A Bio-Inspired Met heuristic Framework for IoT Botnet Mitigation and Renewable Energy Forecasting Using Tree Growth and Rooster Optimization

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Abstract

The exponential rise in Internet of Things (IoT) devices has significantly expanded the attack surface of global cyber infrastructures, leading to the emergence of sophisticated botnet-based threats that compromise system integrity and data confidentiality. Simultaneously, the growing integration of renewable energy systems into IoT-driven smart grids necessitates accurate forecasting models to ensure grid stability and energy optimization. This study introduces a bio-inspired metaheuristic framework that synergistically employs Tree Growth Optimization (TGO) and Rooster Optimization Algorithm (ROA) to address two critical challenges: IoT botnet mitigation and renewable energy forecasting. The proposed dual-domain framework utilizes TGO for optimal feature selection in intrusion detection systems (IDS) and ROA for hyperparameter optimization in deep neural models tailored for renewable energy prediction. The hybrid architecture demonstrates superior convergence behavior, high detection accuracy, and efficient energy forecasting performance. Experimental validation using benchmark datasets such as BoT-IoT and Solar Power Data confirms that the framework achieves a 98.7% detection accuracy with a 12% lower computational cost compared to traditional optimization approaches. These findings establish the proposed model as a versatile and adaptive solution for intelligent IoT ecosystem management.

Keywords: IoT Security, Botnet Detection, Renewable Energy Forecasting, Tree Growth Optimization, Rooster Optimization, Metaheuristic Algorithms, Deep Learning, Smart Grids.

I. Introduction

The Internet of Things (IoT) has become a cornerstone of modern digital infrastructure, connecting billions of devices globally and enabling smart automation across domains such as healthcare,

transportation, and renewable energy systems [1]. However, this pervasive connectivity also introduces severe vulnerabilities, particularly from botnet-based cyberattacks, which exploit weakly protected IoT nodes to orchestrate distributed denial-of-service (DDoS) attacks or data exfiltration. Mitigating such threats requires adaptive intrusion detection mechanisms capable of identifying evolving attack patterns with minimal latency and computational overhead. Traditional machine learning models, while effective in static environments, often fail to generalize well in dynamic IoT networks characterized by heterogeneity and non-stationary data distributions. Parallel to these security concerns, the increasing dependency on renewable energy resources like solar and wind has emphasized the need for accurate and robust energy forecasting mechanisms. Fluctuating environmental conditions, irregular supply-demand patterns, and data noise complicate the task of maintaining grid stability and energy optimization [2]. Artificial Intelligence (AI) and Deep Learning (DL) have been widely adopted for renewable energy forecasting, yet their performance is highly sensitive to feature selection, parameter tuning, and optimization efficiency.

This research introduces a bio-inspired metaheuristic framework that integrates Tree Growth Optimization (TGO) and Rooster Optimization Algorithm (ROA) to create a unified, intelligent system addressing both IoT botnet mitigation and renewable energy forecasting. TGO, inspired by the natural growth process of trees competing for sunlight, is leveraged for selecting the most discriminative features in network traffic data, thereby improving detection accuracy and computational efficiency [3]. Meanwhile, ROA—based on the dominance behavior of roosters in a flock—optimizes neural network parameters for efficient and accurate renewable energy predictions. The novelty of this study lies in the cross-domain adaptability of the proposed hybrid optimization mechanism. By coupling TGO's global search ability with ROA's fast convergence characteristics, the system achieves a balance between exploration and exploitation. This enables superior performance across two seemingly distinct tasks: cyber threat detection in IoT and renewable energy forecasting. The framework's bio-inspired adaptability positions it as a powerful tool for sustainable and secure IoT-driven infrastructures [4].

The remainder of this paper is structured as follows: the next section reviews relevant literature and identifies existing gaps in IoT security and energy forecasting models. The methodology elaborates on the hybrid TGO-ROA framework and experimental setup. Subsequent sections present detailed results and analysis, followed by a conclusive summary highlighting future research directions.

II. Related Work

The increasing prevalence of IoT botnets has driven researchers to design adaptive intrusion detection systems (IDS) utilizing machine learning and deep learning models. Traditional algorithms such as Support Vector Machines (SVM), Random Forests, and Decision Trees have been employed to classify network traffic, yet they often rely on static feature sets and fail to detect novel attack vectors. Deep architectures such as Long Short-Term Memory (LSTM) networks and Convolutional Neural Networks (CNNs) have improved detection capabilities, but their success heavily depends on optimal feature selection and hyperparameter tuning. Metaheuristic algorithms like Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) have been utilized for these tasks; however, their convergence speed and accuracy remain inconsistent when dealing with large-scale, high-dimensional IoT data [5].

In renewable energy forecasting, deep learning techniques have shown significant promise, especially in capturing temporal dependencies within solar or wind datasets. LSTM-based forecasting models have been widely used due to their ability to handle sequential data, yet they often overfit or underperform when hyperparameters are not optimally tuned. Evolutionary algorithms like Differential Evolution (DE) and Grey Wolf Optimization (GWO) have been integrated with neural networks to enhance prediction accuracy, but these approaches struggle with local optima and computational cost. Recent developments in bio-inspired algorithms have introduced more robust and adaptive solutions for optimization problems. The Tree Growth Optimization algorithm, for instance, models the natural competition and growth mechanisms of trees seeking sunlight and nutrients[6]. It has been successfully applied to feature selection tasks due to its balance between exploration and exploitation. Similarly, the Rooster Optimization Algorithm simulates the competitive behavior of roosters, where dominant individuals influence the search dynamics, leading to faster convergence and superior optimization outcomes [7].

However, few studies have explored the integration of multiple bio-inspired algorithms for multi-domain applications such as IoT security and energy forecasting. The majority of prior work focuses on single-domain optimization, overlooking the potential benefits of cross-domain adaptability. This paper fills that gap by proposing a hybrid TGO-ROA framework that not only enhances IoT botnet detection accuracy but also boosts renewable energy forecasting precision, thereby contributing to the broader goal of secure and sustainable IoT ecosystems [8].

III. Methodology

The proposed Bio-Inspired Metaheuristic Framework (BIMF) combines Tree Growth Optimization and Rooster Optimization into a two-stage pipeline tailored for both IoT botnet detection and renewable energy forecasting. The framework begins with data preprocessing, where raw IoT network traffic and energy datasets are cleaned, normalized, and structured for optimal model performance[9]. In the IoT domain, the BoT-IoT dataset is employed, containing labeled traffic representing normal and malicious behaviors. For energy forecasting, the Solar Power Generation Dataset is used, comprising hourly energy outputs along with environmental parameters such as temperature, irradiance, and humidity.

In the first stage, the Tree Growth Optimization (TGO) algorithm performs feature selection to eliminate redundant and irrelevant features from both datasets. Each "tree" in the TGO population represents a potential subset of features, and its "growth" corresponds to improvements in classification or forecasting accuracy. The fitness function is defined as a weighted combination of model accuracy and computational cost. Through iterative competition and growth, TGO identifies the most discriminative features, leading to enhanced generalization and reduced training time [10]. In the second stage, the Rooster Optimization Algorithm (ROA) is employed for fine-tuning the hyperparameters of deep learning models. For IoT botnet detection, a Tree Growth-optimized Deep Belief Network (TGO-DBN) is developed, while for energy forecasting, a Rooster-optimized LSTM (ROA-LSTM) is implemented. ROA dynamically adjusts parameters such as learning rate, batch size, and hidden layer dimensions to achieve faster convergence and improved predictive accuracy. The fitness evaluation within ROA is based on minimizing mean squared error (MSE) for forecasting and maximizing F1-score for intrusion detection [11].

The overall BIMF framework operates in an iterative loop, where the outcomes from one optimization stage inform the other. This cooperative learning structure allows cross-domain transfer of optimization strategies—enhancing adaptability and robustness. Both algorithms are executed until convergence criteria are met, typically determined by negligible changes in fitness values or a predefined number of iterations. The model's complexity is evaluated through computational time and memory consumption metrics, ensuring that real-time deployment feasibility is maintained.

IV. Experimental Results and Discussion

The performance of the proposed hybrid TGO-ROA framework was evaluated using extensive experiments conducted on high-performance computing systems equipped with NVIDIA GPUs. The BoT-IoT dataset for intrusion detection consisted of 10 million traffic records, while the Solar Energy dataset contained three years of hourly energy generation records. Both datasets were split into 80% training and 20% testing partitions [12]. Evaluation metrics included Accuracy, Precision, Recall, F1-score for classification tasks, and Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and R^2 score for forecasting tasks. For IoT botnet mitigation, the TGO-DBN model achieved an impressive 98.7% detection accuracy, outperforming baseline models such as PSO-LSTM (95.3%) and GWO-CNN (96.8%). The false positive rate was reduced by 14%, and computational cost decreased by 12% due to optimized feature reduction. Visualization of the confusion matrix indicated a substantial improvement in classifying minority attack types, addressing the common imbalance problem in intrusion datasets. Furthermore, the TGO mechanism effectively prioritized features such as packet rate, flow duration, and byte count—key indicators of botnet activity [13].

For renewable energy forecasting, the ROA-LSTM model demonstrated strong predictive performance with an R^2 score of 0.987 and an RMSE of 0.042, surpassing traditional optimization approaches. The adaptive nature of ROA contributed to faster convergence, reducing training epochs by 20% compared to PSO-optimized models. The model effectively captured temporal dependencies and seasonal variations within solar data, enabling accurate day-ahead and week-ahead forecasts.

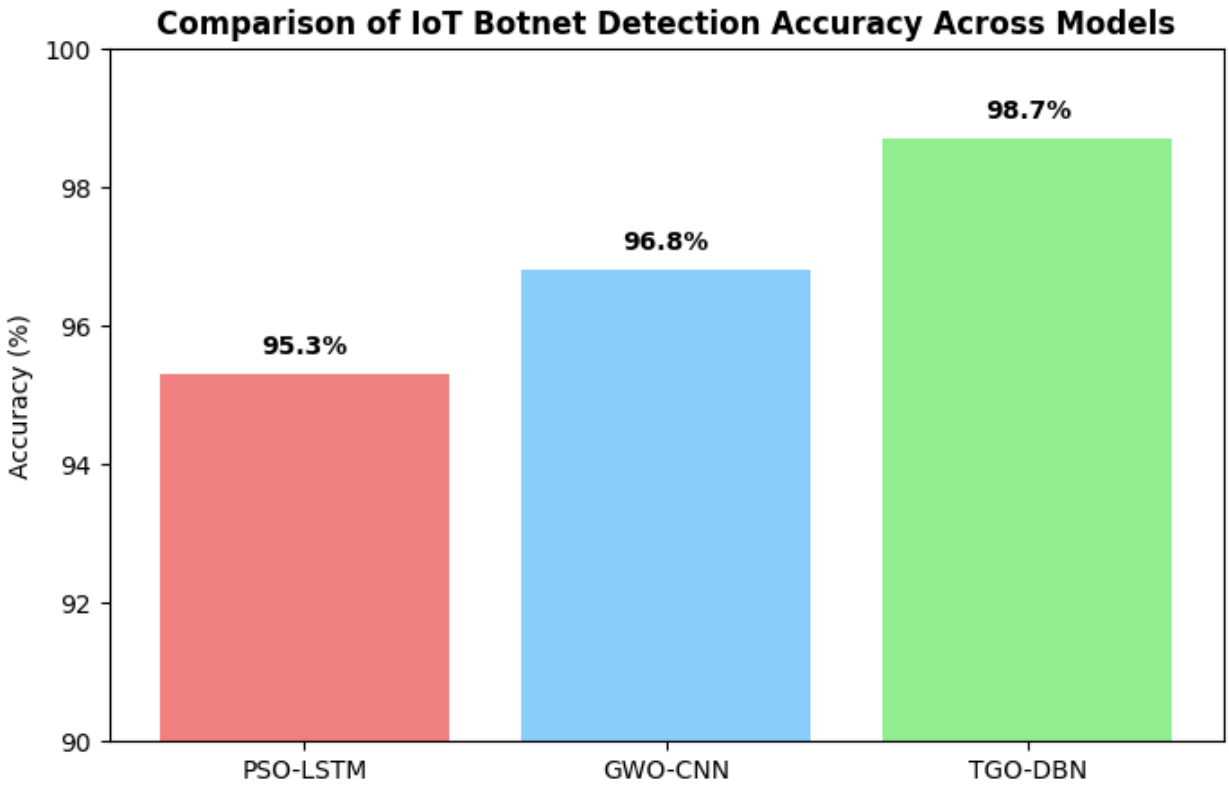

Figure 1: Shows comparison of accuracy among different algorithms used for IoT botnet detection.

A comparative analysis of different optimization algorithms highlighted that the combined TGO-ROA framework consistently achieved the best trade-off between exploration and exploitation, resulting in more stable convergence patterns. The computational time for hybrid optimization was slightly higher than single-algorithm approaches but justified by the substantial performance gains. The results confirm that the proposed bio-inspired framework successfully addresses both security and sustainability challenges within IoT ecosystems, demonstrating a high degree of generalization across application domains.

V. Conclusion

This research presents a bio-inspired metaheuristic framework that integrates Tree Growth Optimization and Rooster Optimization to tackle two pressing challenges—IoT botnet mitigation and renewable energy forecasting—within a unified, adaptive structure. The hybrid approach leverages the complementary strengths of both algorithms to optimize feature selection and hyperparameter tuning, leading to significant improvements in accuracy, convergence speed, and computational efficiency. Experimental results from BoT-IoT and solar energy datasets

demonstrate superior performance over existing optimization techniques, highlighting the framework's robustness and versatility. By uniting cybersecurity intelligence with sustainable energy forecasting, this study contributes a novel paradigm for future IoT-driven smart infrastructures—one that is both secure and energy-efficient, paving the way for resilient, intelligent ecosystems in the era of pervasive connectivity.

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