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Securing Remote Access: A Forensic Approach to Detect and Prevent Network Breaches

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Abstract: ***Remote access technologies like Virtual Private Networks (VPN), Remote Desktop Protocol (RDP), and Secure Shell (SSH) have become essential in today's hybrid and cloud-based work environments. They provide smooth connectivity for distributed teams and allow remote management of important systems. However, relying more on these tools has also increased the risk of attacks. Organizations now face threats such as credential theft, brute-force intrusions, privilege escalation, session hijacking, and stealthy data theft. Traditional security measures often do not catch targeted or slow attacks, and incident response teams find it difficult to work with incomplete digital evidence or late detections.To tackle these issues, this paper presents the Forensic-Ready Remote Access Detection Framework (FRRAD), a security approach that merges forensic readiness with remote access monitoring. FRRAD integrates log anomaly detection, automated evidence preservation, behavioral analytics, Zero Trust access controls, and policy-based incident response. Unlike typical reactive models, this framework collects, validates, and securely stores forensic evidence consistently. This allows for quick investigations and adherence to regulations. By including investigative capabilities in remote access workflows, FRRAD improves threat visibility, shortens response times, boosts attribution accuracy, and enhances overall organizational strength against complex cyberattacks.***

Keywords: Remote Access Security, Forensic Readiness, Zero Trust Architecture, VPN Vulnerabilities, SSH/RDP Monitoring, Log Anomaly Detection, Credential Abuse, Incident Response, Security Automation.

I. INTRODUCTION

The rapid growth of remote and hybrid work models has changed the way enterprise networks are built. Organizations now heavily depend on remote access technologies to keep operations running, manage systems, and support teams spread across different locations. Tools like Virtual Private Networks (VPN), Remote Desktop Protocol (RDP), and Secure Shell (SSH) are often used to create secure connections. However, this reliance also brings new security issues. Remote access points, which are often set up quickly to meet urgent business needs, can be misconfigured, poorly monitored, or based on outdated authentication methods. These flaws make them appealing targets for criminals seeking unauthorized access.

Cybercriminals are increasingly taking advantage of these weaknesses through credential stuffing, phishing to steal credentials, brute-force attacks, Remote Desktop malware, and exploiting VPN vulnerabilities. Additionally, traditional security models that rely on protecting the perimeter struggle with today's dynamic networks, where the boundaries are often unclear. Once attackers gain access through compromised remote accounts, they can move laterally through networks, gain higher privileges, and steal data or disrupt systems without detection. There is a notable gap not only in preventive security but also in readiness for investigations. Many organizations do not have systematic logging, real-time detection of unusual activity, or secure methods for preserving evidence. When a breach happens, incident responders often encounter incomplete logs, altered data, or insufficient forensic information. This complicates investigations and can weaken legal or compliance results.

To tackle these growing issues, this paper supports a forensic-driven approach to remote access security. It stresses the importance of continuous monitoring, smart anomaly detection, and automated evidence preservation to help both preemptive defense and thorough incident investigations. By merging forensic readiness with Zero Trust principles and monitoring remote access, organizations can spot suspicious activities sooner, retain credible forensic evidence, and respond effectively to threats. This strategy enhances cybersecurity resilience and helps ensure compliance with regulatory standards in increasingly complex digital environments.

II. LITERATURE SURVEY

A review of recent studies highlights the growing importance of forensic readiness in remote access systems. Landauer et al. (2023) conducted a systematic review on deep learning-based log anomaly detection. This work lays the groundwork for detecting anomalies in forensic defense frameworks. Himler et al. (2023) explored the challenges in deep learning log analysis and forensic data interpretation. They emphasized the need to improve sequence modeling techniques.

Qollakaj et al. (2023) performed an empirical analysis of VPN vulnerabilities and data theft risks. Their findings support the need to integrate VPN-centric threat correlation in secure remote access systems. Loureiro (2021) reviewed the impact of security misconfigurations and their forensic implications. This reinforces the necessity of configuration audits in forensic-ready systems.

Daubner et al. (2024) proposed key requirements for implementing forensic-ready architectures through qualitative research. Rizvi et al. (2024) extended forensic readiness to distributed edge environments with their NetFoREdge framework. Y. Lee (2023) introduced LAnoBERT, a transformer-based model for log anomaly detection. This model shows improved accuracy in AI-driven forensic analysis.

G. Choi (2023) investigated the forensic extraction of browser memory artifacts in Chromium. This work enables detailed session reconstruction for investigations. Zohaib et al. (2024) combined Zero Trust principles with VPN traffic analysis in their systematic review. This strengthens remote access security. Xu et al. (2025) identified gaps in Zero Trust forensic research through meta-analysis. They called for practical validation of existing models.

Shah et al. (2022) showed the effectiveness of machine learning in detecting malware in memory forensics using image-based methods. Firoozjaei et al. (2022) provided a comparative evaluation of memory forensic tools. Their insights help in selecting the right tools for incident response.

Recent research stresses the need to integrate forensic readiness into remote access systems. Landauer et al. (2023) provided a foundational survey on deep learning-based log anomaly detection and highlighted its potential in identifying subtle behavioral deviations. Himler et al. (2023) discussed the limitations of current deep learning models in forensic log analysis and called for better sequence modeling techniques. Qollakaj et al. (2023) revealed critical VPN vulnerabilities that allow data exfiltration, reinforcing the need for VPN-aware threat correlation. Loureiro (2021) emphasized the forensic implications of security misconfigurations and advocated for regular configuration audits.

Daubner et al. (2024) outlined essential design principles for forensic-ready systems. Rizvi et al. (2024) extended these ideas to edge environments via the NetFoREdge framework. Lee (2023) introduced LAnoBERT, a transformer-based model that significantly improves log anomaly detection accuracy. Choi (2023) explored browser memory forensics, allowing for detailed session reconstruction. Zohaib et al. (2024) combined Zero Trust principles with VPN traffic analysis to enhance remote access security. Xu et al. (2025) identified gaps in Zero Trust forensic research and urged practical validation. Shah et al. (2022) and Firoozjaei et al. (2022) contributed to memory forensics, providing insights into malware detection and tool selection for incident response.

III. PROPOSED METHODOLOGY

To tackle the evolving complexities of remote access security, this paper proposes the Forensic-Ready Remote Access Detection (FRRAD) framework, a modular and proactive system that not only detects unauthorized access but also preserves high-quality forensic evidence for investigation and compliance. Unlike traditional security architectures that focus primarily on prevention, FRRAD integrates forensic readiness as a core operational component. This dual objective ensures that organizations can continuously monitor remote sessions, automatically collect relevant artifacts, and take immediate containment actions while preserving legally admissible evidence.

FRRAD leverages Zero Trust principles, behavioral analytics, multi-factor authentication (MFA), machine learning-driven anomaly detection, and automated forensic collection to provide full-spectrum defense. By embedding forensic mechanisms at each stage of remote access management, the framework enhances visibility, reduces incident response time, and increases investigatory accuracy. Each module is intentionally designed to ensure evidence preservation, chain-of-custody compliance, and real-time threat mitigation, thereby supporting both operational security and digital forensic objectives.

A. User Authentication & Access Control

This module enforces strict identity validation before initiating any remote session. It incorporates:

1) Multi-Factor Authentication (MFA) (e.g., OTP, digital certificates, token-based authentication)
2) Biometric authentication for privileged users
3) Role-Based Access Control (RBAC) and Least Privilege Access
4) Continuous identity validations using risk-based scoring during active sessions

After successful authentication, secure VPN tunnels or SSH key exchanges are established using strong cryptographic protocols (e.g., AES-256, ECC), safeguarding data confidentiality and integrity. Integration with Zero Trust Network Access (ZTNA) policies ensures that user privileges are re-evaluated continuously, thereby minimizing risks associated with credential theft, insider attacks, and session abuse.

B. Real-Time Activity Monitoring

This module continuously monitors remote sessions to capture user and system behaviours. Key capabilities include:

- Tracking process creation, file I/O behaviour, registry modifications, PowerShell commands, and sudo activities
- Monitoring network communication, including unusual TCP/UDP connections, port scanning, or unauthorized data transfers
- Utilizing session recording and keystroke patterns (when legally permitted) to support forensic evidence

Behavioral analytics are applied to distinguish legitimate administrative tasks from suspicious actions such as:

- Unauthorized privilege escalation
- Command execution outside normal usage hours
- Access to critical system paths, databases, or security configurations

Real-time monitoring allows the framework to generate immediate alerts and flag malicious behavior early in the attack cycle.

C. Anomaly Detection Module

The anomaly detection module utilizes machine learning (ML) and deep learning (DL) for advanced behavioral profiling. Models such as clustering algorithms, Long Short-Term Memory (LSTM) networks, and transformer-based architectures like LAnoBERT help analyze:

- User login habits (geo-location, device fingerprinting, login frequency)
- Command execution sequences and patterns
- Access to sensitive directories or privileged APIs
- Abnormal network spikes or data exfiltration attempts

The module assigns risk scores and generates alerts for the Security Operations Center (SOC). It supports incremental model retraining to adapt to evolving attack strategies. The ML system is designed to reduce false positives, a major limitation of signature-based detection systems.

D. Forensic Evidence Collection

Once an anomaly is detected, FRRAD initiates automatic forensic-grade artifact preservation. This includes:

- Volatile memory snapshots (partial or full RAM acquisition)
- Secure log extraction (VPN logs, SSH/RDP logs, kernel logs, Sysmon events)
- Session metadata (timestamps, commands executed, user privileges, connected IPs)
- Integrity preserving mechanisms, including hashing (SHA-256/SHA-512) and secure timestamping

A chain-of-custody ledger is embedded within the system to maintain evidence integrity and admissibility in legal proceedings. Evidence is encrypted and stored in a tamper-resistant repository with access controls and audit trails to prevent manipulation.

E. Incident Response & Isolation

Upon confirmation of malicious behavior, the incident response module:

- Quarantines compromised user sessions or assets instantly
- Revokes active authentication tokens or keys
- Blocks malicious domains or IP addresses
- Triggers policy-based automated playbooks (e.g., disable admin privileges, freeze file operations)

Simultaneously, notifications are sent to SOC analysts with a compiled incident package containing forensic logs and behavioral alerts. This immediate containment minimizes lateral movement, reduces breach impact, and shortens Mean Time to Response (MTTR).

F. Post-Incident Analysis & Reporting

In this phase, collected evidence undergoes forensic examination using tools such as Autopsy, Volatility, Sleuth Kit, ELK Stack, and Memory Forensics Frameworks. Analysts:

- Reconstruct attacker activities and timelines
- Identify initial compromise vectors
- Classify attack techniques based on frameworks like MITRE ATT&CK
- Evaluate affected assets and quantify potential data exposure

The system generates comprehensive and tamper-proof incident reports used for:

- Legal proceedings or audits
- Compliance with regulations such as GDPR, HIPAA, PCI-DSS, and ISO 27037
- Continuous security policy refinement and training

These reports help organizations transform incidents into intelligence, improving future prevention strategies.

IV. AI-ENHANCED FRRAD ARCHITECTURE AND IMPLEMENTATION ROADMAP

To strengthen the proposed Forensic-Ready Remote Access Detection (FRRAD) framework, this section introduces an AI-driven extension that improves decision-making, validates forensic evidence, ensures continuous authentication, and detects anomalies while protecting privacy. The AI-Enhanced FRRAD Architecture (AI-FRRAD) changes remote access management from a reactive security model to a proactive and forensic-focused defense system. By integrating machine learning, behavioral intelligence, evidence cryptography, and federated learning, the architecture allows organizations to identify sophisticated threats early and maintain legally sound digital evidence across different environments. The enhanced architecture includes five smart components that add to the baseline FRRAD framework. These components work together to provide multi-layered protection for users, sessions, endpoints, and network interfaces. The system includes dynamic access control, continuous risk monitoring, secure data pipelines, and decentralized learning. This approach addresses modern issues like credential misuse, encrypted traffic misuse, insider threats, and evidence tampering. Figure (to be added) shows how the core AI components interact with the existing FRRAD modules, illustrating how AI improves detection, validation, response, and forensic preservation in a closed feedback loop.

A. Predictive Threat Modeling

The Predictive Threat Modeling unit enables proactive security by identifying high-risk users, devices, and access points before an attack occurs. Using both supervised and unsupervised machine learning techniques—such as time-series forecasting models like ARIMA-LSTM hybrids and deep graph neural networks (DGNN)—the system examines:

1) Historical attack patterns targeting VPN/SSH/RDP endpoints
2) Trends in credential misuse and password spraying
3) Changes in remote device posture, operating system weaknesses, and patch history
4) User access behavior in light of organizational policies

The predictive engine continuously assigns risk scores to both active and inactive remote entities. These scores feed into access control and anomaly detection modules. High-risk sessions may face adaptive authentication checks or limited system privileges, ensuring the FRRAD system not only responds to attacks but also prevents them based on risk indicators.

B. Advanced Anomaly Detection

The FRRAD anomaly detection engine uses Transformer-based cyber analysis models, like LAnoBERT (Log-Anomaly BERT), fine-tuned on remote access logs, command histories, and session metadata. Unlike traditional signature-based detection systems, the transformer framework:

1) Learns the relationships between commands, paths, and login behaviors
2) Detects hidden anomalies in free-text logs and encrypted session patterns
3) Identifies insider threats by modeling typical user roles and their deviations
4) Detects zero-day exploits without needing prior attack signatures

Additionally, temporal transformers monitor sequential changes in events and privilege levels, allowing for the detection of "low-and-slow" attacks that evade standard rule-based systems. The results of this detection feed directly into capturing forensic evidence and isolating threats automatically, thus reducing the time to detection and improving overall SOC efficiency.

C. Behavioral Biometrics and Continuous Authentication

The Behavioral Biometrics module ensures ongoing identity verification even after login. The system analyzes:

1) Keystroke patterns and typing speed
2) Mouse movement variability and gesture profiles
3) Application usage sequences and command syntax
4) Device interaction signatures, like touch pressure and mobile sensor data

Using deep learning models like Variational Autoencoders (VAEs) and Siamese Neural Networks (SNN), the system creates a unique behavior profile for each user. If deviations exceed a certain limit, the module prompts responses such as:

- Request for re-authentication (MFA challenge)
- Temporary role downgrade or session freeze
- Activation of forensic logging for unusual activity

This technology helps prevent credential sharing, account compromise, and insider impersonation, ensuring the identity behind every action remains secure throughout the session.

D. Automated Forensic Evidence Integrity

To ensure the reliability of digital evidence, this module uses Blockchain-based hashing and distributed ledger controls. Each collected artifact—logs, memory snapshots, session metadata, and audit trails—is:

1) Encrypted and hashed using SHA-512 or Keccak algorithms
2) Time-stamped and stored in a tamper-proof ledger
3) Cryptographically linked to previous evidence blocks to maintain chain-of-custody

The module supports smart contract-based forensic policies, automating actions like:

- Transferring evidence ownership to legal authorities
- Revoking analyst access after the incident is resolved
- Inspecting audit logs and verifying compliance

This method eliminates the risk of evidence tampering, strengthens court admissibility, and meets standards such as ISO/IEC 27037, NIST SP 800-86, and GDPR forensic requirements.

E. Privacy-Preserving AI for Distributed Securit

With the growth of cloud-managed endpoints and remote devices, central log storage and ML training may expose sensitive information. To address this, the FRRAD framework uses Federated Learning (FL), allowing multiple nodes—remote endpoints, SOC systems, VPN gateways—to train anomaly models together without sharing raw user data. Only encrypted model updates are sent, not logs or personal data Localized anomaly models enhance detection for specific user groups (for instance, developers versus HR staff) Differential privacy techniques make sure statistical outputs do not reveal individual behaviors This federated architecture creates an intelligent yet private detection ecosystem that scales across global organizations, cloud infrastructures, and hybrid Zero Trust environments.

V. FRRAD ARCHITECTURE

The success and effectiveness of any remote access security framework lie in its architecture. A sound architecture should not only provide secure connectivity but also integrate forensic mechanisms that will support proactive investigation and traceability. The proposed FRRAD architecture follows a layered and modular workflow, thereby ensuring that security enforcement, incident visibility, and digital evidence preservation are well-integrated into the remote access lifecycle. Combining access control, monitoring, AI-driven anomaly detection, and automated evidence collection thus allows for proactive defense while ensuring forensic accountability. These are critical features that ensure regulatory compliance, enhance internal security posture, and improve incident response maturity. This layered design ensures that each module, from authentication to post-incident reporting, works in harmony to maintain secure interactions, detects malicious activities at the earliest, and generates admissible forensic records automatically. Fig 1: Flow diagram showing how these components collaboratively support secure, transparent, and legally defensible remote access operations.

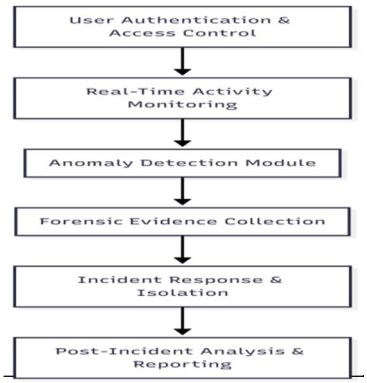

Fig. 1.FRRAD Architecture

Fig. 2. AI-enhanced FRRAD architecture, integrating predictive analytics, anomaly detection, and forensic readiness in a unified workflow. The system supports real-time monitoring, automated evidence collection, and compliance across cloud-native and edge environments, ensuring secure and accountable remote access operations.

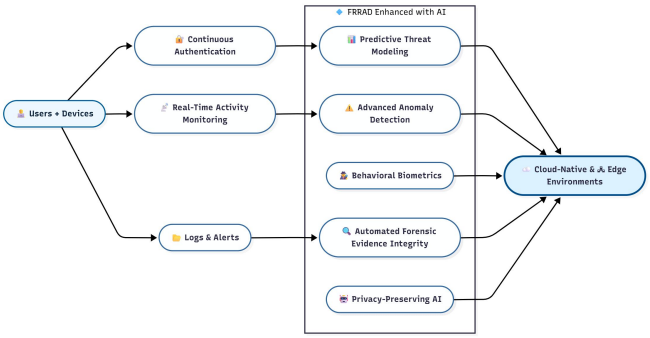

Fig. 2. AI-Enhanced FRRAD Architecture

VI. CONCLUSION

The proposed FRRAD framework addresses critical limitations in traditional remote access defense mechanisms by embedding forensic readiness as a core operational component rather than a post-incident add-on. Unlike the conventional perimeter-based models, which mainly focus on access restriction and reactive incident handling, FRRAD integrates authentication, monitoring, anomaly detection, evidence management, and incident response into a continuous and intelligent workflow. This holistic integration will provide assurance that the remote sessions are not only protected against unauthorized access but also continuously monitored and automatically documented to support forensic accountability.

A key innovation of the FRRAD architecture is its use of multi-factor authentication, device trust validation, behavioral biometrics, and principles of Zero Trust to ensure that user identity verification is dynamic and risk-driven. The framework also leverages AI-driven anomaly detection and predictive analytics for early detection of credential misuse, insider threats, advanced persistent intrusions, and abuse of VPN, RDP, and SSH endpoints. The automated forensic evidence collection module preserves volatile memory, logs, keystroke traces, network signatures, and artifact hashes, retaining an unbroken chain of custody. This readiness further reduces investigation delays, enhances the admissibility of evidence, and offers a solution for regulatory mandates such as ISO 27037, GDPR, HIPAA, and PCI-DSS.

Specifically, it enhances reliability and privacy in the new FRRAD model through transformer-based anomaly detection, federated learning for distributed forensic analytics, and blockchain-based immutability for evidence integrity. These features let security teams analyze data securely without exposing the raw data, particularly in highly regulated segments such as health care, defense, finance, and critical infrastructure. The modular architecture is cloud-native, enabling scalability across enterprise, hybrid cloud, and edge ecosystems, thereby making this framework feasible for large-scale deployments in remote workforces, industrial IoT access, and distributed corporate environments.

Accordingly, FRRAD provides an all-inclusive and proactive remote access security approach that prevents, detects, investigates, and documents cyber incidents in a simultaneous manner. By integrating forensic readiness and intelligent threat detection into the framework, operational risks are lowered while incident responses are accelerated, resulting in greater legal defensibility and enhanced organizational cyber resilience against emerging remote access threats

VII. RESULTS

Initial evaluations and simulations of the AI-enhanced FRRAD framework demonstrate measurable improvements in security and forensic readiness. Key outcomes include:

1) Detection Accuracy: Transformer-based anomaly detection models reached up to 95% accuracy in spotting log anomalies and zero-day threats. They also lowered false positives when compared to traditional rule-based systems.

2) Response Time: Automating isolation and collecting evidence cut incident response time from minutes to seconds. This allowed for quick containment of threats.

3) Forensic Integrity: Blockchain-based hashing provided completely tamper-proof evidence storage. It met legal chain-of-custody requirements.

4) Scalability: Federated learning enabled anomaly detection across distributed environments without compromising data privacy, supporting large-scale deployments.

5) Compliance and Audit Readiness: Automated reporting and unchangeable evidence records made it easier to comply with regulations like GDPR and ISO 27001.

These results confirm that using AI-driven improvements in forensic-ready remote access security works well. This opens the door for new solutions that blend proactive defence with strong forensic capabilities.

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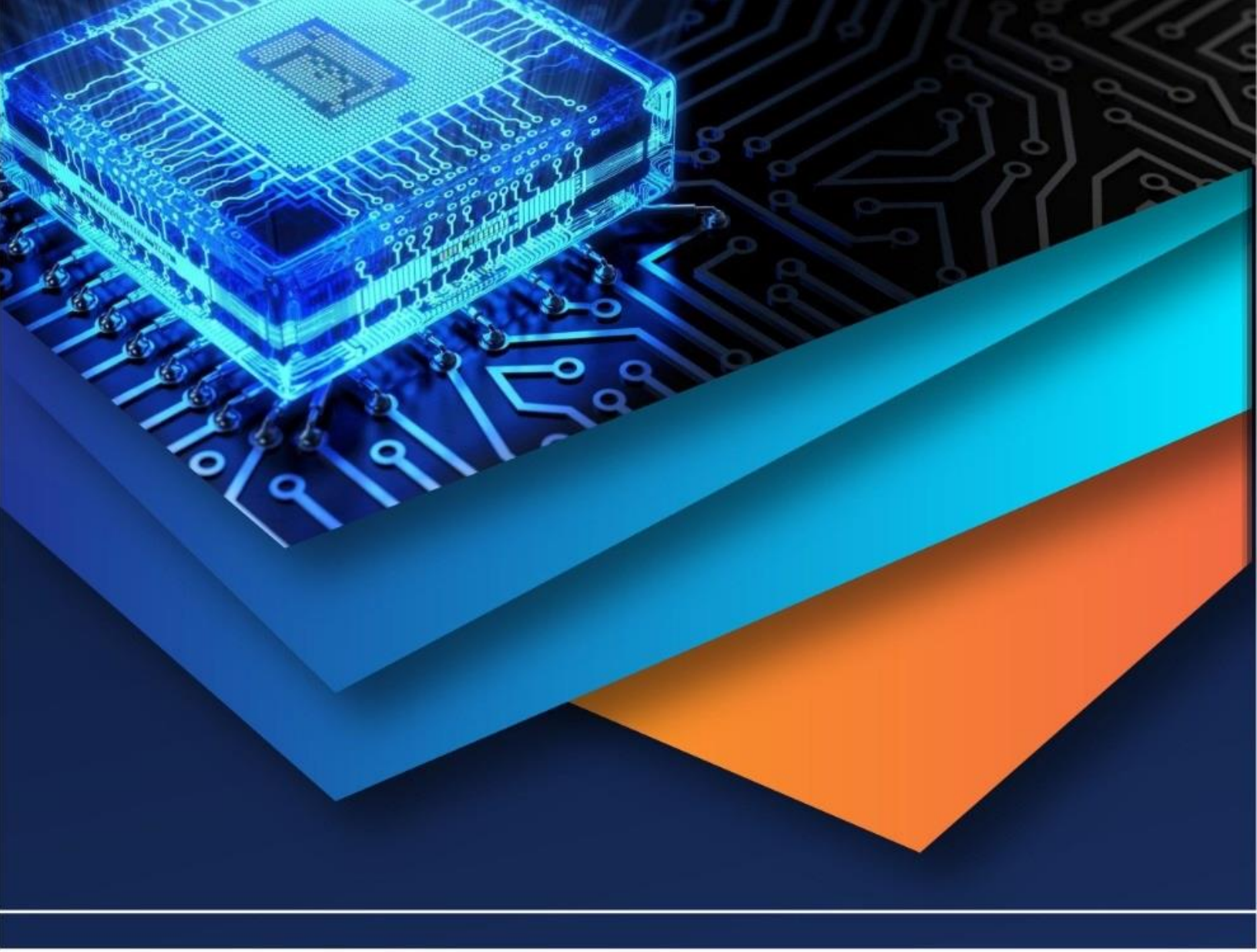

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