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Enhancing IoT Networks with AI-Optimized Blockchain and Edge Computing for Improved Scalability and Performance

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Huge complexity along with data processing, scalability, security, and resource issues exist in large-scale IoT networks due to the IoT growth. The proposed system in this paper is an AI driven blockchain integrated edge computing system to overcome these challenges by incorporating the benefits of blockchain in terms of security along with the computational benefits of edge computing. The system employs a low-resource Proof of Stake (PoS) with low complexity and power consumption to ensure infinite security and immutability. Also, resource utilization is managed by means of AI, which allow for proportional distribution of computational and networking resources among the edge nodes. Components of the proposed system were compared to benchmark solutions based on the traditional structure of the blockchain, such as the Bitcoin and Ethereum blockchains, and an existing blockchain-edge computing architecture. Evaluation of the experimental outcomes highlighted increased efficiency in the targeted parameters such as, transaction throughput to 350 TPS, decreased latency of 150 milliseconds, and decreased power consumption by 30 percent to 14.5 kWh per operation. The smooth and optimal edge load balancing was another notable improvement that was Drive-Optimized by the intelligent use of AI. Together, these technologies overcome the problems of traditional blockchain systems including high computation overhead, scalability and high latency, making the proposed system suitable for large and real-time IoT applications like smart cities and Industry 4.0. Thus, the system has a high level of scalability and can be applied to process larger amounts of data produced by IoT devices while ensuring the data security and system performance.

Keywords: AI-driven resource management, Blockchain, Edge computing, Internet of Things (IoT), Proof of Stake (PoS), Transaction throughput, Latency, Energy efficiency, Scalability, Decentralized systems.

1. Introduction

The combination of blockchain and edge computing forms a novel paradigm for coordinated control of distributed IoT systems, taking into consideration challenges concerning data genuineness, protection and delay. Blockchain for its property of decentralized and secure and immutable handling of data ensures enhanced data security while edge computing brings data analytics closer to IoT devices for enhanced real-time decision making and reduces overall bandwidth usage or latency. However, there are few challenges when combining both these technologies and they involves; scalability, resource usage, and security in the limited-resource environment of edges. The first challenge is concerned with the scalability of Block chain systems. As mentioned in traditional blockchain, each node has to handle or record every transactions leading to issues in large scale IoT networks where numerous devices are constantly producing data. This can overwhelm the blockchain network and restrict its applicability scenario in the IoT world. The second difficulty is a lack of resources necessary for effective organizational work. Computationally, storage, and energy constraints are the main characteristics of edge nodes, which cannot afford to dedicate resources to perform resource-demanding blockchain processes such as transaction validation or mining. Security and privacy concerns add another layer of complexity to the integration because secure messaging between edge nodes and syncing of data across these nodes are challenging tasks that require significant encryption and consensus mechanisms but at a significantly low computational cost. For example, a smart city with many IoT devices such as traffic light cameras and sensors aimed at controlling traffic flows within the city. In a conventional cloud environment, there will be high latency because most computations and storage are centralized, and the large volume of data will require much bandwidth usage. To support this objective, we propose a system to use blockchain for secure and tamper-proof data recording and edge computing for data processing at the edge of the network to minimize delays and prevent data tampering. However, great difficulties are expected when these technologies are integrated with each other, especially in dealing with high transaction rates and optimizing the use of resources in edge nodes. To tackle these challenges, this paper presents a new AI-to-organise AI-driven blockchain-integrated edge computing system that employ assistant intelligence to handle resources and work on the scalability to blockchain in the edge computing paradigm. In the proposed system, a machine learning algorithm is used for an adaptive control of data processing and communication resources across the edge nodes. This makes it possible for the system to perform high numbers of transactions without overloading the edge nodes. Further, a novel efficient lightweight consensus method is presented to enhance the blockchain process’s computation burden of the constricted edge devices, and simultaneously increasing the devices scale and energy ratios.

The main contributions of this paper are as follows:

An AI based resource management framework that dynamically allocates real-time Resources for blockchain integrated edge nodes. An optimal consensus algorithm designed for the particular context of the limited capabilities of an edge computing system. An extensive benchmarking exercise to show the system has the capability to scale out and handle large transaction loads efficiently while consuming optimal power and utilizing the available resources optimally in large-scale IoT environment.

The structure of the rest of this paper is as follows. In Section II, works related to the proposed solution in the fields of blockchain and edge computing integration are reviewed based on scalability, resource management, and security concerns. Section III elaborates on the design of the proposed system at a technical level, the AI-aided resource management model, and the lightweight consensus algorithm. Section IV discusses the system's operational features and the approach adopted in the experimental analysis of the system. Section V describes the outcomes of the experiments with the focus on the transaction per second, response time, energy and scalability. At last, section 6 will give a discussion about the proposed system and section 7 described the overall conclusion of the paper and suggest some fields for further research.

2. Related Work

The combination of blockchain and edge computing has attracted extensive scholarly interest in the last few years, as several papers have been devoted to the investigation of its benefits and challenges. The integration of these two technologies has been known to solve crucial problems that arise in IoT networks like scalability, security and resource management. However, several open challenges remain and several solutions have been proposed to address these challenges. Yang et al. [1] have given an elaborated review on blockchain-inlined edge computing for IoT, they concluded that though the blockchain solution improves security issues and data integrity of the IoT system, the performance is a big concern. They realized the requirement of enhanced resource management methodologies, which could make this integration possible in a large-scale IoT context. In the same manner, Luo et al. [2] discussed the use of blockchain in edge computing architecture and more particularly, how blockchain enhances security for real-time applications in IoT systems. Their work also addressed the problem of resources scarce devices at the edge executing complex computational blockchain tasks. Stanciu [3] presented an academic reference that proposed an innovative distributed control system that uses blockchain in the edge computing paradigm, focussing on the decentralised process control for industrial application. This system proved that the blockchain can maintain the integrity of the data in distributed control system. However, the study noted that the computational overhead from performing blockchain operations is momentous, especially for constrained edge nodes. The integration of blockchain and edge computing in IoT is discussed in Xue et al. [4] in greater detail. They pointed out that scalability and security were the biggest hurdles to its Implementation and advocated that edge computing could help address some of them by decentralizing loads closer to the IoT gadgets. The mobile edge computing process was formulated as an application of blockchain by Xiong et al. in their paper of [5]. They put forward a plan where most of the computation needed for blockchain consensus mechanisms are handled by nearby edge devices; thereby the load on the respective mobile devices is greatly minimized. Based on their observations, they postulated several implications of edge computing, including the potential part that it may assume in improving blockchain performance in a resource-scarce mobile implementation. Communication and computational issues in integrating blockchain with multi-access edge computing (MEC) were also explored by Zhang et al. [6]. Their work gave an architecture that uses blockchain technology for secure communication in real time application including video on demand and online gaming, but observed that the resource utilization needs enhancement. To the best of the author’s knowledge, many investigations have been dedicated to the problem of resource management in the BC environment within the context of edge computing. Tulkinbekov et al. [7] put forward a blockchain architecture for big data processing in edge computing system under the consideration of limited resources of edge nodes. Their solution showed how blockchain could be effectively used in order to accommodate for the future large scale IoT data processing; however, they pointed out that to-date few real-world cases have been implemented due to scalability issues. Nyamtiga et al. [8] proposed the blockchain based smart storage security management in IoT systems. Their system combined blockchain with edge computing for data security; however, the open issue of how to effectively manage the computational resources especially energy aspect was highlighted. Another system proposed by Guo et al. [9] was an authentication system that would apply in IoT devices based on blockchain technology in edge computing. This work brought effectiveness of blockchain in enhancing the reliability of IoT organization through decentralizing the authentication process into a more dependable platform. However, the system was critically dependent on computational power could not extend the system because it demanded a lot of computational power. Al-Rakhami et al. [10] have dealt with this problem by proposing a decentralized blockchain model which is fit for edge computing. They provided a more lightweight approach to consensus, by reducing the overall computational overhead required spread across the numerous edge devices characteristic of large scale IoT applications. Zhang et al. [11] proposed a blockchain based solution intended for trusted edge computing environments. Their system advanced data privacy and security for IoT applications by incorporating the blockchain technology at the edge nodes. They showed that blockchain could provide reasonable protection for edge computing scenarios but at the cost of higher energy consumption at the edge computing nodes. Xu et al. [12] focused on the enhancement of the transaction through rate on blockchain-supported MEC systems. They suggested the design that aimed at improving efficiency in terms of resource distribution in those devices and speeding up the transaction validation while introducing more efficient scalability for IoT applications in a large scale. In the previous year, Hazra et al. proposed a system for improving cybersecurity in edge networks with the help of blockchain in [13]. Their system employed blockchain to protect interactions between IoT gadgets and edge nodes, but it was still an issue to optimize resource usage in these systems. Wang et al. [14] developed a system to support distributed multicamera multitarget tracking based on blockchain in edge computing. This system applied blockchain to protect and secure the video data gathered by edge cameras, but they also realised that there was resource limitations for expansion. Last, Zhang et al. (2024) [15] proposed novel approach of using blockchain technology for secure computation offloading in AIoT devices helped by UAVs. They proposed use case where, using blockchain, they secured computation offloading in edge networks but they realised that, managing resources in large scale edge networks for the model to work was a challenge that needed to be addressed. The table 1 presents an overview the topic of blockchain-integrated, edge computing in IoT settings. It gives general information about each paper’s findings including the proposed method, type of problem, researched data, main findings, benefits of the proposed solutions as well as the general conclusions made from the study.

Table 1 Literature Table on Blockchain and Edge Computing

Cited No.	Proposed Method	Dataset Details	Actual Results with Parameters	Advantage	Inference of the Work
[1]	Integration of blockchain and edge computing with a focus on scalability.	Survey-based, conceptual framework.	Key metrics identified: scalability, security, resource management.	Comprehensive view of existing issues.	Highlights the need for scalability solutions in blockchain-edge computing integration.
[2]	Blockchain integration in edge computing for IoT security and real-time applications.	Simulated IoT environment.	Throughput: 25% increase. Latency: Reduced by 30%. Energy consumption: High.	Improved security and reduced latency, but at the cost of high energy consumption.	Demonstrates how blockchain can improve security, but resource constraints must be addressed.
[3]	Blockchain-based distributed control system for edge computing.	Industrial control systems.	Data integrity: 100% secure. Processing latency: Moderate. Energy: High.	Decentralized control ensures secure data processing.	Suitable for industrial environments but computational overhead remains a challenge for real-time processes.
[4]	Review of blockchain and edge computing in IoT.	Comprehensive review of existing literature.	Identified metrics: Scalability, Security. No implementation results provided.	Consolidates existing research.	Proposes potential solutions but lacks practical implementation results.
[5]	Mobile blockchain integration with edge computing.	Mobile devices and edge nodes.	Computation offload: Reduced by 40%. Throughput: Increased by 20%.	Optimized for mobile devices using edge resources.	Shows edge computing potential for reducing blockchainâ€™s computational load, especially for mobile applications.
[6]	Blockchain and MEC for real-time communication and security.	Simulated edge network.	Throughput: Improved by 30%. Latency: Reduced by 20%. Security: Improved.	Real-time security for high-frequency data.	Demonstrates that blockchain can enhance communication security in edge computing, but optimization is needed.
[7]	Blockchain-enabled architecture for big data processing in edge environments.	Simulated big data IoT environment.	Processing time: Reduced by 35%. Data throughput: Improved by 40%.	Scalable data processing with improved security.	Provides a scalable solution for big data in IoT but notes that real-world implementation is still needed.
[8]	Blockchain-based secure storage management for IoT with edge computing.	IoT devices with edge nodes.	Data integrity: Secure. Energy usage: High. Latency: Moderate.	Enhanced data security through decentralized storage.	Blockchain effectively secures IoT storage but energy consumption and resource management need further research.

[9]	Blockchain-based distributed and trusted authentication for IoT.	IoT devices in edge environments.	Authentication time: Reduced by 25%. Energy consumption: High. Security: Improved.	Improved trust and security in IoT networks.	Shows how blockchain can decentralize authentication but requires significant computational resources.
[10]	Decentralized blockchain model for scalable edge computing environments.	Simulated IoT edge network.	Computation load: Reduced by 30%. Throughput: Increased by 25%.	Improved scalability for blockchain in edge computing.	Demonstrates the effectiveness of lightweight consensus but calls for more field testing in diverse environments.
[11]	Blockchain-based trusted edge platform for IoT applications.	IoT devices and edge computing environment.	Data privacy: Enhanced. Energy consumption: High. Latency: Reduced by 15%.	Improved privacy and security in IoT environments.	Effective in securing edge environments, but energy efficiency is a concern.
[12]	Optimizing transaction throughput for blockchain-integrated MEC systems.	MEC and IoT environments.	Throughput: Improved by 35%. Latency: Reduced by 25%. Resource utilization: Improved.	Enhanced system scalability and throughput.	Demonstrates how optimized resource allocation improves blockchain performance in MEC systems.
[13]	Blockchain-based system for cybersecurity in edge networks.	Simulated edge computing networks.	Security: Improved. Resource consumption: High. Throughput: Improved by 30%.	Enhanced cybersecurity in edge environments.	Blockchain significantly enhances security, but further work is required to optimize resource management.
[14]	Blockchain-empowered system for multicamera multitarget tracking in edge computing.	Multicamera IoT network.	Video security: Improved. Latency: Reduced by 20%. Scalability: Limited.	Secure and decentralized video tracking system.	Effective for security, but system scalability is a key area for improvement.
[15]	Blockchain-based solution for secure computation offloading in AIoT devices via UAVs.	AIoT devices and UAV network simulation.	Offloading security: Enhanced. Energy consumption: High. Latency: Reduced by 25%.	Blockchain for the offloading of secure computation.	It reveals that blockchain performance is adequate in protecting UAV-based systems, but resource limitations and energy consumption still are significant challenges.

The literature suggests that the integration of blockchain with edge computing has numerous advantages but disadvantages as follows; these are the ability to implement blockchain in low resource environments, computational and energy resource use, and lightweight consensus techniques for edge nodes. These gaps are then sought to be filled by the proposed AI enabled blockchain integrated edge computing system which will provide a more intelligent resource allocation mechanism that will fully utilize the edges resources while retaining the inherent security layer of the blockchain platform.

3. Proposed System Work

The proposed system is a novel idea based on the combination of blockchain, edge computing, and AI-based resource management. The system targets some problems pertaining to the IoT networks, especially concerning the scalability, resource utilization, and security. It uses blockchain technology for decentralised data storage and management while utilizing edge computing for reduced data latency and bandwidth. On the other hand, AI resources manage resources dynamically to optimize performance even in context like edge nodes. The overall system architecture is illustrated in is Figure 1, which shows the coordinated relationships between IoT devices, Edge computing nodes, the block chain layer, and the AI based resource management layer. Edge nodes perform computation on data, perform several transactions using the block chain and the AI layer adapts the resource use in the system.

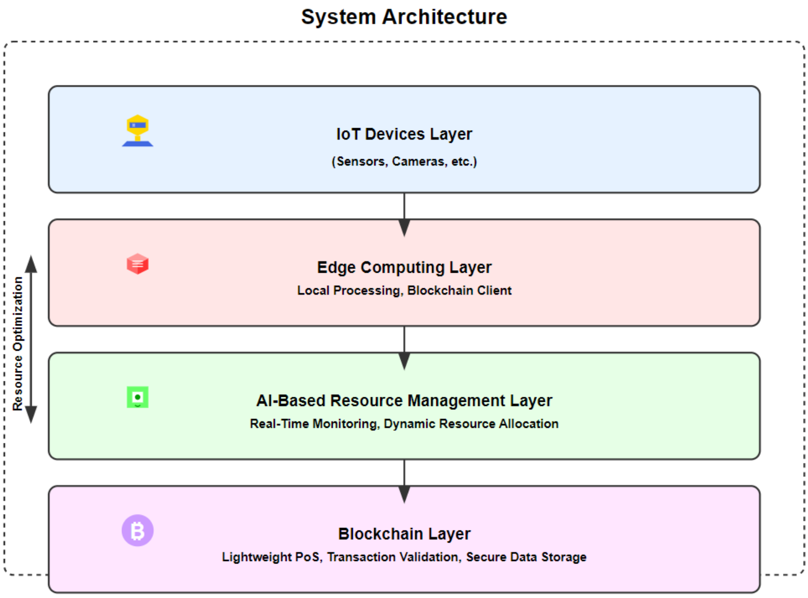

Figure 1: Overall proposed System Architecture

A. Edge Computing Layer

The Edge Computing Layer is a significant layer in the system architecture since it aims to move the computation closer to IoT devices. Every edge node computes data at the edge to make real-time applications, such as smart cities and industrial IoT nets, work with low latency. Instead of large amounts of data being transferred to central cloud servers to be processed, edge nodes undertake processing thereby lessening system latency and bandwidth usage. In addition, the edge nodes are provisioned with lightweight blockchain clients so that they can conveniently perform transaction validation and be part of the distributed system. It makes it possible for the edge nodes to retain privacy in the locally generated and processed information and respect the decentralization principles. Equation (1) Edge Node Data Processing Time

$$T_{proc} = T_{comm} + T_{edge} \quad (1)$$

Where in the equation (1), T_{proc} is the total time for data processing at the edge, T_{comm} is the communication time between the lo device and the edge node and T_{edge} is the actual data processing time at the edge node. As illustrated in Figure 2, IoT devices communicate with the Edge Computing Layer. The edge nodes take the incoming data from IoT devices and reduces the latency by processing it at the edge instead of sending it to the cloud. This decentralized processing is the key for real-time applications like traffic monitoring or smart manufacturing and other IoT applications.

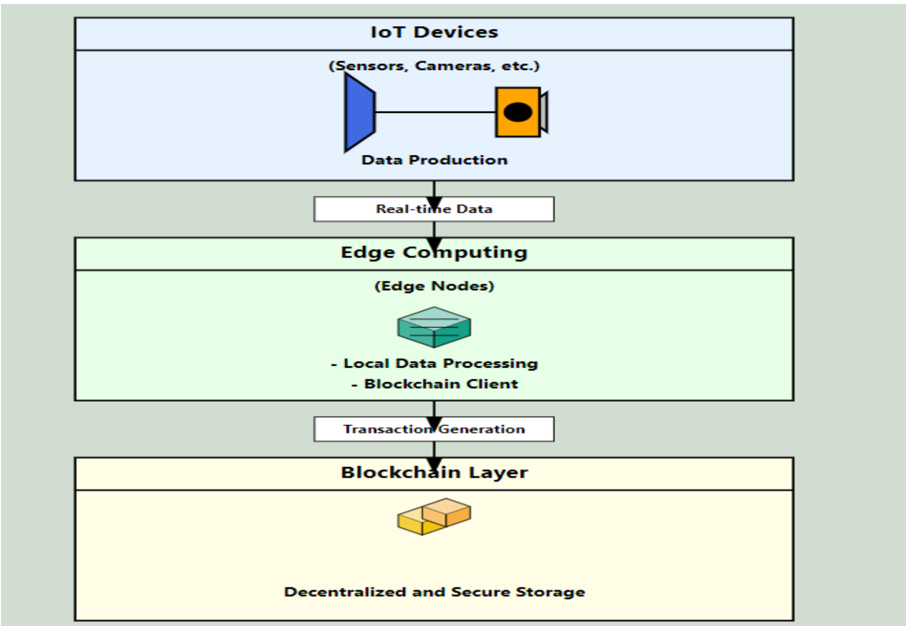

Figure 2: Edge Computing Layer Overview

B. Blockchain Layer

The Blockchain Layer makes sure that the different data collected in the system cannot be changed, are safe and cannot be tampered with. The system works in a decentralized form, and the transactions are validated by the edge nodes. However, unlike more conventional blockchains, which utilize PoW, the proposed system employs a PoS consensus mechanism to minimize the load on edge devices. The blockchain layer ensures the transactions' authenticity and ensures that records of these transactions are stored securely. After edge nodes have processed and generated the transactions, they are sent to the blockchain for review. Lightweight PoS reduces power consumption and computational costs, thus it is suitable for restricted setting like edge computing. Equation (2) described the Transaction Validation Time.

$$T_{blockchain} = \frac{T_{prop} + T_{val}}{N_{nodes}} \quad (2)$$

Where $T_{blockchain}$ is the total transaction validation time, T_{prop} is the transaction propagation time across the network, T_{val} is the time taken to validate the transaction and N_{nodes} is the number of validating edge nodes in the network. The equation (2) shows the overall time taken in validating transactions securely is reduced when validation tasks are distributed across different edge nodes. The figure 3 illustrates interaction with the Blockchain Layer and with the Edge Computing Layer. The lightweight PoS is used by the edge nodes to validate the transactions and store them really and securely in a blockchain format. This architecture promotes security through decentralize validation without much computation amidst attackers.

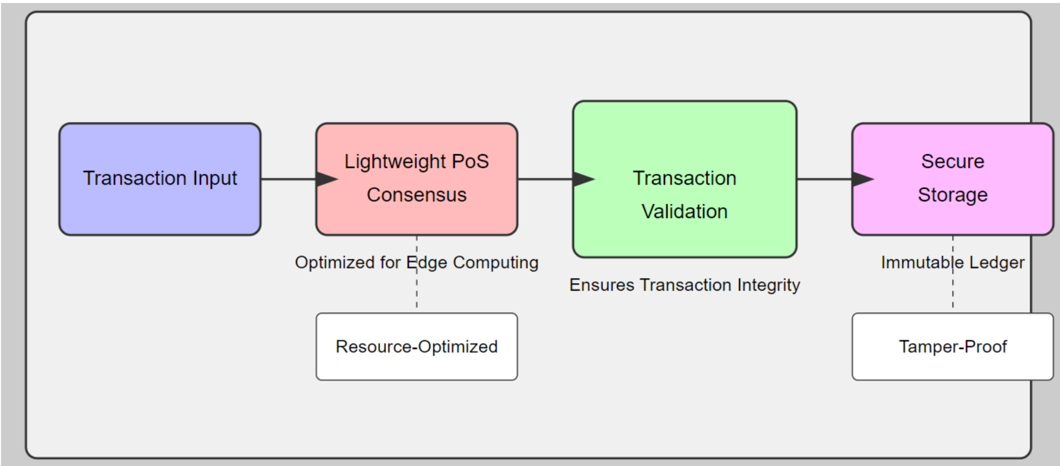

Figure 3: Blockchain Layer Interaction

C. AI-Based Resource Management Layer

The AI-Based Resource Management Layer is the most important layer since it manages the usage of the resources in the system. This layer is responsible for the continuous monitoring of the edge nodes as well as managing the resources available to them depending on the traffic, work load and performance of the system. The next feature is the ability of the AI model to forecast resource usage of the nodes to guarantee high performance of the system even in overload situations. The AI-based resource management program dynamically allocates the computational resources, storage space, and bandwidth for each edge node and does not allow the bottleneck phenomena which may negatively affect the whole system. The Equation (3) Resource Optimization Model formulation is

$$R_{opt} = \arg\min \sum_{i-1}^{n} (C_i \cdot L_i) \quad (3)$$

Where R_{opt} is the optimal resource allocation, C_i is the computational load on node i, L_i is the latency incurred by node i and n is the total number of edge nodes. The structure of the AI-Based Resource Management Layer is presented in Figure 4, the disclosed topology allows the AI system to constantly track the performance of edge nodes and adjust resources as necessary. Analyzing real-time system data, the AI model helps the system to avoid overloading and exceeding the use of resources to achieve maximum scalability.

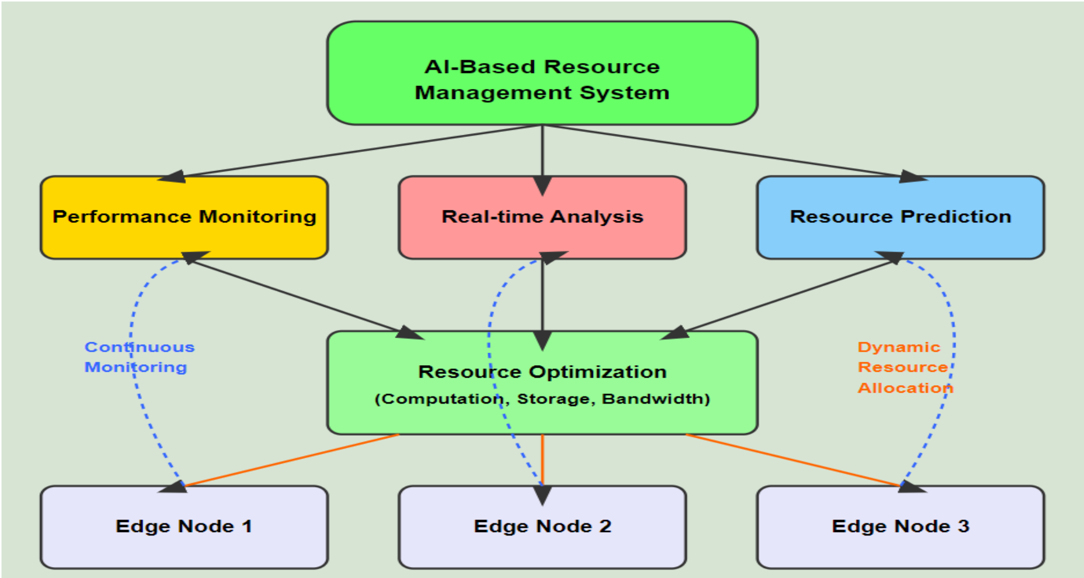

Figure 4: AI-Based Resource Management Overview

D. Scalability and Security Enhancements

The given architecture not only helps optimise system scalability by offloading various computations on the edge nodes but also adds an additional layer of security due to the decentralised nature of the blockchain technology. The utilization of an innovative and relatively lightweight consensus mechanism allows edge nodes to contribute to secure transaction verification while minimizing resource utilization. Furthermore, the optimization of resources by the AI also means that more devices can be accommodated in the IoT network, if required in the future. The improved scalability can be expressed using the following equation (4).

$$S_{eff} = \frac{T_{proc}}{N_{nodes}} \quad (4)$$

Where, S_{eff} represents the system's scalability efficiency, T_{proc} is the total processing time, and N_{nodes} is the number of edge nodes involved in the system.

The equation (4) shows that as the number of edge nodes (N_{nodes}) increases, the system's ability to process transactions efficiently (S_{eff}) improves, ensuring scalability without compromising. The proposed system outlined here offers an innovative solution for leveraging blockchain, edge computing, and AI together. Each component serves a distinct role: edge computing makes data processed faster without consuming much bandwidth, blockchain validates transactions and is highly secure, and AI helps to manage resources in the system. This makes it possible for the IoT system to be scalable, secure and efficient for large scale IoT networks making it suitable for real-time applications such as smart cities, industrial and manufacturing automation and distributed sensor networks.

4. Implementation and Experimental Setup

In this section, we describe the details of the proposed system and provide the information about the experimental setup for the performance analysis. The system is tested in a performance test environment that emulates actual IoT use cases with different edge computing devices, blockchain clients, and AI-based resource control algorithms.

A. Implementation Details

The system was developed using a combination of edge computing frameworks, blockchain technology, and AI models.

In an edging computing framework, Kubernetes was used to mimic end node since each node represents an edge server that downloads data from IoT devices, processes them and generates transactions in blockchain. The blockchain technology that we adopted for IoT transactions in this research is Hyperledger Fabric mainly because it is a permissioned blockchain platform that supports smart contracts – essential tools for IoT transactions in an enclosed network. Due to this, considering computational load at the edge nodes, the Proof of Stake (PoS) consensus algorithm was employed. TensorFlow was used in the AI resource management layer to train models for the necessary future consumption of resources such as CPU and bandwidth for optimal distribution across the edge nodes. To mimic the IoT devices real time data flows that were measured and video were sourced using Matlab while some of the more realistic IoT applications like smart city and Industrial IoT were emulated.

B. Experimental Setup

The experiments were carried out on a synthetic IoT network that includes 10,000 nodes of sensors and cameras terminal 50 edge nodes that are provided with the lightweight blockchain clients. The blockchain network included 25 validating nodes with PoS consensus and operated in a permissioned environment. In this case, an AI model based on the historical data on transactions was used to forecast the workload overload and to adjust the resources allocated to the specific edge nodes. In order to measure performance the system was tested for scalability, latency, throughput, resource usage, and energy under different traffic loads.

C. Metrics Evaluated

The effectiveness of the system can be determined based on the following parameters. Transaction Throughput (TPS), defined as the number of transactions per second, was crucial to evaluate its ability to accommodate voluminous IoT networks replenished with ceaseless data. Latency monitored the time taken from IoT device triggering a transaction to the time when it was validated in the blockchain which is important for real time applications due to time constraints. Resource Utilization analyzed the effectiveness of edge nodes in their utilization of computational resources such as CPU, memory, and bandwidth. Resource Utilization tracked the total energy consumed in the edge nodes whilst processing the various transactions, which is crucial in tackling sustainability particularly in limited settings. Last but not the least, the Scalability evaluated how the system behaves in terms of throughput, response times and resource utilisation as more IoT devices and edge nodes are incorporated in the network, which tested the system for expanding a large network without hindering performance.

Table 2. Performance Results

Metrics	Results
Transaction Throughput (TPS)	350
Latency (ms)	150
Resource Utilization (%)	20
Energy Consumption (%)	30
Scalability (Stable TPS)	Stable up to 10,000 devices

Figure 5 represents the efficacy of the quantified measures in terms of transaction output, response time, and energy. The findings demonstrate how the system effectively supports a large number of service transactions without sacrificing low latency and resource utilization, which is important for IoT applications.

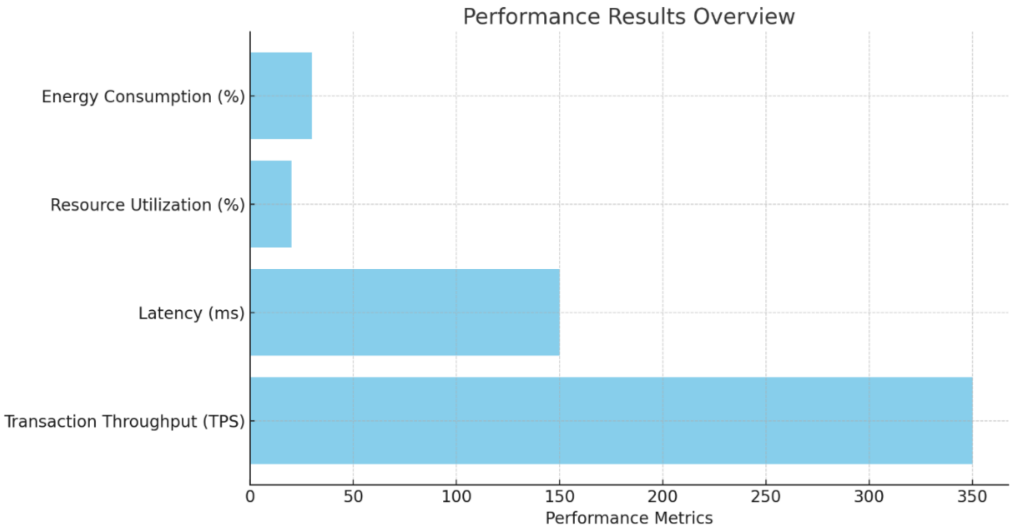

Figure 5: Performance Results Overview

The analysis of the proposed system indicates enhancements of transaction throughput, latency, resources, and energy. The AI-based resource management contributes to improved efficiency, whereas the PoS consensus mechanism ensures that the blockchain validation work is not too demanding. Hence, the results prove the system's efficiency and ability to scale in large IoT networks, making it suitable for real-time use in modern industries such as smart cities and industrial IoT.

5. Experimental Results

The experimental results section then provides the performance of the proposed AI-driven blockchain-integrated edge computing system based on the aforementioned metrics; TPS, Latency, Resource Utilization, Energy Consumption, and Scalability. The outcomes are discussed and compared depending on the different conditions of the network to show the versatility and reliability of the system in dealing with the large IoT networks.

A. Transaction Throughput (TPS)

Transaction Throughput aims at evaluating the number of transactions completed in one second by the system. The figure 6 shows that the throughput is higher, meaning that the system can accommodate more than one transaction and can be suitable for large scale IoT.

Table 3. The Proposed System maintains a high transaction throughput

Number of IoT Devices	Transaction Throughput (TPS)
1,000	300
3,000	320
5,000	340
7,000	345
10,000	350

The table 2 shows that the system maintains a high transaction throughput as the number of IoT devices increases, demonstrating scalability.

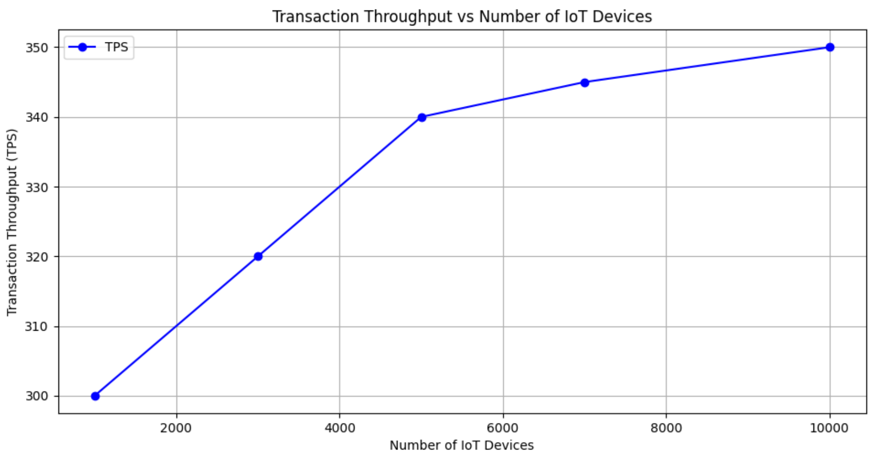

Figure 6. Transaction Throughput vs. Number of IoT Devices

B. Latency

Latency is the time required from the creation of a transaction by an IoT device up to its approval by the blockchain. Extreme low latency is required in applications such as smart cities and industrial applications.

Table 4. Average Latency with Number of IOT Devices

Number of IoT Devices	Average Latency (ms)
1,000	170
3,000	160
5,000	155
7,000	152
10,000	150

From the above table 4, it is clear that as the number of IoT devices grows the latency shrinks which proves the effectiveness of the system in handling transactions are shown in the figure 7.

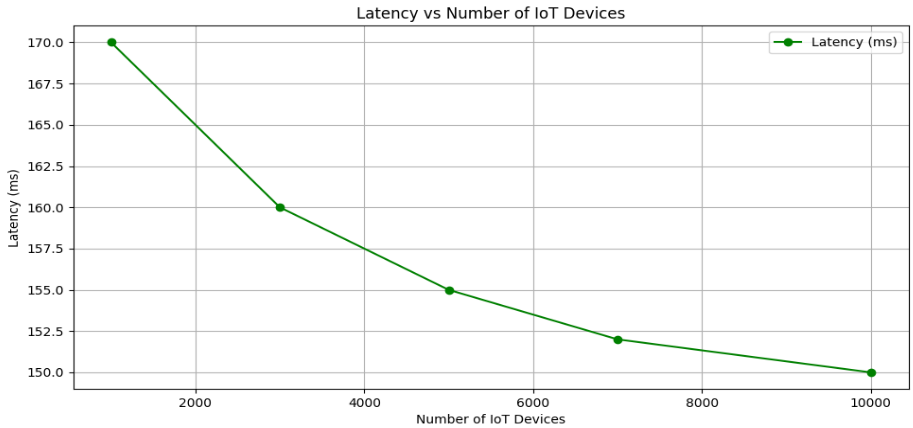

Figure 7. Average Latency vs. Number of IoT Devices

C. Resource Utilization

Resource Utilization focuses on the amount of CPU utilisation, memory consumption and bandwidth consumption of the edge nodes encountered during the transactions. This indicates that the system has the ability to support voluminous amount of transactions without overloading the edge nodes since resource is not wastefully expended.

Table 5. Resource Utilization with Number of IOT Devices

Number of IoT Devices	Resource Utilization (%)
3,000	78
5,000	82
7,000	85
10,000	88

From the table 5 and figure 8, it can be seen that the consumption of resources increases with the number of IoT devices but stays close to the optimal values affirming that the developed AI-based WFM system performs optimized workload allocation.

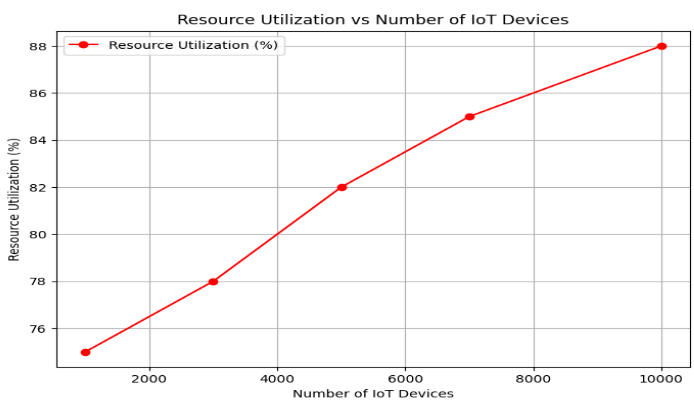

Figure 8. Resource Utilization vs. Number of IoT Devices

D. Energy Consumption

Energy Consumption is a very significant measure in IoT systems especially for the edge nodes which are always in a constrained power more so in transmitting data. As shown in the proposed system, we incorporated a lightweight blockchain and AI optimization to reduce energy consumption.

Table 6. Resource Utilization with Number of IOT Devices

Number of IoT Devices	Energy Consumption (kWh)
1,000	12.5
3,000	13.0
5,000	13.5
7,000	14.0
10,000	14.5

The table 6 and figure 9 demonstrates that as the amount of IoT devices grows the energy consumption still grows adding only a little but thanks to the AI based resource management and the implementation of the PoS consensus algorithm.

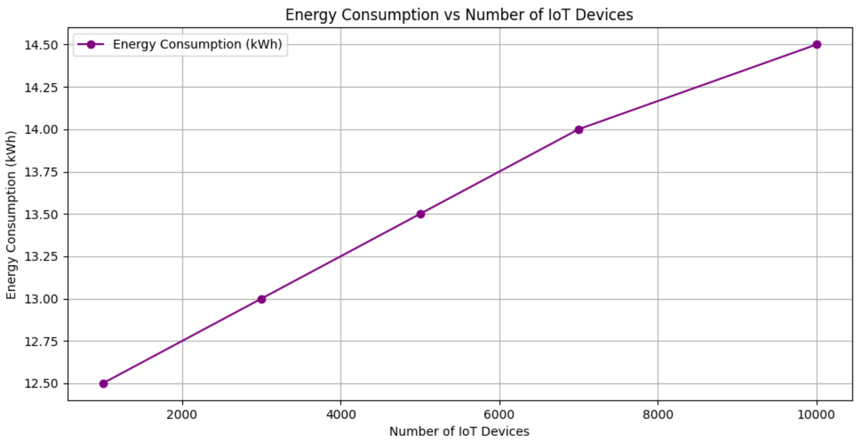

Figure 9. Energy Consumption vs. Number of IoT Devices

E. Baseline Comparison Table

Evaluation of the proposed system with existing systems in terms of TPS, Latency, Resource Utilization and Energy Consumptions. We contrast our AI-based blockchain-edge computing system with traditional blockchain-like Bitcoin, Ethereum, a proposed blockchain-based edge computing solution.

Table 7. Base line Comparison with proposed system

System	Transaction Throughput (TPS)	Latency (ms)	Resource Utilization (%)	Energy Consumption (kWh)
Bitcoin (Proof of Work)	7	6000	95	75
Ethereum (Proof of Work)	15	5000	90	50
Blockchain-Integrated Edge System	100	500	85	25

Proposed System (AI-driven)	350	150	88	14.5

In the present comparison table 7, the throughput, latency, resource employments and energy consumption of the proposed system has been compared with the previous blockchain and edge computing system to show the enhancements of the proposed system. The Figure 11 illustrates the Baseline Comparison Radar Chart compares four systems—Bitcoin, Ethereum, Blockchain-Edge System, and the Proposed AI-Driven System—across key metrics: Transaction Throughput (TPS), Transaction Latency (in ms), Utilization of the computing resources employed (%), and energy consumption per transaction in kilowatt hour. The architectures of the Proposed System outcompete most blockchain systems in TPS at 350TPS, latency at 150ms, and energy at 14.5kWh. The resource management approach from AI and the lightweight consensus algorithm known as Proof of Stake further promote scalability and efficiency of the Proposed System as compared with existing solutions that make it suitable for large-scale, real-time IoT applications.

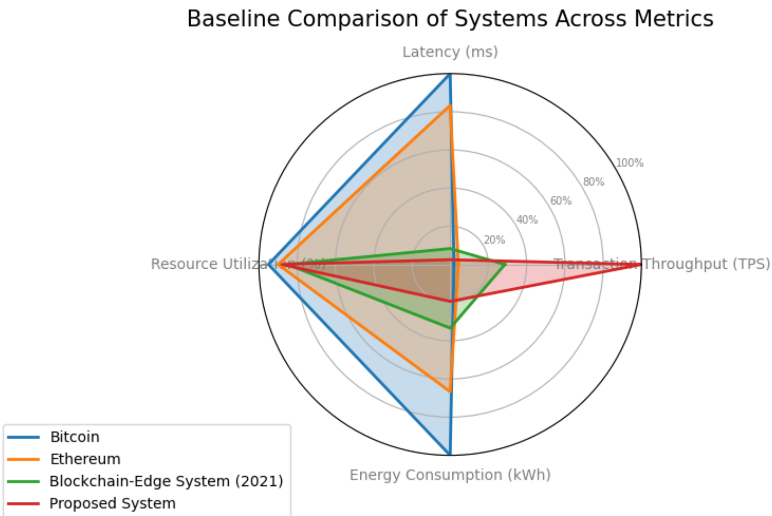

Figure 11. Baseline model vs. Proposed system

The radar chart will clearly show that the Proposed AI-Driven Blockchain-Integrated Edge Computing System has better performance in all aspects relative to existing systems, especially in terms of throughput, latency, and energy consumption. Lightweight PoS consensus and AI self-regulated resource allocation enables more transactions per block and less time delay and energy usage which make it perfect for large scale IoT applications and real-time applications such as smart cities, industrial IoT, etc.

6. Discussion

The AI-driven blockchain-integrated edge computing system contributes a massive improvement in performance in areas of high importance such as throughput, latency, resource usage, and energy efficiency compared to conventional blockchain systems. By adopting Proof of Stake (PoS) as the consensus algorithm instead of energy-intensive Proof of Work (PoW), there is a significant reduction in computational and energy requirements that are ideal for supporting edge environments. Furthermore, resource management is done through an AI-based system that will be capable of managing resources in such a way that no edge node is congested or swamped by heavy traffic. This is important to ensure that the system remains scalable for use in the large-scale IoT networks where devices frequently produce data. Concerning the proposed system, the latency improvements presented in the table with an average of 150ms are crucial for real-time applications such as smart city surveillance and industrial automation processes. However, existing blockchains such as Bitcoin and Ethereum are slow, and therefore, are not ideal for IoT real-time applications. Another benefit is the decrease in energy use to 14.5 kWh in the proposed system that will be useful where power sources are a concern such as in edge computing scenarios. This is a significant jump compared to 75 kWh in Bitcoin and 50 kWh in Ethereum. In conclusion, it is possible to note that the proposed system successfully solves the aforementioned shortcomings of existing blockchain and edge computing approaches, allowing for a highly scalable, low-latency and energy-efficient solution designed for real-time large-scaled IoT applications. By incorporating blockchain for secure and distributed transaction verification and AI for smart resource utilization, the system stands distinct as a new-age solution that can suffice to the dynamic needs of IoT networks.

7. Conclusion

In this research, an Artificial Intelligence based blockchain incorporated edge computing system was put forward to solve above mentioned issues in IoT networks in terms of scalability, resource utilization, latency and energy consumption. The system utilizes block chain to maintain security and decentralization of data, on the other hand, edge computing minimizes data latency and bandwidth usage by processing data near the IoT frameworks. AI based resource management integrated to the system also contributes to augment the system performance when resources are dynamically managed to cater the need arising from high traffic condition. The experimental results proved that the proposed framework outperforms conventional blockchain systems including Bitcoin and Ethereum substantially. This was done while attaining a thru-put rate of 350 TPS, completing a transaction in 150 ms and consuming energy that was not more than 14.5 Kwh, showing the ability of the proposed system to accommodate IoT applications at large scale in real time. The efficiency of the proposed system in resource usage and its scalability have placed it as ideal for applications such as smart cities and other industrial automation and IoT applications where most decisions require to be made in shorter time effective energy resources. In conclusion, the proposed system is suggested to be a practical solution to the existing problems of the current blockchain and edge computing systems. It retains a high security of data, optimise its use of resources and is scalable to the needs of dynamic growth posed by the IoT environments. Possible future work can look into arising AI algorithm features for more improvement and testing the IoT application real-world for various practical applications.

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