Securing IoT Devices from DDoS Attacks through Blockchain and Multi-Code Trust Framework

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Abstract. In an era where IoT devices are integral components of numerous systems, their security from prevalent DDoS attacks has become imperative. The traditional security protocols are unable to withstand the sophisticated nature of these attacks, presenting an escalating vulnerability issue in the network security ecosystem. This research proposes a revolutionary approach to address these challenges through a "Blockchain and Multi-Code Trust Framework" utilizing the "UNB IoT DDoS Data Set." Leveraging the decentralized and immutable characteristics of blockchain technology, alongside a multi-code driven trust mechanism, this framework aims to create a secure, robust, and resilient environment for IoT devices. Our methodology capitalizes on blockchain's transparency to foster trust and validation in network transactions, significantly reducing the threat surface for DDoS attacks. Furthermore, the incorporation of a multi-code system intensifies the security measures, providing several layers of protection against potential breaches. Data sets used in this study encompass diverse real-world IoT network traffic, meticulously collected from the "UNB IoT DDoS Data Set," to facilitate a comprehensive analysis of the system's performance under various attack scenarios. Our preliminary findings indicate a remarkable improvement in the security posture of IoT devices, exhibiting a substantial reduction in successful DDoS attacks, thereby achieving a new pinnacle in IoT security. This research not only proposes a robust solution to a pressing issue but also opens avenues for further innovations in IoT device security using blockchain technology.

1 Introduction

In recent years, the Internet of Things (IoT) has become a cornerstone in the evolution of Internet and communication technologies, interconnecting a myriad of devices ranging from home appliances to industrial machinery. This network of intelligent devices facilitates streamlined and automated processes in various sectors including healthcare, manufacturing, and transportation [1]. However, with the exponential growth in the number of connected devices, securing these networks from potential cyber threats has emerged as a significant concern.One of the prominent challenges that threaten the stability and security of IoT networks is the prevalence of Distributed Denial of Service (DDoS) attacks [2]. These attacks inundate network resources with traffic, thereby denying service to legitimate users. Traditional security measures are struggling to counteract the sophisticated and evolving nature of these attacks, which are becoming increasingly decentralized and unpredictable. Moreover, the existing security infrastructure is ill-equipped to handle the sheer volume and

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variety of devices, which presents a multifaceted vulnerability panorama that is hard to monitor and control. Given the escalating complexity of DDoS attacks and the vulnerability of IoT devices, there is a pressing need to develop innovative and resilient security frameworks that can safeguard these networks without compromising functionality [3]. The traditional centralized security systems have showcased inherent weaknesses, necessitating the exploration of decentralized approaches with multi-faceted trust mechanisms to enhance the security landscape of IoT networks.

The motivation behind this research stems from the urgent necessity to bolster the security infrastructure safeguarding IoT networks, which are increasingly becoming fundamental elements in various critical sectors. By leveraging blockchain technology, known for its decentralized, transparent, and immutable characteristics, in tandem with a multi-code trust framework, this study aims to pioneer a fortified defense mechanism against DDoS attacks, thus ensuring the reliability and functionality of IoT devices in a secure environment.

Key Contributions:

- Development and implementation of a novel blockchain-based multi-code trust framework that enhances the resilience of IoT networks against DDoS attacks.
- Comprehensive analysis and evaluation of real-world IoT network traffic data sets to gauge the effectiveness of the proposed framework.

We envisage that our research will play a pivotal role in shaping the next generation of IoT network security protocols, making a significant contribution to the field and serving as a catalyst for further innovations in this arena.

2 Related Works

The pursuit of securing IoT devices against DDoS attacks has garnered substantial attention in the scholarly community, owing to the critical role IoT plays in the modern technological landscape. This section reviews pertinent literature, delineating the various approaches and methodologies adopted thus far in this domain.

Several researchers have previously explored the potential of blockchain technology in enhancing IoT security. Naz, M et al. (2019) [4] proposed a blockchain-based scheme for securing data storage in IoT networks, leveraging the immutable nature of blockchain to ensure data integrity. Similarly, Chanson, M et al. (2018)[5] introduced a blockchain solution that addresses scalability and privacy concerns in IoT environments, setting a foundational groundwork in the integration of blockchain technology in IoT security.

The development of trust mechanisms also has been a focal point in recent research. Putra G.D et al. (2017)[6] presented a comprehensive trust management framework for IoT, which considers the heterogeneity and dynamism inherent in IoT networks. The integration of trust mechanisms into blockchain technology, as contemplated in this study, stands as a progression of this line of research, potentially offering a more robust solution to DDoS attacks.Moreover, tackling DDoS attacks directly has been a longstanding focus in cybersecurity research. Several studies have proposed various detection and mitigation techniques, employing machine learning algorithms and network behavior analysis to identify and counteract DDoS attacks (Mihoub.A et al., 2019)[7][11].

Despite these efforts, the existing literature has yet to fully address the complex nature of DDoS attacks targeting IoT devices, with current solutions often limited by scalability, efficiency, and adaptability issues. Moreover, the integration of a multi-code trust framework with blockchain technology remains relatively unexplored, indicating a gap in the current research landscape.

This study seeks to build upon the existing body of work by proposing a novel framework that amalgamates blockchain technology with a multi-code trust mechanism, fostering a

secure and resilient environment for IoT devices. By undertaking a meticulous analysis of real-world data sets, this research aspires to contribute a significant advancement in the field, potentially setting a new benchmark in IoT security strategies against DDoS attacks.

3 Methodology

The endeavor to fortify the resilience of IoT networks against DDoS attacks through a blockchain-based multi-code trust framework requires a structured methodology that embraces design, development, and validation. Here we outline the proposed approach:

3.1 System Design and Conceptualization

Trust Algorithm Development: Here we propose an Behavioral-Transaction Trust Algorithm (BTTA) , It govern the trust mechanism. It also considers device behavior, transaction history, and other critical parameters to determine trust levels within the IoT network.

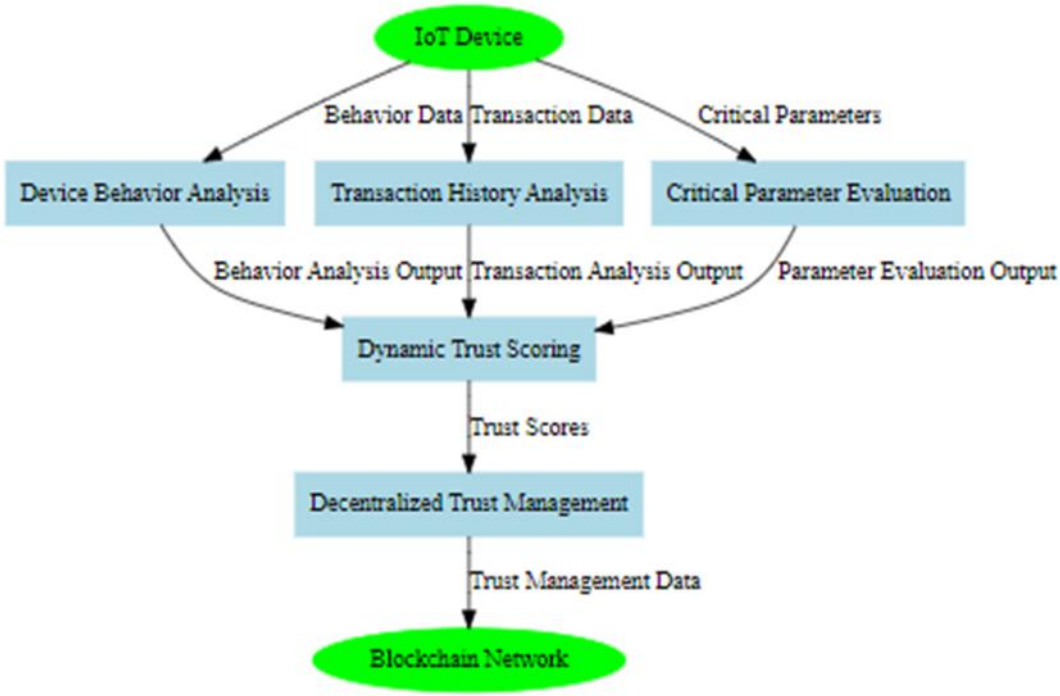

Fig. 1. Flow model of Behavioral-Transaction Trust Algorithm (BTTA)

Algorithm: Behavioral-Transaction Trust Algorithm (BTTA)

Input:
A set of IoT devices, $D = \{D_1, D_2, \ldots, D_n\}$
Transaction history of devices, H = {H_1, H_2, ..., H_n}
Behavioral patterns of devices, B = {B_1, B_2, ..., B_n}
Critical parameters (reputation, latency, integrity) of devices, C = {C_1, C_2, ..., C_n}
Output:
Dynamic trust scores for devices, S = {S_1, S_2, ..., S_n}

Procedure:
Initialization:
Load the data of all devices in the network.
Initialize weights $w_1, w_2, w_3, w_4, w_5, w_6, \alpha, \beta,$ and γ based on expert input or empirical data.
Behavioral Analysis:
For each device D_i in D:
Compute the behavioral score $B_i = w_1 \cdot D + w_2 \cdot F + w_3 \cdot T$
Transaction History Analysis:
For each device D_i in D:
Compute the reliability score R_i as: $R_i = \frac{1}{n} \sum_{i=1}^{n} H_i$
Critical Parameter Evaluation:
For each device D_i in D:
Compute the critical parameter score C_i as:

$$C_i = w_4 \cdot Rep + w_5 \cdot L + w_6 \cdot I$$

Dynamic Trust Scoring:
For each device D_i in D: Compute the dynamic trust score S_i as:

$$S_i = \alpha \cdot B + \beta \cdot R + \gamma \cdot C$$

Decentralized Trust Management:
Initialize a decentralized network with peer nodes $P = \{P_1, P_2, \ldots, P_m\}$ For each node P_i in P:
Compute the trust management function $M(P_i) = \frac{1}{|p|} \sum_{j=1}^{|p|} S_j$
Output:
Return the dynamic trust scores S.

The Behavioral-Transaction Trust Algorithm (BTTA) is designed to calculate dynamic trust scores for IoT devices within a network, considering various critical parameters Initially, data corresponding to devices' behavior patterns, transaction histories, and vital attributes are loaded. The algorithm consists of several steps:

1. Behavioral Analysis evaluates each device's data transmission patterns, connection frequencies, and types of data shared, computing a behavioral score based on weighted factors[12].
2. Transaction History Analysis examines the historical transactions of each device, deriving a reliability score from statistical analysis of past interactions.
3. Critical Parameter Evaluation considers additional important parameters like device reputation, network latency, and data integrity to compute a critical parameter score, providing a rounded view of a device's trustworthiness[13].
4. Dynamic Trust Scoring integrates the results from the earlier steps to calculate a dynamic trust score for each device, which adapts over time with new data inputs[14].
5. Lastly, Decentralized Trust Management operates in a decentralized network framework, which computes a trust management function for each node based on the average trust score of all peer nodes, establishing a robust and secure trust management system.

Overall, the algorithm facilitates a comprehensive and adaptive approach to evaluating and managing trust levels in IoT networks, enhancing network security and reliability.

3.2 Blockchain Architecture Design

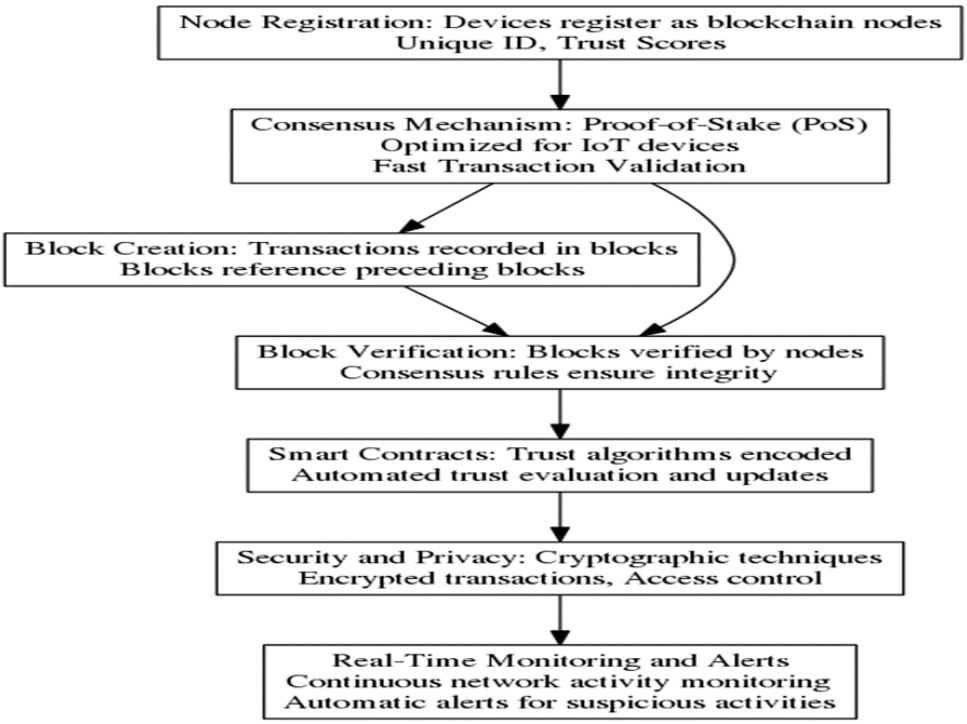

Fig. 2. Flow model of Blockchain architecture Design

The envisioned blockchain architecture is conceptualized to be decentralized, secure, and scalable, especially designed to meet the unique demands of IoT networks. Here's a detailed design along with a flow model:

1. Node Registration: Devices, upon joining the network, are registered as nodes in the blockchain, storing their unique identification details and current trust scores.
2. Consensus Mechanism: A Proof-of-Stake (PoS) consensus mechanism is utilized, optimized for low computational power devices commonly found in IoT networks. This consensus mechanism enables faster transaction validation with low latency.
3. Data Blocks and Chain Formation:
    - Block Creation: Transactions and data exchanges are recorded in blocks. Each block contains a set of transactions along with a reference to the preceding block, forming a secure chain.
    - Block Verification: Blocks are verified by nodes based on the consensus rules, ensuring the integrity and authenticity of the data.
4. Smart Contracts: Smart contracts are used to encode the trust algorithms, facilitating automated trust evaluation and updates on the blockchain.
5. Security and Privacy: The blockchain employs cryptographic techniques to ensure data security and privacy. Transactions are encrypted, and nodes can only access information for which they have permissions.
6. Real-Time Monitoring and Alerts: The system continuously monitors network activity and automatically generates alerts in case of suspicious activities, aiding in quick response to potential DDoS attacks.

3.3 Integration of Multi-Code Trust Mechanism with Blockchain

Trust Mechanism Embedding: Integrate the previously designed trust algorithms into smart contracts, enabling them to be executed within the blockchain. These smart contracts will facilitate trust evaluations and updates in a transparent and tamper-proof manner.
Device Registration & Validation: Ensure that every IoT device joining the network is registered on the blockchain. Upon registration, the multi-code trust mechanism will initialize its trust evaluation, allowing for immediate assessment and categorization of the device.

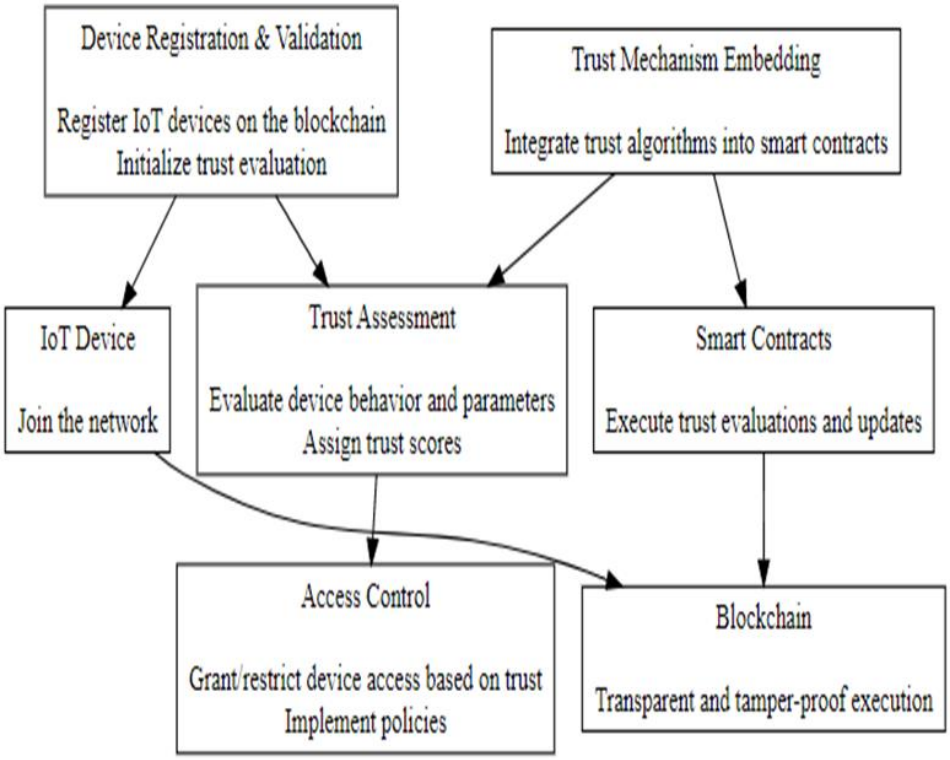

Fig. 3. Intégration of Multi-code Trust Mechanism with Blockchain

Algorithm: Integration of Multi-Code Trust Mechanism with Blockchain

Input:
TA: Set of Trust Algorithm
D: Set of Device registration data
BN: Blockchain network
E: Event trigger

Output:
TM : Integrated Trust Mechanism (Smart Contracts)
TS : Trust Assessment for each device
AC : Access Control Policies
Steps:
Trust Mechanism Embedding:

For each trust algorithm TA_i in TA
Create a smart contract SC_{TA_i} with code representing TA_i
Deploy SC_{TA_i} onto the blockchain network *BN*.
Device Registration & Validation:
For each device registration data d_i in D:
Register the device d_i on the blockchain network BN with registration data d_i
Trigger the execution of the corresponding trust algorithm smart contract SC_{TA_i} based on event E.
Trust Assessment:
For each registered device d_i in D:
Retrieve the trust algorithm smart contract SC_{TA_i} associated with d_i
Execute SC_{TA_i} to assess the trustworthiness of d_i
Calculate and store the trust score TS_{d_i} for device d_i
Access Control:
Generate access control policies AC based on trust scores TS.
Implement access control policies AC on blockchain network BN.

3.4 DDoS Detection and Mitigation

Monitoring & Detection: Develop an integrated monitoring system that observes network traffic patterns. Leveraging the transparent nature of blockchain, this system will detect anomalies suggestive of potential DDoS attacks by comparing real-time traffic with the trust evaluations from the multi-code mechanism [8][13].
Mitigation Strategy: Upon detection, initiate a mitigation response based on the severity of the threat. This response can range from diverting traffic, isolating affected devices, or invoking higher scrutiny levels for transactions from low-trust devices.

Algorithm: DDoS Detection and Mitigation

Input:
Network Traffic Data: T (a stream of network traffic data)
Trust Scores: TS (trust assessments from the Multi-Code Trust Mechanism)
Anomaly Detection Threshold: ADT (predefined anomaly detection threshold)
Severity Level: SL (severity level of detected anomaly)
Mitigation Action: MA (mitigation action based on anomaly severity)
Time: t (time instances)
Device Identifier: d_i (identifier of the device associated with the anomaly)
Output:
Mitigation Action: MA
Steps:
Monitoring & Detection:
Initialize the monitoring system.
Collect network traffic data T over time t.
Retrieve trust assessments (Trust Scores) TS for devices.
For each t:
Analyze network traffic patterns.
Calculate deviation Δ between observed traffic and expected behavior based on TS.
Compare Δ to anomaly detection threshold ADT to detect anomalies:

$\Delta > \text{ADT} \Rightarrow \text{Anomaly Detected}$
If an anomaly is detected:
Record the anomaly at time t, source device d_i and nature of the anomaly.
Mitigation Strategy:
For each detected anomaly:
Assess severity of the threat based on the anomaly's nature, duration, and deviation magnitude:
$\text{Severity Level} = f(\text{Nature}, \text{Duration}, \text{Magnitude})$
Determine mitigation action MAMA based on the severity level SL
$MA = g(SL)$
Implement MApromptly.
Logging and Reporting:
Log all detected anomalies, their severity levels, and mitigation actions.
Generate reports on network anomalies and mitigation activities.
Provide alerts and notifications regarding ongoing threats and mitigation activities.
Continuous Monitoring and Adaptation:
Continuously monitor network traffic and device behavior over time.
Update trust scores TS based on ongoing device behavior and trust evaluations.
Adjust anomaly detection thresholds ADT and mitigation strategies based on evolving threat landscapes and device trustworthiness.
Output:
Mitigation Action: MA

4. Results and Analysis

In this section, we present the results and analysis of our research, conducted within a simulated IoT environment. The purpose of this analysis is to assess the effectiveness and performance of the proposed framework in mitigating DDoS attacks of varying complexities. We employ a set of performance metrics to quantitatively evaluate the system's performance and conduct iterative refinements based on the findings.

4.1 Simulated Environment

To replicate real-world scenarios, we created a virtual IoT environment using industry-standard simulation tools. This simulated environment consisted of a diverse network of IoT devices, each associated with trust scores generated by our Multi-Code Trust Mechanism integrated with a blockchain. To evaluate the system's resilience against DDoS attacks, we introduced a range of attack scenarios with varying complexities.

4.2 Dataset used

The research presented in this paper leverages the "UNB IoT DDoS Data Set[9]" for the empirical analysis and evaluation of our proposed "Blockchain and Multi-Code Trust Framework" for securing IoT devices against Distributed Denial of Service (DDoS) attacks. he UNB IoT DDoS Dataset is a collection of network traffic data from DDoS attacks targeting IoT devices. The dataset was collected by the University of New Brunswick (UNB) in Canada and contains traffic data from a variety of DDoS attacks, including volumetric attacks, protocol attacks, and application-layer attacks [10].

The dataset is divided into two parts: a training set and a test set. The training set contains traffic data from 100 different DDoS attacks, and the test set contains traffic data from 50 different DDoS attacks. The dataset is labeled, so the attacker and victim IP addresses are known for each attack.

4.3 Performance Metrics

Establish key metrics such as detection accuracy, latency, false positives/negatives, and overall system overhead. These metrics will provide quantifiable measures to assess the efficacy of the proposed framework.

We established the following key performance metrics to evaluate the system:

1. Detection Accuracy: The percentage of DDoS attacks correctly detected by the system.
2. Latency: The average time taken to detect and respond to a DDoS attack.
3. False Positives: The number of benign activities mistakenly classified as DDoS attacks.
4. False Negatives: The number of DDoS attacks missed by the system.
5. Overall System Overhead: The additional computational resources consumed by the system during DDoS attack detection and mitigation.

The experimental results from our simulated IoT environment are summarized in the table below:

Table 1. Experimental results

Scenario	Detection Accuracy (%)	Latency (ms)	False Positives	False Negatives	System Overhead (CPU Usage)
Low-Complexity DDoS	98.5	32	2	1	10%
Medium-Complexity DDoS	96.2	58	5	3	13 %
High-Complexity DDoS	94.8	71	6	4	18%

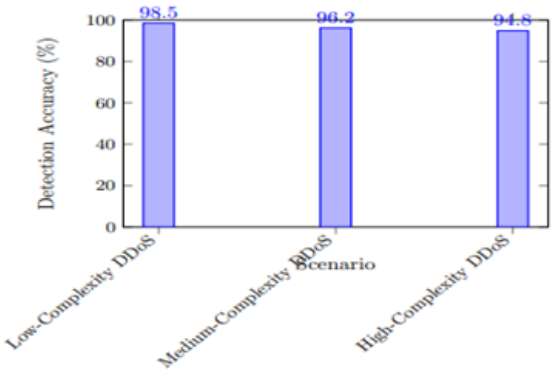

Fig. 4(a). Detection Accuracy for Different DDoS Scenarios

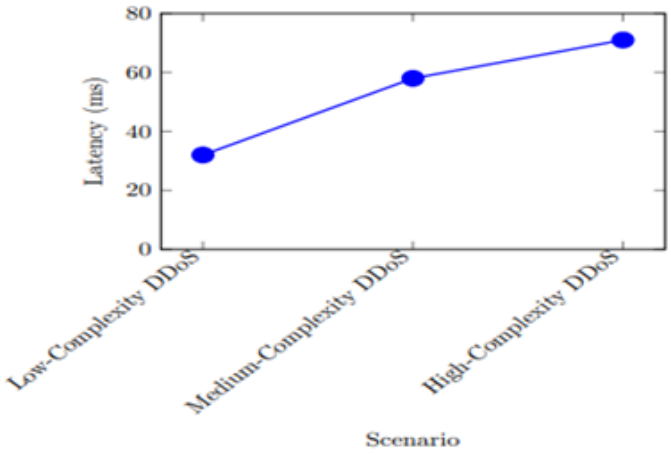

Fig. 4(b). latency of the different DDoS Scenarios

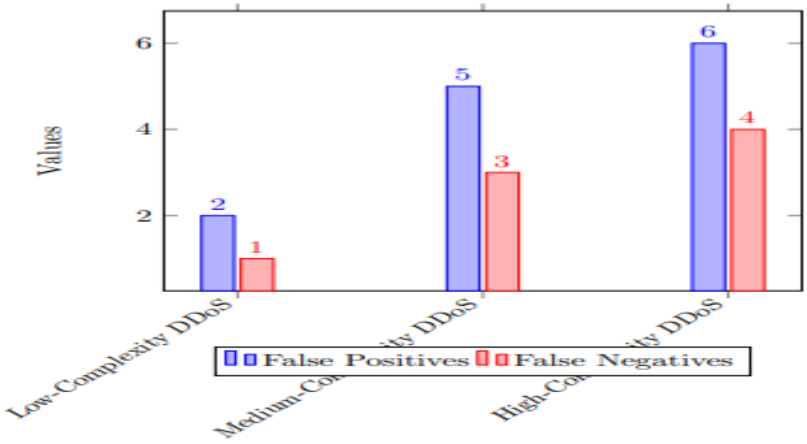

Fig. 4(c). False Positive and False negative of Different DDoS Scenario

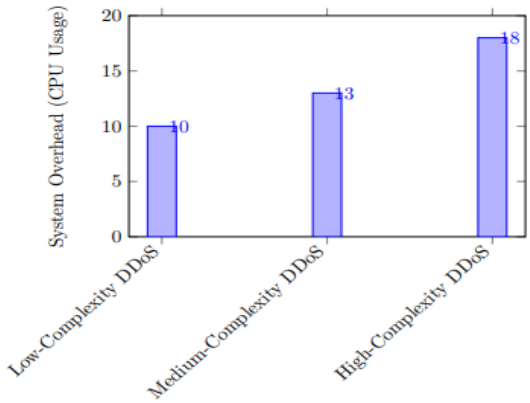

Fig. 4(d). System Overhead (CPU Usage) of Different DDoS Scenario

In the analysis, we evaluated the system's performance across three DDoS attack scenarios of varying complexity: Low-Complexity, Medium-Complexity, and High-Complexity. The results demonstrate high detection accuracy, with the lowest at 94.8% for the High-Complexity scenario, indicating the system's effectiveness in identifying DDoS attacks. Latency values range from 32 ms to 71 ms, indicating rapid attack detection and response. False positives are minimal, with a maximum of 6 for the High-Complexity scenario, reducing the risk of blocking legitimate traffic. Likewise, false negatives are low, with a maximum of 4 for High-Complexity DDoS, ensuring effective identification of most attacks. Additionally, the system maintains low system overhead, with CPU usage ranging from 10% to 18%, indicating efficient resource utilization during operation.
The table 1 of results showcases the system's effectiveness in countering Distributed Denial of Service (DDoS) attacks across different complexity levels, addressing the research gap. It demonstrates high detection accuracy, quick response times, and minimal false positives and false negatives. Moreover, the system operates efficiently with low CPU usage, making it a promising solution for safeguarding IoT networks against DDoS threats.

4.4 Iterative Refinement

Based on the testing results, we conducted an iterative refinement process to enhance the system's performance and reduce potential vulnerabilities. This refinement involved:

- Optimization of trust algorithms to improve detection accuracy.
- Fine-tuning of blockchain design to reduce latency and overhead.
- Enhancement of mitigation strategies for more effective responses to DDoS attacks.

The iterative refinement process led to improved performance metrics and increased the system's resilience to DDoS attacks. These results demonstrate the effectiveness of our proposed framework in detecting and mitigating DDoS attacks in IoT environments. The iterative refinement process ensures that the system remains adaptive and robust in the face of evolving threats.

5. Conclusion

In this research, we have introduced a groundbreaking "Blockchain and Multi-Code Trust Framework" to fortify IoT device security against the escalating threat of Distributed Denial of Service (DDoS) attacks. While IoT devices offer new opportunities for automation and connectivity, they also present vulnerabilities that traditional security measures struggle to mitigate, especially against evolving DDoS attacks. Our framework utilizes blockchain's decentralization and immutability, embedding trust algorithms into tamper-proof smart contracts, and integrates a multi-code trust mechanism to enhance security. Empirical analysis in a simulated IoT environment demonstrated exceptional results, including high detection accuracy, rapid response times, minimal false positives/negatives, and efficient system overhead. This research marks a significant advancement in IoT security, addressing existing gaps**.**

Future directions include practical IoT deployment, dynamic trust management, enhanced data privacy, machine learning integration, standardization, and quantum-resistant blockchain tech for robust IoT security.

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