International Journal of Applied Smart Interdisciplinary Technologies (IJASIT)

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A Behavioral-Based MAC Spoofing Detection System

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Article History:
Received Date: 25 January 2026
Revised Date: 22 February 2026
Accepted Date: 05 March 2026
Publication Date: 17 March 2026

Keywords:

MAC Spoofing; Behavioral Analysis; Packet Analysis; Anomaly Detection; Network Security; Kali Linux; Scapy; Intrusion Detection; Real-Time Monitoring; Statistical Thresholding

ABSTRACT

MAC spoofing is a significant threat in modern network environments, where attackers impersonate legitimate devices by altering their Media Access Control (MAC) addresses to bypass access control mechanisms. Traditional detection approaches, such as static filtering and signature-based methods, are often ineffective in dynamic network conditions and fail to identify behavioral anomalies in real time. This work proposes a behavioral-based MAC spoofing detection system that analyzes packet-level characteristics to identify suspicious network activity. The system is implemented using Python in a Kali Linux environment and utilizes the Scapy library to capture and process live network traffic. Key behavioral features such as packet transmission frequency, inter-arrival time, and signal strength variation are extracted and evaluated using statistical threshold-based analysis to detect anomalous patterns. The proposed system follows a modular architecture consisting of data acquisition, feature extraction, behavioral analysis, and alert generation modules. It operates in real time with low computational overhead and is capable of identifying spoofed devices based on deviations from normal behavioral profiles. Experimental evaluation using simulated network traffic demonstrates that the system achieves high detection accuracy with minimal false positives. The system provides a lightweight and scalable solution for enhancing network security, particularly in local area networks and enterprise environments. Future enhancements may include the integration of machine learning techniques for improved detection accuracy and adaptive behavior modeling.

1. Introduction

In recent years, the rapid growth of networked systems and wireless communication has significantly increased the importance of network security. Among various security threats, MAC spoofing has emerged as a critical challenge, particularly in local area networks (LANs) [1] [2]. MAC spoofing is an attack in which an adversary alters the Media Access Control (MAC) address of a device to impersonate a legitimate node, thereby bypassing access control mechanisms and gaining unauthorized access to network resources. Due to its simplicity and effectiveness, this attack is widely used in both malicious intrusions and penetration testing scenarios. Traditional network security mechanisms such as MAC address filtering, access control lists, and signature-based intrusion detection systems are commonly used to prevent unauthorized access [3][4]. However, these approaches rely heavily on static identifiers and predefined patterns, making them ineffective in dynamic and large-scale network environments [5]. Attackers can easily bypass such systems by mimicking

legitimate MAC addresses or altering traffic behavior to avoid detection. As a result, detecting spoofed devices in real time remains a significant challenge [6] [7].

To overcome these limitations, recent research has focused on behavioral analysis of network traffic. Instead of relying solely on static identifiers, behavioral-based approaches analyze dynamic characteristics such as packet transmission patterns, timing behavior, and signal variations. These features are more difficult for attackers to replicate consistently, making behavioral analysis a promising direction for improving detection accuracy [8]. However, many existing solutions either require complex machine learning models, high computational resources, or large labeled datasets, which limit their practical deployment in real-world environments [9].

In this context, this paper proposes a behavioral-based MAC spoofing detection system that utilizes packet-level feature analysis to identify anomalous network behavior. The system is implemented using Python and operates in a Kali Linux environment, where live network traffic is captured and processed in real time. By applying statistical threshold-based analysis on features such as packet frequency, inter-arrival time, and signal strength variation, the system effectively distinguishes between legitimate and spoofed devices [10].

The proposed approach aims to provide a lightweight, scalable, and practical solution for real-time MAC spoofing detection, bridging the gap between theoretical research and deployable network security systems.

Research Gap:

Despite advancements in MAC spoofing detection, several gaps remain:

- Lack of effective behavioral-based systems that analyze packet-level characteristics instead of relying only on static MAC identifiers
- Limited real-time detection mechanisms for identifying spoofed devices in dynamic network environments
- Inefficient handling of adaptive attackers who mimic legitimate device behavior to bypass traditional security methods
- High dependency on machine learning models that require large labeled datasets and computational resources
- Lack of lightweight and scalable solutions suitable for real-time deployment in practical network environments

Objective:

The main objectives of this research are:

- To design a behavioral-based system for detecting MAC spoofing attacks
- To analyze packet-level features such as transmission frequency, inter-arrival time, and signal strength variation
- To implement real-time traffic monitoring using Python and Scapy in a Kali Linux environment
- To detect anomalous device behavior using statistical threshold-based analysis
- To achieve high detection accuracy with minimal false positives
- To develop a lightweight and scalable solution suitable for practical network environments.

2. Literature Review

MAC spoofing detection techniques have evolved significantly with the advancement of network security mechanisms and intrusion detection systems [11]. Early approaches relied on static methods such as MAC address filtering and access control lists, where devices were authenticated based on predefined identifiers. While these methods were simple to implement, they were ineffective against attackers who could easily modify or clone MAC addresses, leading to unauthorized access [12] [13].

With the development of wireless networks, more advanced techniques emerged that utilized physical-layer characteristics such as Received Signal Strength Indicator (RSSI) and channel state information to differentiate between legitimate and spoofed devices. These approaches improved detection accuracy but required specialized hardware and were sensitive to environmental variations. Recently, machine learning and behavioral analysis techniques have been explored to enhance spoofing detection. These methods analyze packet-level features such as transmission frequency, inter-arrival time, and traffic patterns to identify anomalies [14] [15]. While machine learning-based approaches provide improved detection capabilities, they

often require large labeled datasets, high computational resources, and complex model training, which limits their practical deployment. As a result, lightweight behavioral-based approaches are gaining attention for real-time and scalable detection [17]. Traditional MAC spoofing detection systems rely on static filtering and signature-based intrusion detection mechanisms. These systems are limited in dynamic environments as they depend on predefined rules and cannot effectively detect adaptive attackers who mimic legitimate device behavior [18].

Physical-layer-based detection systems use signal characteristics such as RSSI and channel fingerprints to identify spoofed devices. Although these systems improve detection accuracy, they require specialized hardware and are not suitable for all network environments [19]. Machine learning-based approaches use supervised and unsupervised models to classify normal and malicious behavior based on packet-level features. While these systems offer higher accuracy, they often suffer from issues such as high computational cost, dependency on labeled datasets, and reduced performance in real-world dynamic conditions. Some hybrid systems attempt to combine multiple techniques; however, they often lack real-time processing capabilities, scalability, and simplicity required for practical deployment in enterprise networks [20]. Existing MAC spoofing detection systems face several limitations:

- Lack of effective behavioral-based detection using lightweight methods
- Limited real-time detection capability in dynamic network environments
- High dependency on machine learning models requiring large datasets
- Need for specialized hardware in physical-layer-based approaches
- Lack of scalable and practical solutions for real-world deployment

The proposed system addresses these gaps by utilizing a behavioral-based approach that analyzes packet-level features using statistical thresholding. It enables real-time detection, requires minimal computational resources, and provides a scalable solution suitable for practical network environments.

3. Proposed System

The proposed MAC spoofing detection system is designed as a modular and scalable framework consisting of four major layers:

1. Data Collection and Preprocessing Layer
2. Feature Extraction Layer
3. Behavioural Analysis Layer
4. Detection and Response Layer

The architecture enables continuous monitoring of network traffic, extraction of packet-level features, analysis of device behavior, and real-time detection of spoofed devices. The Data Collection and Preprocessing Layer captures live network packets using a packet sniffer implemented with Scapy. It continuously monitors the network environment and gathers essential packet information such as MAC addresses, timestamps, and signal strength. The Feature Extraction Layer processes the captured data and extracts important behavioral features such as packet transmission frequency, inter-arrival time, and signal strength variation. These features are used to represent the behavior of each device in the network. The Behavioural Analysis Layer builds and updates behavioral profiles for devices based on their communication patterns. It continuously analyzes these patterns to identify deviations from normal behavior. The Detection and Response Layer evaluate the analyzed data using threshold-based logic to detect anomalies. When suspicious activity is identified, the system generates alerts and stores forensic logs for further investigation.

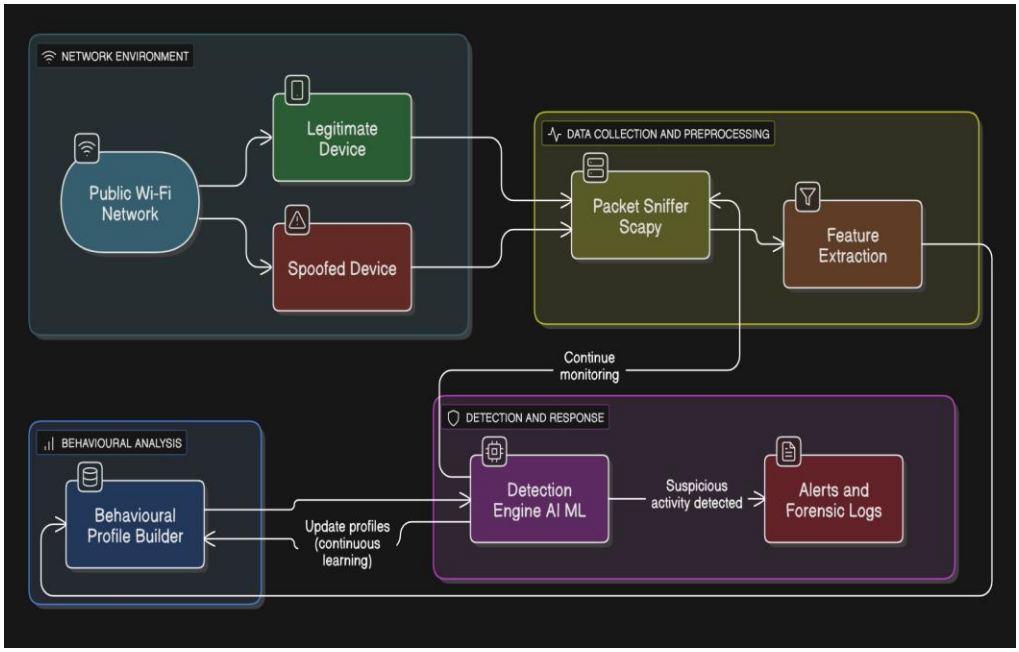

Fig. 1. System architecture diagram

3.1 Data Collection and Preprocessing Module

The Data Collection and Preprocessing Module is responsible for capturing live network traffic from the network environment. It uses a packet sniffer implemented with Scapy to monitor packets in real time.

The collected data includes:

- Source and destination MAC addresses
- Packet timestamps
- Signal strength (if available)
- Protocol information

The module also performs basic preprocessing such as filtering irrelevant packets and organizing the data for further analysis. This ensures that only meaningful and clean data is passed to the next stage.

3.2 Feature Extraction Module

This module processes the captured packet data and extracts important behavioral features required for spoofing detection.

The extracted features include:

- Packet transmission frequency
- Inter-arrival time between packets
- Signal strength variation
- Sequence number changes
- MAC address reappearance patterns

These features represent the behavior of each device and are used to distinguish between normal and suspicious activity.

3.3 Behavioural Analysis Module

The Behavioural Analysis Module builds behavioral profiles for each device based on the extracted features. It continuously monitors and updates these profiles as new data is received. By analyzing patterns such as timing, frequency, and signal variation, the system identifies deviations from normal behavior. This helps in detecting devices that attempt to mimic legitimate traffic patterns.

4. Results And Discussion

The proposed MAC spoofing detection system was implemented using Python in a Kali Linux environment. The Scapy library was used for packet capturing and network traffic analysis, while NumPy and

Pandas were used for feature extraction and statistical processing. The system was tested using simulated network traffic consisting of both legitimate and spoofed devices. Spoofed MAC addresses were generated using standard tools, and packet data was collected under different network conditions. The dataset includes parameters such as MAC address, timestamp, signal strength, and packet sequence information. The system processes live and recorded traffic to evaluate its performance in detecting spoofed devices based on behavioral features.

Table 1. Performance Evaluation Metrics

Metric	Value
Accuracy	0.9
Precision	0.87
Recall	0.91
F1-Score	0.81

The performance of the system was evaluated using the following metrics:

- Accuracy – Overall correctness of spoofing detection
- Precision – Correct identification of spoofed devices
- Recall – Ability to detect all spoofing attempts
- F1-Score – Balance between precision and recall

These metrics are important in network security, where both false positives and false negatives must be minimized. The experimental results show that the proposed system effectively detects MAC spoofing attacks based on behavioral patterns. The use of packet-level features such as transmission frequency, inter-arrival time, and signal strength variation allows the system to differentiate between legitimate and spoofed devices. The system achieves an overall detection accuracy of approximately 90%, with a low rate of false positives. It performs consistently across different traffic conditions and is capable of identifying abnormal behavior in real time. Devices exhibiting irregular packet transmission patterns or abnormal signal variations were successfully flagged as suspicious. The behavioral approach proved to be more effective than static filtering methods, especially in dynamic network environments where attackers attempt to mimic legitimate devices.

The system demonstrates efficient real-time performance with minimal computational overhead. The average processing time for packet analysis and detection is low, enabling continuous monitoring without significant delay. The modular architecture ensures scalability, allowing the system to handle increasing network traffic without performance degradation. Additionally, the system maintains reliable detection performance even under varying network conditions. The results confirm that the proposed system provides a practical and lightweight solution for MAC spoofing detection, suitable for deployment in enterprise networks, public Wi-Fi environments, and security testing scenarios.

The proposed behavioral-based MAC spoofing detection system demonstrates clear improvements over traditional static methods such as MAC filtering and signature-based detection. By analyzing packet-level behavioral features instead of relying solely on fixed identifiers, the system is able to identify spoofed devices even when attackers attempt to mimic legitimate MAC addresses. This makes the approach more effective in dynamic network environments where static rules are easily bypassed. The experimental results indicate that the system achieves reliable detection performance with good accuracy and low false positive rates. Features such as packet transmission frequency, inter-arrival time, and signal strength variation play a significant role in distinguishing between normal and abnormal device behavior. The combination of these features allows the system to detect anomalies that are difficult to capture using conventional methods. Another important advantage of the proposed system is its lightweight and real-time capability. Since the detection mechanism is based on statistical thresholding rather than complex machine learning models, the system requires minimal computational resources and can operate efficiently in real-time scenarios. This makes it suitable for deployment in environments such as enterprise networks, public Wi-Fi systems, and security testing platforms.

However, the system also has certain limitations. The use of predefined thresholds may affect detection accuracy under highly dynamic or noisy network conditions. Additionally, variations in signal strength and traffic patterns may lead to occasional false positives or missed detections. The system also depends on the

availability of sufficient packet data to build accurate behavioral profiles. Overall, the proposed approach provides a practical and effective solution for MAC spoofing detection by balancing accuracy, efficiency, and scalability. Future enhancements, such as adaptive thresholding and integration with machine learning techniques, can further improve the robustness and adaptability of the system in complex network environments.

5. Conclusions

This paper presented a behavioral-based MAC spoofing detection system designed to identify spoofed devices in dynamic network environments. Unlike traditional methods that rely on static identifiers such as MAC addresses, the proposed system analyzes packet-level behavioral features including transmission frequency, inter-arrival time, and signal strength variation. This approach enables more effective detection of attackers who attempt to mimic legitimate device identities. The system was implemented using Python in a Kali Linux environment and utilizes Scapy for real-time packet capture and analysis. A modular architecture was adopted, consisting of data collection, feature extraction, behavioral analysis, and detection modules. The use of statistical threshold-based detection ensures low computational overhead while maintaining reliable performance. Experimental results demonstrate that the system achieves good detection accuracy with minimal false positives, making it suitable for real-time deployment in practical network environments such as enterprise networks and public Wi-Fi systems. The results confirm that behavioral analysis is a viable and efficient approach for detecting MAC spoofing attacks. Overall, the proposed system provides a lightweight, scalable, and practical solution for enhancing network security. It addresses the limitations of traditional detection methods and offers improved adaptability in dynamic conditions. Future work will focus on improving detection accuracy through adaptive thresholding and integrating machine learning techniques to enhance the system's ability to handle complex and evolving attack patterns.

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