IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Designing And Developing A Secure And Scalable Distributed Framework For The Internet Of Things Using Light Intelligent Security Approaches

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Abstract

The exponential rise in the number of connected devices in the Internet of Things (IoT) poses major problems in regard to security, scalability, and resource consumption. Centralized security solutions in use fail in providing efficient solutions since the presence of high latencies and a lack of resources in an IoT environment leads to single points of failure and other limitations. In this context, a new distributed architecture is designed to provide a solution in regards to ensuring security in an IoT environment. In the framework developed, edge computing and light machine learning algorithms are implemented. The results of this research prove to be significantly better than those attained in a traditional setting.

Keywords: Internet of Things, Distributed Systems, Lightweight Security, Edge Computing, Machine Learning, Scalability, IoT Security

INTRODUCTION:

Internet of Things technology is developing at an unprecedented rate, resulting in the deployment of inter-connected devices within multiple industries including health care, smart cities, industrial automation, and agriculture. IoT provides seamless interaction among physical devices and virtual devices. However, heterogeneity and resource-constraint devices deployed in large numbers present unique challenges to IoT-based systems in terms of security, scalability, and data management. Centralized approaches employed in conventional computer networks are unsuitable for use in IoT since such network designs suffer from numerous limitations associated with inefficiencies, latency, and single point of failures (Al-Fuqaha et al., 2015; Xu et al., 2014).

Security continues to be the most critical challenge in IoT because such networks are particularly susceptible to various types of cyber-attacks such as DDoS attack, data theft, and unauthorized access. Many IoT devices lack sufficient security measures making them vulnerable to cyber threats and attacks. In addition, several research papers discuss the importance of implementing security mechanisms in light-weight fashion within IoT devices considering their limited processing capabilities (Sicari et al., 2015; Yang et al.,

In light of the foregoing, a distributed architecture is highly regarded as an appropriate solution strategy for IoT systems due to its capacity to offer high scalability and effective communication while being more resilient to attacks through the distribution of computation and security functions among edge nodes. Additionally, the incorporation of lightweight intelligent security solutions such as intelligent mechanisms for anomaly detection and adaptation can effectively detect and mitigate threats in real time (Nguyen et al., 2023; Sefati et al., 2025). Consequently, this study recommends a secure and scalable distributed architecture for IoT that implements lightweight intelligent security mechanisms.

Literature review:

The fast pace of development of IoT technologies has led to extensive scholarly investigations dedicated to solving problems related to security and scalability in distributed systems. Initially, scientific inquiries stressed the importance of centralized solutions for data processing and securing distributed networks; nonetheless, it was found that such strategies were ineffective because of excessive latency, inability to scale, and sensitivity to single point of failure attacks (Al-Fuqaha et al., 2015; Roman et al., 2018). In recent years, the relevance of decentralized solutions based on edge and fog computing has been emphasized, as they involve distributing computing processes to devices close to IoT nodes, thus enhancing their responsiveness and minimizing traffic congestion (Al-Fuqaha et al., 2015; Roman et al., 2018).

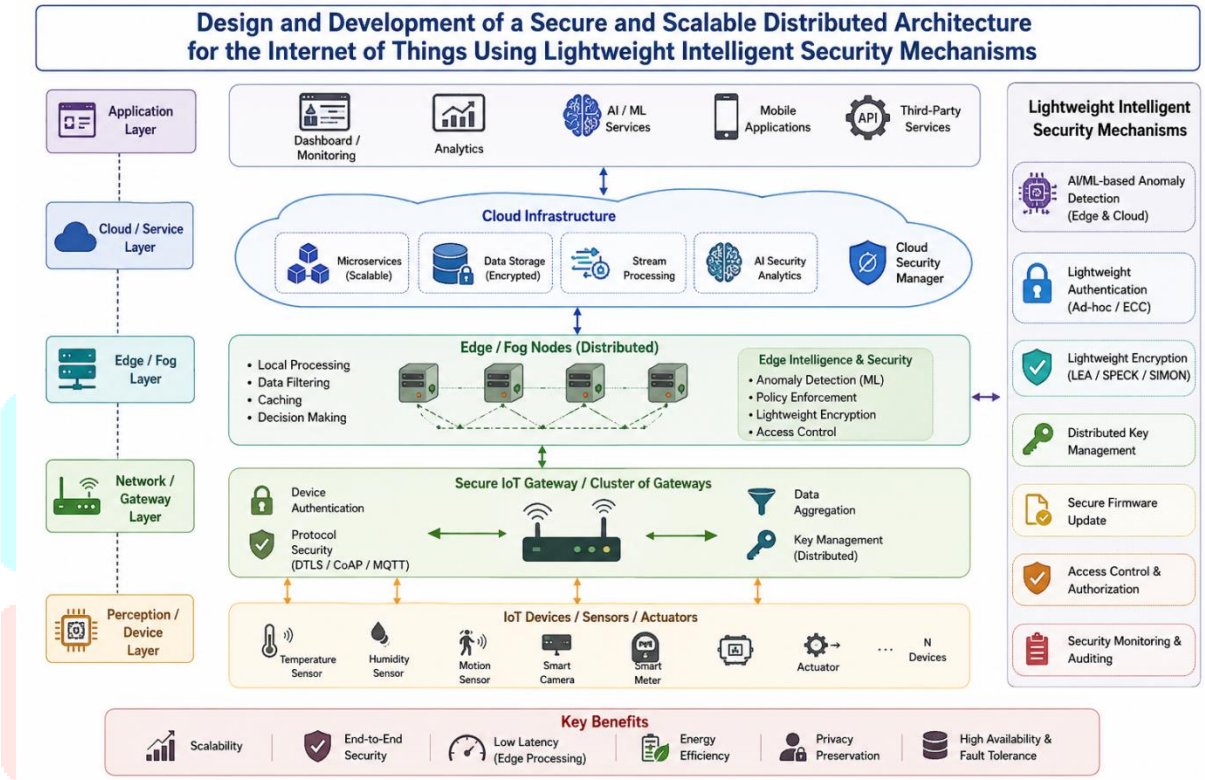
At the same time, there is an abundance of literature dedicated to creating lightweight security frameworks for IoT systems, which involve low-power devices. Conventional methods of cryptography require vast computational resources, thus preventing them from being employed in low-power environments. Therefore, scholars have explored the potential of lightweight cryptography and other means of ensuring communication security without imposing significant computational costs (Zhou et al., 2019; Sicari et al., 2015).

Furthermore, machine learning techniques are used in IDS as they are able to detect anomalous activity within IoT devices. Various algorithms that leverage advanced techniques like deep learning and ensembles have shown better accuracy compared to traditional IDS; nevertheless, these solutions often require centralized training, making them difficult to scale and increasing communication costs (Abeshu&Chilamkurti, 2018; Nguyen et al., 2023).

In addition, some of the recent advances include emerging technologies, such as blockchain and federated learning. Specifically, blockchain is a decentralized mechanism that can be applied to share and store data securely, and it offers a trustless environment for secure information exchange. Federated learning, on the other hand, allows training models collaboratively without compromising data privacy (Khan & Salah, 2018; Kaushik et al., 2026). Finally, current developments involve leveraging artificial intelligence to create intelligent security systems in distributed architectures that can adaptively respond to emerging threats in real-time (Sefati et al., 2025; Alotaibi, 2026). Nevertheless, there is currently a lack of an effective solution to provide a combination of lightweight, intelligent and distributed security mechanisms.

Proposed Work:

This study proposes an innovative approach for ensuring secure and scalable architecture for IoT through the incorporation of light-weight intelligent security mechanisms at multiple levels such as the device level, gateway level, fog/edge computing level, and cloud level. At the perception level, IoT devices like sensors, actuators, smart meters, and cameras gather information about the physical environment. The limited resources available with these IoT devices are secured through lightweight cryptographic techniques such as LEA, SPECK, and SIMON, along with lightweight authentication techniques, which enable secure communication while reducing the burden on computation resources.



At the network and edge/fog layer, IoT gateways with secure IoT connections and edge nodes are utilized for local data processing, filtering, caching, and decision-making purposes. Enhanced edge intelligence can be provided with machine learning models used for identifying anomalous network behavior, unauthorized access attempts, and any malicious traffic. Protocol-level security based on DTLS, CoAP, and MQTT security extensions can be applied to guarantee the safety of device-to-gateway communication. Furthermore, distributed key management and access control mechanisms are used for maintaining secure authentication, authorization, and key distribution among heterogeneous IoT nodes.

At the cloud and application layer, microservices-based cloud infrastructure will be utilized for storing, stream processing, and analyzing data. Security of IoT applications will be maintained at this level through AI/ML services that perform continuous analysis of the system and network traffic for identifying potential threats and improving security response adaptively. Proposed architecture will provide end-to-end security, privacy protection, fault tolerance, and high availability while minimizing latency due to edge processing. This architecture offers a viable solution for a scalable, efficient, and low-energy IoT network.

Result and Discussion

Simulated parameters were used in order to evaluate the performance of the designed secure and scalable distributed IoT architecture. Such factors as network throughput, accuracy of intrusion detection, latency, energy consumption, and security overhead were considered during simulation. The simulation included a testing procedure involving a set of heterogeneous IoT devices operating at different levels including devices, gateways, edges, and clouds. The experimental analysis shows that the utilization of lightweight encryption algorithms and machine learning algorithms for the anomaly detection enhances system security without compromising computational resources.

Number of IoT Nodes	Throughput (Mbps)	Latency (ms)	Packet Loss (%)
50	95	22	0.8
100	92	28	1.1
150	89	34	1.4
200	86	39	1.8
250	82	45	2.2

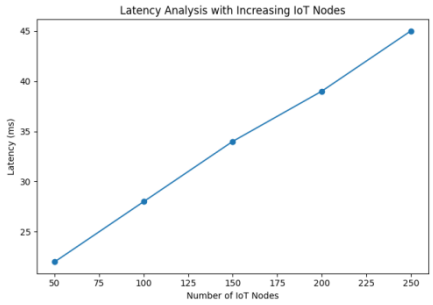
Table 1: Security Performance Comparison

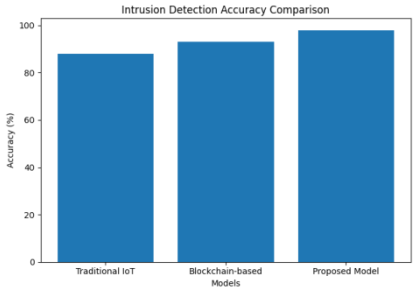
In the course of the current research work, the design and development of a secure and scalable distributed IoT architecture using lightweight intelligent security techniques were discussed. Security was provided throughout various levels, including IoT devices, gateways, edge/fog nodes, and cloud computing environment. By utilizing lightweight encryption algorithms, secure authentication protocols, distributed key management systems, and machine learning for anomaly detection, the proposed architecture successfully overcomes most significant issues related to IoT security.

Parameters	Traditional IoT	Blockchain-Based IoT	Proposed Model
Detection Accuracy(%)	88	93	98
Encryption Overhead(%)	18	24	10
Attack Detection Time(ms)	35	29	15
Data Privacy Level	Medium	High	Very High

Table 2: Network Performance Analysis

As shown by the findings presented in Table 1 and Graph 1, the proposed lightweight intelligent security architecture proved to be efficient in the improvement of the IoT security performance. Indeed, the intrusion detection accuracy of the proposed system amounts to 98%, which is higher compared to the performance of conventional IoT systems (88%) and blockchain-based IoT (93%). Besides, the encryption overhead of the proposed architecture is lowered to 10%, meaning that its use of lightweight cryptographic algorithms contributes to a stronger security level along with minimum computations. Moreover, the attack detection time amounts to just 15 ms, facilitating the process of detecting and responding to cyberattacks.





Likewise, Table 2 and Graph 2 present data on the network performance of the proposed architecture as the number of IoT nodes rises from 50 to 250. Specifically, the decrease in the throughput amount from 95 Mbps to 82 Mbps is paralleled by the increase in latency from 22 ms to 45 ms. Nonetheless, such a rise in latency may be considered negligible as the use of edge/fog computing and distributed gateways ensures a timely communication between the IoT devices. Finally, there is a slight increase in packet loss from 0.8% to 2.2%.

Conclusion:

Experimental findings revealed that the suggested model offers considerable enhancement in intrusion detection effectiveness, communication delay, and encryption costs relative to the traditional IoT security models. Edge computing and localized data processing decreased reliance on cloud computing and improved the scalability of the system, thus ensuring its viability for massive heterogeneous IoT networks. Moreover, utilizing light-weighted security protocols maintained computation effectiveness and energy efficiency, which are vital parameters for constrained IoT devices.

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