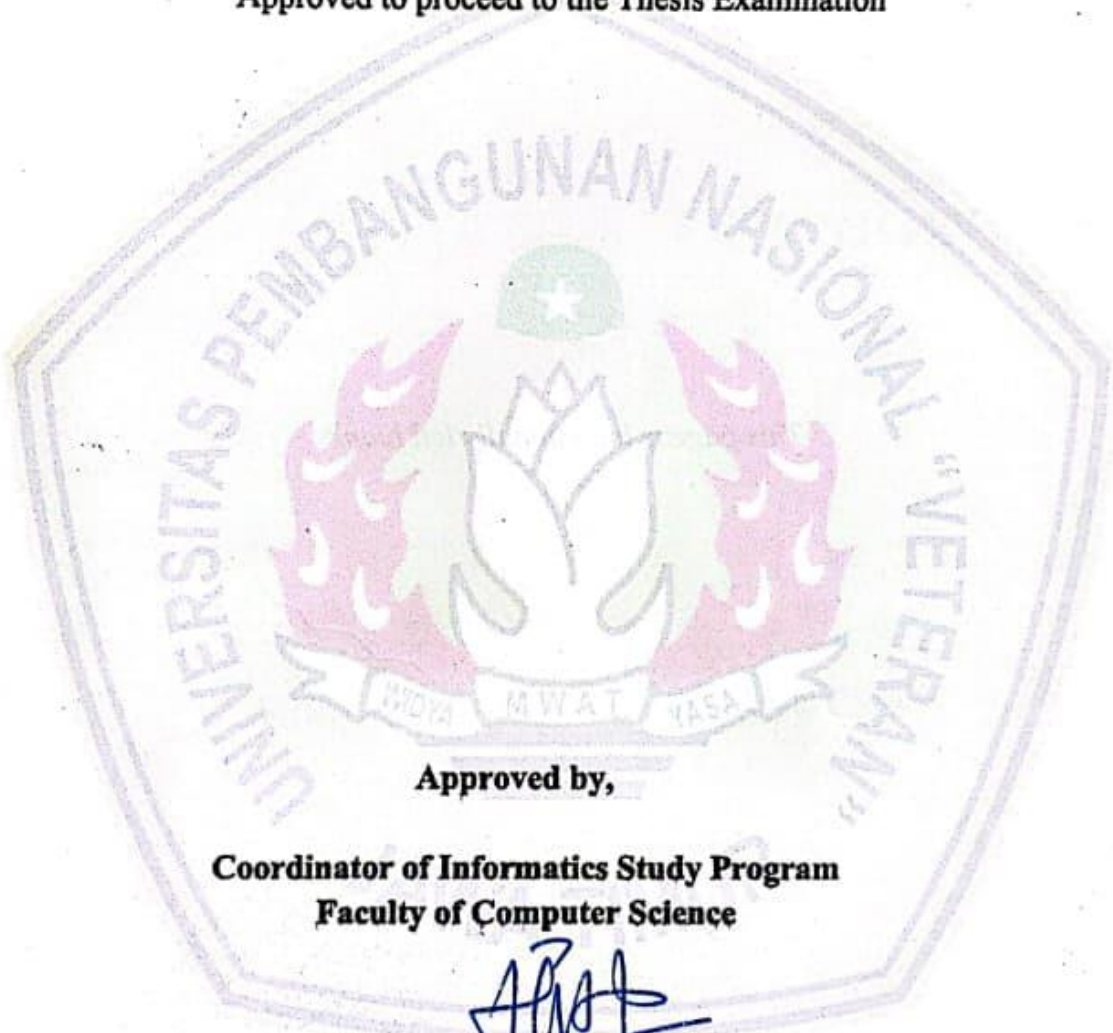
ACCURACY AND INFERENCE TIME OPTIMIZATION USING MULTI- OBJECTIVE XGBOOST ON THE NF-UNSW-NB15 DATASET

By:

RACHMANANTA IBNU FAJAR

NPM. 22081010175

Approved to proceed to the Thesis Examination



Approved by,

**Coordinator of Informatics Study Program
Faculty of Computer Science**

Dr. Intan Yuniar Purbasari, S.Kom., M.Sc.
NIP.198006022 025212 029

STATEMENT OF ORIGINALITY

I am the undersigned:

Student Name : Rachmananta Ibnu Fajar
NPM : 22081010175
Degree Program : Bachelor (S1)
Study Program : Informatics
Faculty : Faculty of Computer Science

Hereby declares that this undergraduate thesis contains no part of any other scientific work that has been submitted to obtain an academic degree at any higher education institution. Furthermore, it does not contain any work or opinions previously written or published by others, except for those which are explicitly cited in this thesis and listed completely in references.

And I declare that this scientific document is free from elements of plagiarism. If in the future indications of plagiarism are found in this Thesis, I am willing to accept sanctions in accordance with the applicable laws and regulations.

Thus, I made this statement without any coercion from anyone and to be used as it should.



Surabaya, June 23, 2026
Declarant,



Rachmananta Ibnu Fajar
NPM. 22081010175

ABSTRACT

Student Name / NPM: Rachmananta Ibnu Fajar / 22081010175
Thesis Title: ACCURACY AND INFERENCE TIME OPTIMIZATION USING MULTI-OBJECTIVE XGBOOST ON THE NF-UNSW-NB15 DATASET
Supervisor: 1. Prof. Dr. Basuki Rahmat, S.Si., MT., ITS-AI
2. Dr. Eng. Agussalim, MT.

In the era of digital transformation, Network Intrusion Detection Systems (NIDS) serve as a critical frontline against cyber threats. However, modern machine learning-based NIDS often experience evaluation bias, orienting exclusively toward maximizing detection accuracy while neglecting computational inference latency, which can cause catastrophic packet queuing in high-speed networks. This study addresses this multi-objective optimization problem by developing an efficient NIDS framework utilizing the eXtreme Gradient Boosting (XGBoost) algorithm enhanced with cost-sensitive hybrid class weighting to mitigate extreme class imbalance on the NF-UNSW-NB15-v3 dataset. To navigate the extensive hyperparameter space under conflicting criteria, this study evaluates and compares two distinct optimization strategies: the evolutionary Non-dominated Sorting Genetic Algorithm II (NSGA-II) and the Bayesian probability-based Tree-structured Parzen Estimator (TPE), against a default XGBoost baseline. Furthermore, a trace-driven prototype simulation was developed using Streamlit to validate the system's pseudo-real-time feasibility. Empirical outcomes on unseen testing data (473,085 samples) demonstrated that both optimization methods significantly outperformed the default baseline model. The TPE-optimized configuration achieved the superior overall performance, yielding a Macro F_1 -Score of 0.8632 (a +3.84% relative gain over the baseline's 0.8313) while maintaining an exceptionally low inference latency of 2.1681 μ s/sample, rendering it 47.5% faster than the NSGA-II model (4.7720 μ s/sample). Formal Kruskal-Wallis hypothesis testing confirmed that these performance discrepancies were statistically significant ($p < 0.05$). Notably, the hybrid weighting mechanism induced a substantial +17.8% recall jump for the minority Denial of Service (DoS) class. Explainable AI (XAI) analysis based on global feature gain consistently highlighted temporal and packet-volume indicators (MIN_TTL and MIN_IP_PKT_LEN) as the most sensitive network anomalies, establishing a balanced, reliable, and deployable framework for resource-constrained architectures.

Keywords: *Network Intrusion Detection System, Multi-Objective Hyperparameter Optimization, XGBoost, Class Imbalance, Real-Time Simulation.*

ACKNOWLEDGEMENTS

Praise and gratitude be to Allah SWT for His boundless blessings, guidance, and grace, which have enabled the author to successfully complete this undergraduate thesis titled **“ACCURACY AND INFERENCE TIME OPTIMIZATION USING MULTI-OBJECTIVE XGBOOST ON THE NF-UNSW-NB15 DATASET”**.

This thesis was conducted to fulfill one of the requirements for obtaining a Bachelor's Degree in Informatics (S1) at the Faculty of Computer Science, Universitas Pembangunan Nasional “Veteran” Jawa Timur.

Throughout the research and writing process, the author received immense support, guidance, and assistance from various parties. Therefore, the author wishes to express the deepest gratitude and appreciation to:

1. Bapak Andreas Nugroho Sihananto, S.Kom., M.Kom., as the thesis coordinator, for his assistance in streamlining the administrative processes.
2. Bapak Prof. Dr. Basuki Rahmat, S.Si., MT., ITS-AI., and Bapak Dr. Eng. Agussalim, MT., as the thesis advisors, for their exceptional guidance, insights, and continuous support throughout the development of this research.
3. Ibu Eva Yulia Puspaningrum, S.Kom., M.Kom., and Ibu Yisti Vita Via, S.ST., M.Kom., as the thesis examiners, for their valuable feedback, constructive critiques, and corrections toward perfecting this thesis.
4. Ibu Dr. Ir. Kartini, S.Kom., MT., as the academic advisor, for her continuous advice, guidance, and encouragement since the beginning of the author's university studies.
5. The Administrative Staff, Facilities Caretakers, and Security Personnel of the Faculty of Computer Science, such as Pak Aries, Mas Lilik, and Mas Pur, for maintaining a conducive environment and ensuring the smooth operation of campus facilities throughout the author's studies.
6. My Beloved Family: Bapak Suliyanto, Ibu Emi, Mas Tomy, Mbak Umi, Mbak Suci, Mas Adi, and the entire extended family, for their endless prayers, profound affection, and unwavering support that served as the author's ultimate source of strength.
7. Wahyu, my close friend since junior high school, for his relentless loyalty, assistance, and incredible support across all circumstances, and thanks to all of his Densus Friend that supports me as well.
8. The Pemuda Hijrah Friends: Abdi, Adib, Bagas, Daffa, Ivan, Desta, Raihan, and Dani, for the companionship, insightful discussions, and moral support through both academic and non-academic challenges.
9. The Mamino Friends: Kupluk, Basroil, Fadika, Ryan, Ken, Yassar, Kevin, Acil, Irfan, Bram, Alief, Rizki, Leon, Ojan, Yossie, Slotong, Aji, and Erlang,

for the unforgettable memories, camaraderie, and solidarity that lightened the academic workload.

10. The Mabas Langgeng Friends, who cannot be mentioned individually, thank you for the solidarity, support, and invaluable shared memories over the years in Langgeng.
11. My Peer Mentors and Study Partners: Mas Gosal, Mas Aghis, Mas Miftah, Mas Nizar, Mbak Dhavina, Mbak Ica, Yuana, Anjas, Hafidz, Habib, Dwi, Rahma, Tiara, Shalsa, Ribka, and Aimee, for their companionship and for generously sharing their knowledge.
12. My Kiddos : Hilmi, Hikma, Rejak, Iwang, Icha, Isna, Syanda, Nana, Tasya, Inul, Ariel, and Jazuli for their dedication, hard work, and brilliant synergy during my tenure as their department head. Thank you for trusting my leadership, sharing the workload, and making the bureau feel like a true family.
13. The Executive Board of Students (BEM) of the Faculty of Computer Science (Odysseus Cabinet 2024 and Astranova Cabinet 2025) and the Informatics Student Association (HIMATIFA), for providing a collaborative platform to grow, voice aspirations, and shape the author's intellectual and organizational journey.
14. The Seniors and Juniors of the Faculty of Computer Science, UPN "Veteran" Jawa Timur, for sharing experiences, references, motivation, and for bringing joy and vibrant cooperation into campus life.
15. All Fellow Students of the Faculty of Computer Science, Class of 2022, for the strong solidarity, late-night discussions, shared laughter, and collective struggles at this Bela Negara campus.
16. To a certain unexpected presence who stopped by my life just long enough to leave a lasting impact. Thank you for the brief moment you were there for me, helping me carry the weight of this journey. Though our paths crossed only for a moment and have now diverged, I am truly grateful for the shared chapters and the person you helped me become.
17. Last but not least, to myself, for the unwavering resilience and discipline through countless sleepless nights, and for never walking away when the code broke or when the weight of it all felt endless. Thank you for showing up every single day and turning the late-night grinds into reality. Remember. Be Bold. Be Original. Be [Title Card].

Surabaya, June 23, 2026



Author

LIST OF CONTENTS

APPROVAL SHEET	i
APPROVAL SHEET	iii
STATEMENT OF ORIGINALITY	v
ABSTRACT.....	vii
ACKNOWLEDGEMENTS	ix
LIST OF CONTENTS.....	xi
LIST OF FIGURES	xv
LIST OF TABLES	xix
LIST OF PROGRAM CODES.....	xxi
CHAPTER I INTRODUCTION	1
1.1 Background	1
1.2 Problem Formulation	4
1.3 Research Objectives.....	5
1.4 Research Benefit	6
1.5 Research Limitation	7
CHAPTER II LITERATURE REVIEW.....	9
2.1 Related Literature.....	9
2.2 Network Intrusion Detection Systems (NIDS)	14
2.2.1 Network Intrusion Detection System (NIDS).....	14
2.2.2 Machine Learning-Based Anomaly Detection.....	15
2.2.3 Flow-Based Traffic Analysis (NetFlow)	17
2.3 Dataset and Data Characteristics	18
2.3.1 The NF-UNSW-NB15 Dataset	19
2.3.2 Features and Flow Data Representation	20
2.3.3 Attack Taxonomy and Class Imbalance Problems	21
2.4 Knowledge Discovery in Database Framework	23
2.4.1 Concepts and Stages of KDD	23
2.4.2 The Role of KDD in the Research Workflow.....	25
2.5 Data Preprocessing.....	26
2.5.1 Feature Dropping	27
2.5.2 Label Encoding	28

2.5.3 Standard Scaling	28
2.5.4 Sample Weighting for Class Imbalance	30
2.6 Classification Model and Optimization	31
2.6.1 The XGBoost Algorithm	31
2.6.2 Regularization and GPU Acceleration	33
2.6.3 Multi-Objective Hyperparameter Optimization	34
2.6.4 Pareto Front and Trade-offs.....	35
2.7 Search Algorithms in the Optuna Framework.....	36
2.7.1 Tree-structured Parzen Estimator (TPE)	36
2.7.2 Non-dominated Sorting Genetic Algorithm II (NSGA-II).....	38
2.7.3 XGBoost Baseline	40
2.8 Evaluation, Transparency, and Validation	40
2.8.1 Performance Evaluation Metrics	41
2.8.2 Feature Importance Analysis	43
2.8.3 Statistical Testing and Validation Methods.....	44
2.9 Concepts of Trace-Driven Detection Simulation	46
2.9.1 Definition and Operational Principles	46
2.9.2 Relevance to Inference Time Measurement	47
2.9.3 Interactive Visualization and Monitoring.....	48
CHAPTER III METHODOLOGY	49
3.1 Research Design	49
3.2 Implementation Environment and Experimental Setup	52
3.2.1 Hardware and GPU Specifications	53
3.2.2 Development Environment and Software Libraries	54
3.3 Stage 1: Data Selection.....	57
3.3.1 Source and Characteristics of the NF-UNSW-NB15 Dataset	57
3.3.2 Stratified Data Partitioning.....	59
3.4 Stage 2: Data Preprocessing	60
3.4.1 Removal of Irrelevant Features	62
3.4.2 Handling of Anomalous Values and Missing Data	64
3.5 Stage 3: Data Transformation.....	66
3.5.1 Categorical Label Encoding	68
3.5.2 Numerical Feature Standardization	70

3.5.3 Class Imbalance Mitigation	71
3.6 Stage 4: Data Mining	75
3.6.1 XGBoost Model Architecture and GPU Acceleration.....	75
3.6.2 Multi-Objective Objective Function Formulation	81
3.6.3 Hyperparameter Search Strategies (TPE, NSGA-II)	84
3.6.4 Tree-structured Parzen Estimator	87
3.6.5 Non-dominated Sorting Genetic Algorithm II.....	92
3.6.6 XGBoost Baseline Default Parameter	97
3.7 Stage 5: Interpretation and Evaluation.....	100
3.7.1 Hyperparameter Importance Analysis	102
3.7.2 Performance Analysis of the Optimal Model	106
3.7.3 Cohen’s Kappa Reliability Analysis.....	109
3.7.4 Pareto Front Analysis.....	113
3.7.5 Feature Importance XGBoost	117
3.7.6 Statistical Validation.....	120
3.8 Design of the NIDS Prototype Simulation.....	127
3.8.1 Simulation Architecture	127
3.8.2 Simulation Logical Flow.....	130
3.8.3 Model Testing Scenarios.....	133
3.8.4 User Interface Design and Visual Metrics	134
CHAPTER IV RESULTS AND DISCUSSION	139
4.1 Experimental Environment and System Specifications	139
4.1.1 Hardware Specifications	139
4.1.2 Software Specifications and Library Catalog	142
4.2 Dataset Characteristics and Class Mapping Results	145
4.2.1 Reconstruction of Network Traffic Attack Categories	145
4.2.2 Audit of Feature Cleaning and Transformation Results	147
4.3 Data Imbalance Analysis and Weighting Impact.....	153
4.3.1 Imbalance Ratio Calculation.....	153
4.3.2 Evaluation of the Model Attention Space	155
4.4 Analysis of the Multi-Objective Hyperparameter Exploration Process	157
4.4.1 TPE Optimal Parameter Exploration Log.....	158
4.4.2 NSGA-II Optimal Parameter Exploration Log	160

4.4.3 Objective Parameter Convergence Trajectory.....	162
4.5 Performance Analysis of the Control Model.....	164
4.5.1 Initial Decision Boundary of Standard Parameters	165
4.5.2 Sectoral Detection Quality and Baseline Latency Constraints	167
4.6 Comparative Efficiency Solution Mapping.....	169
4.6.1 Distribution of Non-Dominated Solutions	169
4.6.2 Relative Position to the Control Baseline Group	171
4.7 Real Performance Evaluation on Testing Data	172
4.7.1 Final Performance Evaluation of the NIDS.....	172
4.7.2 Confusion Matrix Analysis.....	177
4.7.3 Final Model Artifacts and Deployment Package.....	180
4.8 Statistical Significance and Reliability Validation Testing.....	180
4.8.1 Reliability Analysis via Cohen's Kappa Index	181
4.8.2 Performance Stability Validation via Stratified 5-Fold Cross-Validation	182
4.8.3 Formal Kruskal-Wallis Hypothesis Testing	185
4.9 Meta-Insight Sensitivity Analysis	187
4.9.1 Sensitivity of Hyperparameter Architecture.....	188
4.9.2 Extraction of Critical Cyber Traffic Indicators	191
4.10 Discussion of Experimental Results.....	194
4.10.1 Rationalization of TPE as the Optimal Overall Solution	195
4.10.2 NSGA-II Mechanics in Mapping the Pareto Frontier	195
4.10.3 Significant Recall Enhancement for the DoS Class	196
4.10.4 Persistent Detection Challenges in the Probe Class	196
4.10.5 Operational Implications and Trade-offs in Real-World NIDS	197
4.11 NIDS Prototype Simulation Implementation	197
4.11.1 Dashboard Interface Display	198
4.11.2 Simulation Scenario Test Results.....	203
CHAPTER V CLOSING	209
5.1 Conclusion.....	209
5.2 Future Recommendations	212
BIBLIOGRAPHY.....	215

LIST OF FIGURES

Figure 3. 1 Flowchart of the KDD-Based Research Framework.....	50
Figure 3. 2 Diagram of the Research Technology Stack (Tech Stack).....	56
Figure 3. 3 Flowchart of the Data Preprocessing Stages	61
Figure 3. 4 Flowchart of the Data Transformation Stages.....	67
Figure 3. 5 Architectural Workflow of Gradient Boosting (XGBoost).....	76
Figure 3. 6 Structural Diagram of the XGBoost Mechanism with GPU Acceleration	80
Figure 3. 7 Comparison Diagram of Objective Function Scoring Mechanisms.....	83
Figure 3. 8 Procedural Workflow of the TPE System.	88
Figure 3. 9 Procedural Workflow of the NSGA-II System.	93
Figure 3. 10 Comprehensive Model Evaluation Framework.....	101
Figure 3. 11 Process Flowchart of Hyperparameter Importance Analysis Using a Surrogate Model.....	105
Figure 3. 12 Procedural Flowchart of the Confusion Matrix.....	106
Figure 3. 13 Procedural Flowchart of Cohen's Kappa	110
Figure 3. 14 Illustrative Diagram of the Pareto Front Curve	116
Figure 3. 15 Flowchart of the XGBoost Feature Importance Analysis.	119
Figure 3. 16 Architectural Diagram of the Validation Schema (Stratified K-Fold Cross Validation)	121
Figure 3. 17 Logical Flowchart of the Significance Test.....	124
Figure 3. 18 Modular Architecture of the Streamlit-Based NIDS Simulation	128
Figure 3. 19 Flowchart of the Simulation Logical Flow.....	131
Figure 3. 20 Dashboard Wireframe	136
Figure 4. 1 Output of the Experimental Computing Environment Verification	141
Figure 4. 2 Output of the Core Library Version Catalog.....	143
Figure 4. 3 Class Frequency Distribution of the Training and Testing Datasets....	147
Figure 4. 4 Audit Results of the Dataset Preprocessing Pipeline	149
Figure 4. 5 Audit Results of NetFlow Features Ready for Training.....	152
Figure 4. 6 Comparison of Class Distribution Before and After Hybrid Weighting	155

Figure 4. 7 Hybrid Weight Multipliers per Class and Weighting Impact	156
Figure 4. 8 Optimal Parameters and Objective Values of TPE Pareto Solutions....	160
Figure 4. 9 Optimal Parameters and Objective Values of NSGA-II Pareto Solutions	162
Figure 4. 10 Convergence Curves of the Validation Macro F1-Score and Pareto Solution Positions for TPE and NSGA-II	164
Figure 4. 11 Default Operational Parameters of the XGBoost Baseline	167
Figure 4. 12 Output of the Baseline Model Classification Report	169
Figure 4. 13 Pareto Frontier and Baseline Marker	171
Figure 4. 14 Master Table of Final NIDS Performance Results	174
Figure 4. 15 Classification Report of the TPE Testing Set	175
Figure 4. 16 Classification Report of the NSGA-II Testing Set.....	176
Figure 4. 17 Classification Report of the Baseline Testing Set.....	176
Figure 4. 18 Comparison of the Raw Confusion Matrices Across Three Models (Baseline, TPE, and NSGA-II).....	178
Figure 4. 19 Comparison of the Normalized Confusion Matrices Across Three Models	179
Figure 4. 20 Cohen's Kappa Reliability Table and Model Association Bar Chart..	181
Figure 4. 21 Boxplot Distribution of Macro F1-Scores and Inference Times Across Cross-Validation Folds	183
Figure 4. 22 Performance Report per Fold for the NSGA-II Model	184
Figure 4. 23 Performance Report per Fold for the TPE Model.....	184
Figure 4. 24 Performance Report per Fold for the Baseline Model	184
Figure 4. 25 Decision Log Output of the Kruskal-Wallis Statistical Significance Test	186
Figure 4. 26 Hyperparameter Importance Scores against Target Macro F1-Score and Latency	189
Figure 4. 27 Comparison of the Most Important Features Based on Gain Across Three Models	192
Figure 4. 28 Heatmap Comparing Feature Gain Across Methods	194
Figure 4. 29 Main Dashboard Interface of the NIDS (Initial State)	198
Figure 4. 30 Dashboard Screenshot during Baseline Scenario Execution	204
Figure 4. 31 Dashboard Screenshot upon Attack Detection (True Positive).....	206

Figure 4. 32 Post-Simulation Summary Chart Screenshot	206
---	-----

LIST OF TABLES

Table 2. 1 Prior Studies.....	9
Table 2. 2 Comparison of Detection Approaches in NIDS	15
Table 2. 3 Classification of Machine Learning Approaches in Anomaly Detection	16
Table 2. 4 Comparison of Packet-Based and Flow-Based Traffic Analysis.....	17
Table 2. 5 Categories of Selected Features in the NF-UNSW-NB15 Dataset.....	20
Table 2. 6 Attack Taxonomy in the NF-UNSW-NB15 Dataset	22
Table 2. 7 Default Hyperparameter Values of the XGBoost Baseline	40
Table 3. 1 Experimental Hardware Specifications	53
Table 3. 2 Development Environment and Software Libraries	54
Table 3. 3 Sample Raw Data Structure of NF-UNSW-NB15 (First 5 Rows)	58
Table 3. 4 Class Distribution of the NF-UNSW-NB15-v3 Dataset After Label Grouping	59
Table 3. 5 Simulation of Identity Feature Removal.....	63
Table 3. 6 Dataset Metrics Before and After Median Imputation	66
Table 3. 7 Transformation Schema for Categorical Labels (Label Encoding).....	69
Table 3. 8 Summary of Class Weight Modifications Across Pipeline Stages.....	74
Table 3. 9 Sample Network Behavioral Feature Extraction for Multiclass Classification.....	76
Table 3. 10 Recurrence Simulation of Tree Formation (Boosting) on Sample S3 (DDoS).....	79
Table 3. 11 Hyperparameter Search Space for the Optimization Experiments	84
Table 3. 12 Comparative Summary of TPE Density Metrics	92
Table 3. 13 Summary of the XGBoost Baseline Metric Profile	99
Table 3. 14 Node Data Profile for Hyperparameter Importance	104
Table 3. 15 Illustration of Confusion Matrix Analysis for the Classification Model	107
Table 3. 16 Binary Aggregation Matrix Simulation for Kappa Evaluation.....	111
Table 3. 17 Summary of Pareto Dominance Filtering Outcomes.....	115
Table 3. 18 5-Fold Cross-Validation Data Partitioning Schema	123
Table 3. 19 Rank Summary for the Kruskal-Wallis Test.....	125

Table 3. 20 Design of Stability and Latency Testing Scenarios.....	133
Table 3. 21 Interface Component Specifications and Visual Logic.....	137
Table 4. 1 List of Libraries and Their Versions in the Experiment.....	144
Table 4. 2 Data Distribution by Attack Category	146
Table 4. 3 Step-by-Step Preprocessing Audit.....	148
Table 4. 4 Summary of Sample Weighting Metrics	154
Table 4. 5 Summary of Optimization Overhead and Pareto Solutions	157
Table 4. 6 TPE Pareto Solutions and Parameter Profiles	159
Table 4. 7 NSGA-II Pareto Solutions and Parameter Profiles	161
Table 4. 8 XGBoost Default Parameter Specifications	165
Table 4. 9 Baseline Model Classification Report.....	167
Table 4. 10 Performance Comparison of the Optimal Pareto Solutions Against the Baseline	172
Table 4. 11 Final Performance Comparison of Methods on Testing Data	173
Table 4. 12 Comparison of Critical Sectoral Recall Metrics.....	176
Table 4. 13 Interpretive Results of the Cohen's Kappa Index	182
Table 4. 14 Summary of Cross-Validation Performance Comparison Across Methods	184
Table 4. 15 TPE Parameter Importance with respect to Macro F1-Score.....	189
Table 4. 16 TPE Parameter Importance with respect to Latency	190
Table 4. 17 NSGA-II Parameter Importance with respect to Macro F1-Score	190
Table 4. 18 NSGA-II Parameter Importance with respect to Latency	190
Table 4. 19 Summary of Dominant Parameters Across Methods	190
Table 4. 20 Top 15 NetFlow Features Based on Global Gain Value	192
Table 4. 21 Control Panel Components in the Sidebar	200
Table 4. 22 Visualization Components in the Main Dashboard Panel.....	201
Table 4. 23 Model Specification Catalog on the Dashboard.....	202

LIST OF PROGRAM CODES

Code Program 4. 1 Verification of the Hardware Environment	139
Code Program 4. 2 Library Catalog and GPU Dry-run Test	142
Code Program 4. 3 Dataset Loading, Class Mapping, and Stratified Splitting	145
Code Program 4. 4 Preprocessing and Audit of 49 NetFlow Features	147
Code Program 4. 5 Imbalance Ratio and Hybrid Weight Calculation.....	153
Code Program 4. 6 Operational Impact of Weighting on Effective Samples	155
Code Program 4. 7 TPE Pareto Solution Log Extraction	158
Code Program 4. 8 NSGA-II Pareto Solution Log Extraction	160
Code Program 4. 9 Objective Parameter Convergence Trajectory	162
Code Program 4. 10 Default Parameters of the XGBoost Baseline	165
Code Program 4. 11 Baseline Classification Report (Validation Set)	167
Code Program 4. 12 Combined Pareto Frontier of TPE and NSGA-II	169
Code Program 4. 13 Marking the Baseline Position Against the Pareto Frontier ..	171
Code Program 4. 14 Master Table of Final Performance Results (df_results).....	173
Code Program 4. 15 Raw and Normalized Confusion Matrices.....	177
Code Program 4. 16 Cohen's Kappa Calculation.....	181
Code Program 4. 17 Stratified 5-Fold Cross-Validation	182
Code Program 4. 18 Kruskal-Wallis Hypothesis Testing.....	185
Code Program 4. 19 Surrogate Model Random Forest (Hyperparameter Importance)	188
Code Program 4. 20 Feature Gain Across Models	191
Code Program 4. 21 Dashboard NIDS Inference Pipeline	199
Code Program 4. 22 Simulation Loop and Event Classification	205