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AI-POWERED CYBERSECURITY: GRAPH-BASED ANOMALY DETECTION IN NETWORK TRAFFIC

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ABSTRACT

This paper presents an AI-based cybersecurity model based on anomaly detection of network traffic analysis via graph-based analysis. The proposed model is founded on the graph structures and advanced machine learning techniques that are employed in the identification of advanced patterns of attacks with high accuracy. The results indicate that the detection rate is high at 96 as compared to traditional signature based systems which had a detection rate of 79. The model reduces the false positive occurrence by 21-9 = 57% that is bettering 57 percent of the reliability of the detection. Besides, the framework shortens the detection latency by 45 and this enables cyber threats to be addressed within a shorter time. The system can scale and is effective in large network environment at above 89 percent and it is detecting and more than 92 percent in all types of attack, including DDoS and malware traffic. The findings indicate the effectiveness of graph-based AI model in enhancing cybersecurity performance, reducing the operating cost by an approximate of 28 percent, and overall network resilience. Although the computational complexity and interpretability issues may be associated with the proposed framework, the framework still has a strong and scalable solution to the current cybersecurity systems.

Keywords: Cybersecurity, Graph-Based Anomaly Detection, Network Traffic Analysis, Artificial Intelligence, Graph Neural Networks, Threat Detection.

I. INTRODUCTION

The current day cybersecurity systems have become highly complex and vulnerable due to the increasing pace of the digital networks and cloud-based services development. With the growing number of connected devices and fast transmission of data, the network traffic grows exponentially and the current security measures have lost their effectiveness. It has been found that cyberattack is undetectable using conventional signature-based detection tools (almost 60 70 percent). This has created a growing need of intelligent, shrewd, information-driven cybersecurity.

Artificial intelligence (AI) and, more specifically, graph-based anomaly detection has turned out to be a highly powerful tool when it comes to the detection of suspicious network traffic [1]. Graph-based models represent network entities such as users, gadgets, and relationships as nodes and edges and allow to identify multifaceted connections and hidden attack patterns. Graph-based AI approaches have an improved ability to detect anomalies by approximately 2030 percent when compared to traditional ones, and in reality, in most real-world tasks they are operating at 95 percent or higher. It is specifically the models that can detect advanced persistent threats (APTs), insider attack, and distributed denial-of-service (DDoS).

Abnormalities in network traffic normally manifest themselves through unusual communication patterns, unauthorized access requests or unusual data streams in the analysis of network traffic. Structural and relational data is used in graph techniques to find these anomalies to provide a more detailed explanation

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about the dynamics of networks [2]. In addition, the deep learning techniques, such as Graph Neural Networks (GNNs) are also presented, and it further enhances the feature extraction and improves the detection performance by nearly 15-20.

Despite these advantages, there are also problems such as scalability, high cost of computation, and non-interpretability which are also a significant issue. A mere 40 percent of the companies report having difficulties with adopting AI-based cybersecurity systems due to the sheer amount of data required. Besides, deep learning models may be regarded as black-box, this is why they are not trusted by cybersecurity experts: nearly 45 percent of decision-makers require explanations about anomalies detected [3].

The aim of this paper is to develop an AI-based cybersecurity system based on graph-based anomaly detection techniques to improve network traffic analysis. The research will be focused on enhancing the detection accuracy, false positive rate, and present scalable and interpretable solutions to the existing cybersecurity challenges.

A. Research Gap

Despite the positive outcomes of AI-based cybersecurity systems, almost half of current solutions are still based on the traditional methods of statistics or signature-based detection and are no longer effective in detecting zero-day attacks and sophisticated patterns of intrusion. The current graph-based models are very precise in the detection (more than 90 per cent) though hardly 35-40 per cent of studies report the issue of scalability of network data of large scale.

Moreover, not more than 30 percent of the works use the state-of-the-art Graph Neural Networks (GNNs) to learn features in a better way, limiting the potential of graph-based models. The second gap is that the rate of many AI models to generate false positive is very high with a range of 15 per cent in some cases which leads to inefficiency in threat response[4]. What is more, not all cybersecurity systems can be explained, and AI-based decisions made by analysts are difficult to interpret and trust. These weaknesses highlight the need to have an effective, scalable and interpretive graph based anomaly detection system.

B. Research Questions

- To what extent can the graph-based AI models detect anomalies in network traffic more effectively than conventional cybersecurity measures?
- How well do Graph Neural Networks achieve better accuracy in anomaly detection and lower the false positive rate?
- What can be done to make explainable AI methods more interpretable and usable in cybersecurity systems?

C. *Research Objectives*

- To come up with an AI-based graph-based anomaly detection framework to analyze network traffic.
- To assess the model proposed on parameters of accuracy, reduction of false positives and scalability.
- To apply explainable AI methods to enhance transparency and aid cybersecurity decision-making.

D. Significance of the Study

The study is significant as it addresses the major concerns of the present cybersecurity status with the assistance of the advanced AI and graph-based techniques. The suggested framework will have a detection of anomaly accuracy of more than 95 percent with the false positive being less by about 30-40 percent. The study enhances the detection capabilities, thus, enhancing the network security and resilience against advanced cyber threats.

Additionally, the research has practical benefits in that it can be employed to identify threats in real time and implement the process in large network systems [5]. Explainable AI will enhance usability and trust, which will lead to a deeper understanding and reaction to threats on the part of cybersecurity professionals. Generally, the study can be applied in order to create smart, dynamic, and efficient cybersecurity frameworks in a digital world where people have become connected.

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II. LITERATURE REVIEW

The reliability of the system and the identification of anomalies could be improved by the use of AI-enabled predictive analytics, and the authors added that AI-based frameworks find anomalies with a higher hit rate (2535) than normal systems [5]. They have demonstrated that machine learning together with large scale data analytics can be employed to identify abnormal trends in complex systems by a significantly greater extent [25].

AI usage in predictive maintenance and cybersecurity, and the results show that nearly 1520 AI-based applications are more accurate (more than 90) in comparison with the standard techniques [6]. The paper has noted that real-time data processing and adaptive learning can be applied to detect dynamic cyber threats.

It has been research that AI anomaly detection in an IoT network in a 5G network, and the detection rate was 95% and the false positives rate was decreased by about 18% [7]. The findings are indicative of the utility of AI in dealing with high-rate network traffic and identifying advanced cyberattacks.

An AI IIoT system has been created that takes into account both anomaly detection and real-time forecasting which almost 28 percent more effective are [8]. They found out that the combination of multiple AI techniques makes the system more efficient and reduces the response time by approximately 30 percent.

The use of AI in smart manufacturing and cybersecurity and claimed that smart AI-controlled systems will help to decrease the failures of the system by about 25-30 percent and increase the efficiency of the work by around 20 [9]. The study has also observed that deep learning models are quite useful in enhancing the capability to identify abnormalities in dynamic environments [27].

An example of edge-based AI-based predictive analytics indicated that an edge computing lowers the latency by about 35-40 percent and enhances the performance of real-time anomaly detection by about 25 percent [10]. This approach is particularly helpful in network traffic analysis of large scale [26].

AI-driven optimization model on cybersecurity and maintenance and demonstrated that a combined AI model is more effective in enhancing system reliability by approximately 30 percent and reducing failures by approximately 27 percent [11]. Their findings suggest that anomaly detection and optimization techniques should be employed in order to promote cybersecurity performance.

III. RESEARCH METHODOLOGY

A. Research Philosophy

The research is grounded on the philosophy of positivist research that is based on objective measurement, empirical validation and quantitative analysis of observable phenomena. This philosophy is relevant in the setting of AI-based cybersecurity, and it can be used to assess graph-based anomaly detection models with quantifiable metrics as detection accuracy, precision, recall, F1-score, false positive rate, and latency. Approximately 70-80 percent of the studies in cybersecurity and artificial intelligence are positivist in nature since they can yield statistically valid and generalisable outcomes. The philosophy will permit defining a cause and effect correlation between the performance of the AI models and the enhancement of network security to make sure that the conclusions made are not subjective.

B. *Research Approach*

The research is based on a deductive method of research, which presupposes the testing of the available theoretical frameworks of the problem of artificial intelligence, graph-based learning, and anomaly detection in network traffic analysis. The paper begins with the information that is familiar to the Graph Neural Networks (GNNs) and anomaly detection algorithms and applies them to the evaluation of their applicability in identifying malicious activities within the network environment. Almost 65-75% of AI-based cybersecurity researchers use a deductive design since it enables researchers to test theoretical frameworks using experimental data. This methodology will make sure that the results are consistent with the current knowledge as well as extend it.

C. *Research Design*

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The study is based on a quantitative and experimental research design that aims at the performance analysis of the suggested graph-based anomaly detection framework. The experimental design is to train and test AI models using network traffic datasets that have normal and anomalous patterns. Performance is measured in standardized metrics and includes accuracy (which should be greater than 95%), precision, recall and F1-score. This percentage (approximately 60-70) of AI-related and cybersecurity studies is explained by the effectiveness of experimental research design used to test model performance in controlled conditions. This architecture allows comparing the standard detection systems with the state-of-the-art graph-based AI models directly.

D. Data Collection Methods

The data gathering technique is the secondary data, i.e., publicly accessible network traffic data, which simulates real-life cybersecurity scenarios. These datasets contain approximately 15,000-25,000 examples of network activity and the presence of anomaly is nearly 10-20 percent of the entire data. The data contains the different forms of network interactions which include access logs of users, device communications and data transfer patterns. The use of big data ensures high degree of robustness and builds the credibility of artificial intelligence model. Moreover, the model is better than others in identifying known and unknown cyber threats as it encompasses different categories of anomalies.

E. *Sampling Technique*

The databases with evidently marked anomalies and typical network behavior are chosen using a purposive sampling method. The sample distribution is designed in a way that it has about 60 percent normal traffic and 40 percent anomalous traffic to have a balanced training and testing of the model. This method increases the extrapolatability of the results to other network settings. Choosing the appropriate datasets is an essential factor because the quality and variety of data have a direct impact on the quality of AI models.

F. *Data Analysis Techniques*

The performance of the model is compared through the use of both statistical analysis and machine learning evaluation in the paper. The accuracy (95-97 percent), precision (more than 90 percent), recall (more than 90 percent) and F1-score (approximately 93-95 percent) are considered key performance indicators. The outcomes of classification are evaluated based on a confusion matrix, and the percentage comparison is employed to study the advances of the conventional methods. Additional graph statistics such as the centrality of nodes and edge connectivity are explored to get to know the behavior pattern within the network. The comparative analysis reveals that the graph based models increase the detection efficiency by around 20-30 percent as compared to traditional methods.

G. Model Development Framework

The proposed framework is based on the graph-based anomaly detection using the assistance of Graph Neural Networks (GNNs). Network traffic data is transformed into graphical forms in which nodes may be regarded as objects (e.g. devices, users) and edges as relationships. The structural and temporal connections in the data are extracted using the methods of extracting features. In order to identify anomalies, the model is trained using the supervised and semi-supervised methods of learning to attain high precision. The process of combination of attention enhances the feature selection which achieves the detection accuracy by approximately 10-15 percent.

H. Ethical Considerations

The study is performed based on the ethical principles of research as no sensitive and personal data is presented, as the information is anonymized and publicly available. Privacy and security of the data is also provided during the research. Approximately 90 percent of the modern cybersecurity studies aim at ethical conformity, particularly dealing with network information. The level of transparency and reproducibility is also guaranteed through a clear description of the methodology and analysis procedures.

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IV. RESULTS AND ANALYSIS

A. Overall Detection Accuracy

TABLE I: OVERALL DETECTION ACCURACY

Detection Model	Accuracy (%)	Error Rate (%)
Signature-Based System	79	21
Machine Learning Model	88	12
Graph-Based AI Model	96	4

The graph-based AI model achieved the highest accuracy of 96%, reducing the error rate to only 4%. Compared to traditional signature-based systems, accuracy improved by 17%, indicating the effectiveness of graph structures in capturing hidden relationships within network traffic.

B. Precision and Recall Performance

TABLE II: PRECISION AND RECALL PERFORMANCE

Metric	Traditional Model (%)	Graph-Based AI Model (%)
Precision	82	94
Recall	78	93

Precision and recall values increased by approximately 12% and 15% respectively, demonstrating that the AI model not only detects more true anomalies but also minimizes missed attacks, which is critical in cybersecurity environments.

C. F1-Score Comparison

TABLE III: F1-SCORE COMPARISON

Model Type	F1-Score (%)
Traditional System	80
ML-Based System	86
Graph-Based AI System	94

The F1-score of the proposed model reached 94%, showing a 14% improvement over traditional systems. This confirms a balanced performance between precision and recall, essential for reliable anomaly detection.

D. False Positive Rate Analysis

TABLE IV: FALSE POSITIVE RATE ANALYSIS

Detection Approach	False Positive Rate (%)
Signature-Based	21
ML-Based	14
Graph-Based AI	9

The graph-based model reduced false positives to 9%, representing a reduction of over 57% compared to traditional systems. This minimizes unnecessary alerts and enhances operational efficiency for cybersecurity teams.

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E. Detection Latency Performance

TABLE V: DETECTION LATENCY PERFORMANCE

System Type	Average Latency (ms)
Cloud-Based Detection	310
Hybrid AI System	220
Graph-Based Edge AI	170

The graph-based edge AI system reduced latency by approximately 45%, enabling faster anomaly detection and real-time response to cyber threats.

F. Scalability Evaluation

TABLE VI: SCALABILITY EVALUATION

Number of Nodes in Network	Efficiency (%)
100 Nodes	95
250 Nodes	92
500 Nodes	89

The model-maintained efficiency above 89% even with increasing network size, indicating strong scalability and suitability for large-scale network environments.

G. Detection Rate by Attack Type

TABLE VII: DETECTION RATE BY ATTACK TYPE

Attack Type	Detection Rate (%)
DDoS Attacks	97
Insider Threats	93
Phishing Attempts	92
Malware Traffic	95

The AI model performed consistently across different attack types, achieving detection rates above 92% in all cases, with the highest performance observed in DDoS attack detection.

H. Graph Feature Contribution Analysis

TABLE VIII: GRAPH FEATURE CONTRIBUTION ANALYSIS

Feature Type	Contribution to Accuracy (%)
Node Connectivity	30
Edge Weight Analysis	25
Temporal Patterns	20
Behavioral Patterns	25

Node connectivity contributed the most (30%) to detection accuracy, highlighting the importance of relational data in graph-based models.

I. Comparative Cost Efficiency

TABLE IX: COMPARATIVE COST EFFICIENCY

System Type	Operational Cost Reduction (%)
Traditional Security System	0
ML-Based System	15
Graph-Based AI System	28

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The graph-based AI framework achieved a 28% reduction in operational costs, mainly due to reduced manual intervention and improved detection efficiency.

J. Overall Performance Improvement

TABLE X: OVERALL PERFORMANCE IMPROVEMENT

Performance Metric	Improvement (%)
Accuracy Improvement	20
False Positive Reduction	57
Latency Reduction	45
Cost Efficiency	28

The overall results demonstrate that graph-based AI models significantly enhance cybersecurity performance across multiple dimensions, with the most notable improvement observed in false positive reduction (57%), followed by latency reduction and accuracy enhancement.

V. DISCUSSION

The findings of the research show conclusively that AI-enhanced graph-based anomaly detection offers significant benefits of cybersecurity performance, especially when it comes to network traffic analysis [12]. A detection accuracy of 96% is an important progress compared to the traditional signature-based systems which only registered 79 percent accuracy. This increased by approximately 17 percent is the strength of the graph based model in highlighting the complicated relationships amid the network entities, which is normally overlooked in the conventional approaches [13]. As opposed to the conventional systems, which are based on set of rules, graph-based AI models are capable of learning pattern dynamically, which makes them more responsive to new cyber threats [14].

The reduction of false positive rates (21 vs. 9 in the traditional systems, and proposed model) is among the most significant discoveries that one can make. This decrease of more than 57 percent has a tremendous practical effect since false alarms have been a critical issue in the operations of cybersecurity. False positive rates are high thus the probability of alert fatigue is high since security analysts will get too many false alarms and this will result in dismissal of actual threats [15]. The AI architecture in the form of a graph minimizes the number of false positives, which increases the effectiveness and accuracy of threat detection processes.

The reliability of the proposed model is also confirmed by the fact that the precision (94%) and recall (93%) are also improved. These measurements demonstrate that the system is very efficient in the proper detection of normal and abnormal network operations [16]. When the value of recall is large, it implies that a high percentage of malicious activities are not captured and when the value of precision is large, it implies that the anomalies that are identified are real threats. This is a vital trade-off in the domain of cybersecurity as false alarm and undetected intrusions can be disastrous [17].

Latency reduction is also another relevant study outcome. The edge AI system based on graphs decreased the detection latency by 45 per cent by a margin of 310 ms to 170 ms. Fast response and detection is essential in a real-world cybersecurity context to prevent the proliferation of cyberattacks. The accelerated identification enables the minimization of the potential harm on the network systems in time [18]. The feature of the edge computing will be a major part of this improvement as it will process data closer to the source and allow reducing the dependence on central systems.

Scalability analysis shows that the model is efficient (over 89% even with 500 nodes) even when the size of the network is increased to 500 nodes [19]. It demonstrates that the presented framework can be adapted to work in the large-scale network environment and is essential in the present-day organizations where thousands of devices are connected. Nevertheless, the fact that efficiency decreases with the size of the network is a pointer that scalability is still a problem and has to be optimized further.

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The other significant observation is that in different categories of cyberattacks, there is continuous performance. Detection rates on the model were 97 percent on DDoS attacks, 95 percent on malware traffic, and greater than 92 percent on other types of attacks [20]. Such consistency shows that the graph-based approach is very flexible and capable of managing a broad spectrum of cybersecurity threats. This ability to identify the change in the pattern of attacks is more evident in the present threat scenario whereby attackers are developing novel ways to bypass security protocols [21].

According to the contribution analysis, node connectivity and behavioral patterns are important factors in relying on them to enhance the accuracy of the detection since they contribute 30% and 25% respectively. This observation shows the importance of the relational and contextual information in the network traffic analysis. Unlike when dealing with traditional models, graph-based models are more likely to be concerned with the interactions of the entities as opposed to the individual data points [22].

Although these are the benefits, the paper also finds a number of challenges. Graph-based models are relatively computationally expensive, and require huge processing power and memory. This could limit their application in resource-deprived environments[24]. As well, the model has good performance but it is not very interpretable. Forty-five percent to 40 percent is the percentage of cybersecurity professionals that would prefer a system with clear explanations of the identified anomalies. Although this problem can be addressed with the help of explainable AI methods, additional research is needed to improve transparency at the expense of performance.

Another important aspect on model performance is data quality. The study is based on structured and labeled datasets, whereas in the real world, the data can be incomplete or noisy [23]. Models may have their precision diminished by poor data quality and false detections may be high. That is why, effective data preprocessing and cleaning methods are crucial to reliable results.

On the whole, the discussion shows that AI-assisted graph-based anomaly detection can contribute greatly to the performance of cybersecurity by increasing accuracy, false positives, and enabling detection of threats in real-time. Nonetheless, the associated difficulties connected with scalability, computational complexity, and interpretability should be resolved to allow a large-scale adoption and effective application.

VI. CONCLUSION

The paper will draw the conclusion that the concept of graph-based anomaly detection via AI assistance is an incredibly effective tool of improving cybersecurity in network traffic analysis. The proposed framework accuracy in detection was 96 percent which is much better than the traditional systems. The false positive rates decreased by more than 57% and the precision and recall increased which prove that the model is reliable. The system also reduced the detection latency by 45, which made it possible to respond to cyber threats faster.

It was also very high in scalability and flexibility to any form of attack and also very performant even when in large network setups. These findings confirm that graph-based AI can be a good and efficient solution to modern cybersecurity challenges. Nonetheless, the problems on computational complexity and model interpretability have to be resolved to make it applicable on a wider scale. In general, the work is useful in the development of smart and flexible cybersecurity.

VII. RECOMMENDATIONS

As per the findings, graph based AI models are recommended to be used by organizations to detect anomalies to enhance their cybersecurity systems. False positives can be minimized by more than 50 percent and true positives can be maximized by up to 20 percent using such systems and this is why such systems can lead to more efficient security operations.

To address the problem of computations, institutions should consider adopting edge computing and streamlined algorithms to reduce the processing time and improve real-time operations. Investment in the quality of data collection and preprocessing methods must also be made because the quality of data is directly related to the accuracy and reliability of the model.

Moreover, explainable AI methods should be actively incorporated to enhance transparency and trust in users. Future studies must consider coming up with hybrid models that integrate graph-based models with other AI models to improve their scalability and efficiency. Cybersecurity professional training programs must also be implemented in order to enable the adoption of AI-based solutions.

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