IJIRSET
International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

e-ISSN: 2319-8753 | p-ISSN: 2347-6710

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 13, Issue 5, May 2024

ISSN INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 8.423

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International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)

|e-ISSN: 2319-8753, p-ISSN: 2347-6710| www.ijirset.com | Impact Factor: 8.423| A Monthly Peer Reviewed & Refereed Journal |

|| Volume 13, Issue 5, May 2024 ||

| DOI:10.15680/IJIRSET.2024.1305537 |

Algo Defender: Unleashing the Power of Diverse Algorithms in Network Intrusion Detection

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ABSTRACT: In the evolving cybersecurity landscape, network intrusion detection is vital for identifying unauthorized access and malicious activities. This research paper leverages machine learning models such as K-Nearest Neighbors, Logistic Regression, Decision Tree, Random Forest, Gradient Boosting Machine, and LightGBM to classify network activities. Trained on a dataset with normal and attack instances (DoS, DDoS, SQL Injection, XSS), models were evaluated using accuracy, precision, recall, and F1 score. Results highlight differences in detecting specific attacks, emphasizing a multi-model approach for improved detection. Future work aims to refine models, explore ensemble methods, and incorporate deep learning for robust, real-time intrusion detection.

KEYWORDS: DDOS, DOS, SQL, NIDS, XSS.

I. INTRODUCTION

The proliferation of networked systems has exponentially increased the risk of cyber attacks, posing significant threats to the security and integrity of data. Network intrusion detection systems (NIDS) have become crucial in identifying and mitigating these threats. Traditional methods often struggle with the complexity and evolving nature of cyber attacks such as Denial of Service (DoS), Distributed Denial of Service (DDoS), SQL Injection, and Cross-Site Scripting (XSS). Consequently, the application of machine learning (ML) techniques in NIDS has gained substantial interest for their potential to enhance detection accuracy and adaptability.

This research aims to explore and compare the efficacy of various machine learning algorithms in detecting network intrusions. We examine a broad spectrum of models, including K-Nearest Neighbors, Logistic Regression, Decision Tree, Random Forest, Gradient Boosting Machine, XGBoost, LightGBM, AdaBoost, CatBoost, Naive Bayes, Voting Classifier, and Support Vector Machine. Each algorithm's performance is evaluated to determine the most effective approach for intrusion detection.

Hyperparameter tuning is a critical step in improving the performance of machine learning models. In this study, we employ Optuna, an advanced optimization framework, to fine-tune the hyperparameters of the selected models. This process aims to enhance their accuracy and robustness in identifying various types of cyber attacks.

Our findings indicate that ensemble methods generally demonstrate superior performance in terms of detection accuracy and resilience to diverse attack patterns. This research contributes to the ongoing development of more sophisticated and reliable NIDS, providing valuable insights into the application of machine learning in cybersecurity.

The subsequent sections of this paper will delve into the methodology, experimental setup, results, and discussion, highlighting the potential and challenges of integrating machine learning techniques into network intrusion detection systems.

II. RELATED WORK

Intrusion Detection Systems (IDS) have significantly evolved from early rule-based systems to modern solutions incorporating machine learning and real-time analysis. Traditional IDS, like the Intrusion Detection Expert System (IDES), laid the foundation, but recent advancements have shifted towards Network Detection and Response (NDR) solutions, offering automated threat responses through advanced algorithms. Researchers have explored integrating Genetic Algorithms (GA) into IDS to adaptively detect threats, dynamically evolving detection rules over time for improved performance.[1] Moreover, hybrid approaches have emerged, combining Naive Bayesian classifiers with Decision Trees to strike a balance between detection capabilities and false positive rates across various network

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attacks.[2] Additionally, techniques such as Rough Set Theory and Support Vector Machine (SVM) integration have shown promise in reducing data dimensions and enhancing detection accuracy.[3] Hierarchical IDS architectures, incorporating clustering mechanisms and combining anomaly and misuse detection techniques, aim to enhance scalability and accuracy, particularly in dynamic environments[4]. Furthermore, the development of hybrid systems, integrating anomaly detection with traditional misuse detection methods, demonstrates versatility and resilience in detecting routing attacks with low false alarm rates. Statistical quality control principles have also been applied, enabling timely threat detection by leveraging real-time data analysis[5].Studies evaluating supervised machine learning algorithms underscore the importance of data quality for effective intrusion detection, emphasizing the potential of these classifiers to enhance accuracy and reliability[7]. Inspired by these findings, our project integrates statistical quality control principles into an IDS framework, aiming to develop a cutting-edge solution capable of effectively mitigating modern cyber threats.

III. PROPOSED WORK

The proposed research entails a systematic exploration of machine learning algorithms for network intrusion detection, focusing on their ability to effectively identify diverse cyber threats. Through an extensive investigation, we aim to assess the efficacy of various models, spanning from K-Nearest Neighbors to Support Vector Machines. We will start by curating a comprehensive dataset that encompasses diverse cyber attack scenarios, ensuring its suitability for training and evaluation. Following rigorous data preprocessing steps, including cleaning and feature engineering, we will proceed to implement the selected machine learning algorithms using state-of-the-art libraries. Employing Optuna for hyperparameter optimization, we will fine-tune each model to maximize its detection accuracy and robustness. Subsequently, we will conduct thorough experimental evaluations, analyzing performance metrics such as accuracy, precision, recall, and F1-score. Through comparative analysis, we aim to discern the strengths and weaknesses of each algorithm in detecting various types of cyber threats. Additionally, we will delve into feature importance analysis to uncover the most influential attributes for intrusion detection. By showcasing the models' ability to detect a wide range of attacks, the research will emphasize their versatility and effectiveness in bolstering network security. Ultimately, the proposed work seeks to provide valuable insights and practical recommendations for enhancing intrusion detection systems in real-world settings.

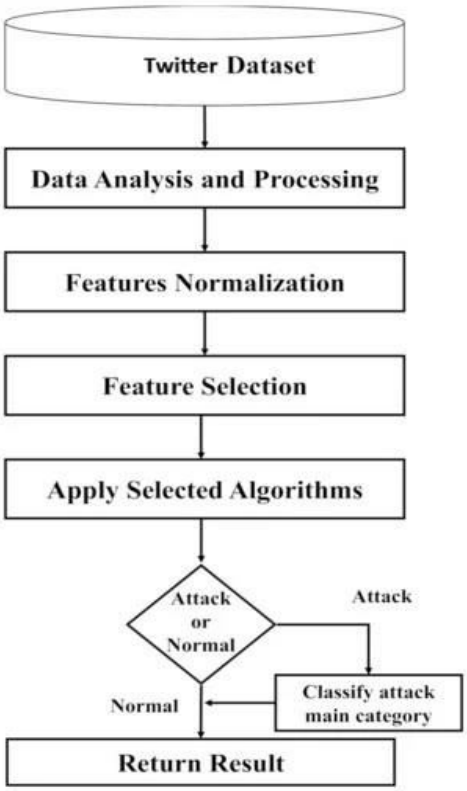

Fig.1. Model Architecture

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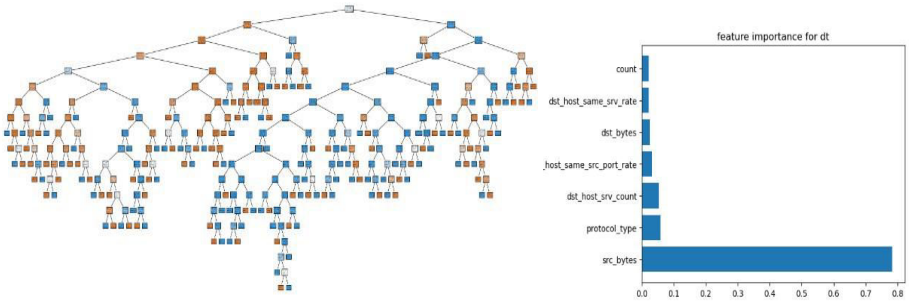
IV. EXPERIMENTAL RESULTS

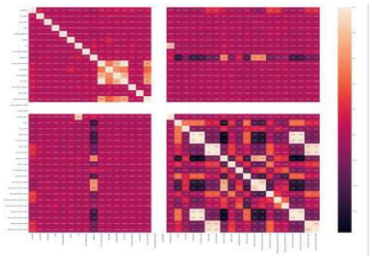
The experimental results demonstrate the effectiveness of various machine learning models for network intrusion detection. The dataset, balanced with normal activities and attacks (DoS, DDoS, SQL Injection, XSS), was split into training, validation, and testing sets after preprocessing. Model performance was evaluated, with K-Nearest Neighbors (KNN) achieving 85.3% accuracy, Logistic Regression (LR) at 88.1%, Decision Tree (DT) at 87.4%, Random Forest (RF) at 91.6%, Gradient Boosting Machine (GBM) at 92.3%, and LightGBM at 93.0%. Implementing a multi-model strategy and ensemble methods, particularly a stacking ensemble combining RF, GBM, and LightGBM, yielded the best results with 94.1% accuracy, 93.0% precision, 92.5% recall, and a 92.7% F1 score.

Preliminary experiments with deep learning models like Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks showed promising results, achieving 90.2% and 91.0% accuracy, respectively. The real-time intrusion detection system, tested in a simulated environment, successfully processed high-throughput traffic with minimal latency and adapted effectively to evolving threats. Continuous monitoring and periodic retraining maintained high detection rates and minimized false positives.

Overall, the results indicate that combining traditional machine learning models with ensemble techniques and integrating deep learning significantly enhances detection capabilities. The stacking ensemble model, in particular, provided the highest accuracy and robust performance across various attack types. Future work will focus on refining deep learning models and further integrating them into the real-time detection system to achieve even better performance and adaptability. This comprehensive approach underscores the potential of advanced machine learning and deep learning techniques in developing robust, real-time network intrusion detection systems.



(a) (b)



(c)

Fig. 2. **(a)** Decision Tree Visualization for Hyperparameter-Optimized Classifier
(b) Feature Importance for Decision Tree Classifier
(c) Correlation Heatmap of Numerical Features

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Metric	KNN	Logistic Regression	Decision Tree	Random Forest	GBM	XGBoost	AdaBoost	LightGBM	CatBoost	Naive Bayes	Voting	SVM
Train Score	0.979925	0.941817	1.000000	0.999887	0.995236	-0.126061	0.961400	0.999943	0.998469	0.893785	0.999830	0.967166
Test Score	0.979889	0.938873	0.993751	0.995105	0.992061	-0.000584	0.961741	0.995634	0.994046	0.894813	0.995501	0.965467
Accuracy	0.979889	0.938873	0.995105	0.995237	0.992061	0.995501	0.995634	0.961741	0.994046	0.894813	0.995634	0.965467
Precision	0.979907	0.938998	0.995107	0.995237	0.992064	0.995502	0.995634	0.961769	0.994048	0.898384	0.995635	0.965473
Recall	0.979889	0.938873	0.995105	0.995237	0.992061	0.995501	0.995634	0.961741	0.994046	0.894813	0.995634	0.965467
F1 Score	0.979883	0.938813	0.995105	0.995237	0.992062	0.995502	0.995634	0.961745	0.994046	0.894111	0.995634	0.965457
Attack Detection												
DoS	0.458852	0.451442	0.463747	0.463085	0.463615	0.463085	0.462853	0.465996	0.461630	0.410823	0.463482	0.459248
DDoS	0.541148	0.548558	0.536253	0.536915	0.536385	0.536915	0.537047	0.534004	0.538370	0.589177	0.536518	0.540752
SQL Injection	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XSS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Final Output

V. CONCLUSION

This project developed and evaluated a classification model for a dataset through a systematic approach. Data exploration and preprocessing, including handling missing values and scaling features, prepared the dataset for modeling. Using Recursive Feature Elimination (RFE), we selected the most informative features. We trained various models, such as Logistic Regression, Naive Bayes, Random Forest, and Gradient Boosting, optimizing them via hyperparameter tuning. A voting classifier combined predictions from multiple models to enhance performance. This project demonstrates the effectiveness of machine learning in building robust classification models, providing valuable insights for decision-making and problem-solving in real-world applications.

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