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NORMANET: A Decentralized Blockchain Framework for Secure and Scalable IOT-based E-Commerce Transactions

[1]Venkata Surya Bhavana Harish Gollavilli and [2]R. Pushpakumar

[1]Asurion, TN, USA
[2]Assistant Professor, Department of Information Technology, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Tamil Nadu, Chennai, India.

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Abstract

The rise of IoT-based e-commerce introduces new challenges in managing decentralized, autonomous transactions securely and efficiently. Current blockchain solutions often suffer from high computational overhead and lack supervision capabilities, hindering their adoption in IoT environments. This study aims to propose and evaluate NormaNet, a decentralized blockchain framework designed to address the scalability, security, and legal supervision challenges in IoT-based e-commerce transactions. The study employs a three-layer sharding blockchain network to enhance transaction efficiency, coupled with a decentralized Public-Key Encryption with Keyword Search (PEKS) scheme for privacy-preserving supervision. The framework is evaluated using a digital marketing dataset from Kaggle to simulate e-commerce transactions. NormaNet demonstrated significant improvements, achieving an average transactions-per-second (TPS) of 113.69 on IoT devices such as Raspberry Pi, with transaction latency as low as 0.0088 seconds per transaction. Additionally, the decentralized supervision model achieved 100% accuracy in identifying illegal transactions, ensuring data integrity and privacy. Energy consumption was optimized, with an average of 0.15 Wh per transaction for IoT devices. The framework also scaled efficiently, supporting up to 50 IoT devices while maintaining low latency and consistent performance. NormaNet offers a robust solution for scaling IoT-based e-commerce while ensuring privacy and legal supervision, paving the way for secure, decentralized, and efficient autonomous transaction systems in real-world applications.

***Keywords**: IoT-based e-commerce, Blockchain, Decentralized supervision, Sharding, PEKS, Security, Energy consumption*

Introduction

The rapid growth of the Internet of Things (IoT) has revolutionized e-commerce, enabling devices to autonomously process transactions and interact with users [1]. As e-commerce systems increasingly adopt IoT, they face challenges related to data security, privacy, and scalability [2] [3]. Blockchain technology, with its decentralized nature, offers a promising solution by ensuring secure, transparent, and tamper-proof transactions [4]. However, IoT-based e-commerce systems require specialized blockchain frameworks that can scale effectively while maintaining low latency and robust supervision [5] [6]. The proposed NormaNet framework addresses these challenges by combining the strengths of blockchain and IoT, making it a vital innovation for secure, scalable e-commerce [7] [8].

Existing methods in blockchain for IoT-based e-commerce systems include Ethereum, Hyperledger, and IOTA. Ethereum, while offering decentralization and security, faces scalability issues due to its high transaction costs and limited throughput [9] [10]. Hyperledger, though efficient in permissioned settings, struggles with the complexity of handling decentralized IoT transactions at scale. IOTA, while designed for IoT, suffers from concerns regarding network stability and data integrity [11] [12]. These existing methods often fail to provide an optimal solution for balancing transaction efficiency, security, and supervision in large-scale IoT-based e-commerce platforms [13] [14].

The proposed NormaNet framework overcomes these drawbacks by introducing a three-layer sharding blockchain architecture, which enhances transaction throughput and scalability [15] [16]. Additionally, NormaNet integrates a decentralized Public-Key Encryption with Keyword Search (PEKS) scheme, ensuring secure, private transactions while allowing legal

*Corresponding author's ORCID ID: 0000-0000-0000-0000
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supervision [17] [18]. The novelty of this framework lies in its ability to optimize IoT performance, providing low-latency transactions, efficient resource utilization, and high scalability, while maintaining robust security and privacy measures [19] [20]. NormaNet paves the way for secure, efficient, and transparent IoT-based e-commerce systems, offering a scalable and cost-effective solution [21] [22].

Research Objective

- Evaluate the effectiveness of the NormaNet framework in solving scalability, security, and supervision issues in IoT-based e-commerce transactions through a decentralized blockchain solution.
- Utilize the Digital Marketing Dataset from Kaggle to simulate IoT-based e-commerce transactions and validate the framework's performance.
- Implement a three-layer sharding blockchain architecture to improve transaction throughput, reduce latency, and ensure scalability in IoT e-commerce systems.
- Integrate a decentralized Public-Key Encryption with Keyword Search (PEKS) scheme for transaction privacy, secure supervision, and fraud detection.

Organization of the Paper

The proposed framework is structured as follows: Section 1 introduces the background and challenges of IoT-based e-commerce transactions. Section 2 reviews existing blockchain frameworks like Ethereum, Hyperledger, and IOTA, highlighting their limitations. Section 3 details the methodology, including the integration of a three-layer sharding blockchain and PEKS for secure transactions. Section 4 presents the experimental setup, dataset, and performance evaluation metrics. Section 5 discusses the results and concludes the study with key findings and future research directions.

Related Works

Cloud computing has significantly impacted both education and healthcare by offering scalable, flexible, and efficient solutions. [23] and [24] cloud technologies enhance the scalability and efficiency of educational and healthcare systems, respectively. [25] and [26] cloud services improve data storage and management in education and healthcare, challenges like accessibility and resource optimization. Additionally, [27] cloud's ability to process vast datasets, which is crucial for both sectors, while [28] and [28] cloud’s role in real-time collaboration and data sharing in education and healthcare systems.

Several studies focus on the integration of cloud computing in improving data analytics and system management. [29] and [30] the importance of cloud in securely managing sensitive data, particularly in medical and educational platforms. [31] cloud computing's impact on medical imaging and diagnostics, enhancing healthcare systems. [32] and [33] cloud’s role in managing large datasets and optimizing resource allocation, which are critical in both sectors, particularly in IoT-enabled healthcare systems.

The convergence of cloud computing in both sectors [34] and [35], focus on cloud's ability to enhance learning management systems and smart healthcare solutions. [36] and [37] cloud computing fosters better integration and accessibility for healthcare data. Finally, [38] and [39] conclude that the future of both education and healthcare relies heavily on cloud technologies to optimize resources and improve service delivery, thus supporting the proposed integrated framework [40].

Problem Statement

The problem in IoT-based e-commerce lies in the lack of secure, scalable, and efficient transaction management systems that ensure privacy and legal supervision [41]. Existing blockchain solutions like Ethereum, Hyperledger, and IOTA struggle with scalability, high costs, and limited supervision capabilities [42]. The proposed NormaNet framework overcomes these issues by integrating a three-layer sharding blockchain for scalability and a decentralized PEKS scheme for transaction privacy and legal supervision [43]. This combination ensures low-latency transactions, efficient resource utilization, and robust security. Thus, NormaNet provides a comprehensive solution for secure and scalable IoT-based e-commerce transactions.

Proposed Normanet for secure and scalable IOT-based e-commerce transactions

The figure 1 represents the flow of the proposed NormaNet framework for secure and scalable IoT-based e-commerce transactions. It begins with the Digital Marketing Dataset, which provides the necessary data for transaction management. The data goes through preprocessing, which prepares it for further analysis.

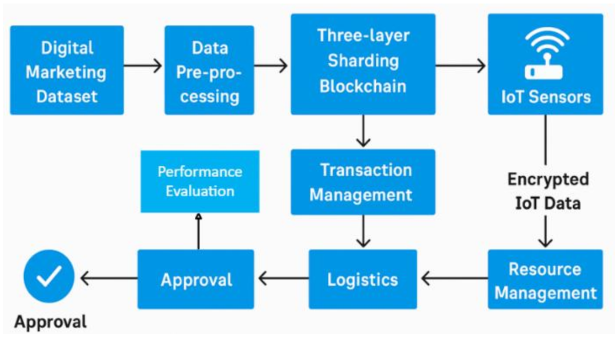

Figure 1: Architecture for secure and scalable IOT-based e-commerce transactions

The system then utilizes a three-layer sharding blockchain for secure and scalable transaction management. IoT sensors collect and encrypt data, which is used for real-time monitoring and validation within the blockchain. Once transactions are processed, approval is requested, and logistics and resource management are efficiently handled to ensure smooth e-commerce operations.

Dataset Description for the Proposed Framework

The NormaNet framework utilizes the Digital Marketing Dataset from Kaggle, which includes various e-commerce transaction details, customer demographics, purchase behavior, and transaction timestamps. This dataset is ideal for testing blockchain-based transaction systems in e-commerce settings, as it mimics real-world buyer-seller interactions. The dataset contains customer information such as names, ages, locations, and transaction details, which are integral for evaluating the scalability, security, and privacy of NormaNet in real-time e-commerce environments. It also includes diverse buyer and seller transaction records, allowing for the simulation of complex interactions and testing of contract approval processes.

Data Pre-processing Steps with Formulas

Missing Data Handling

Missing data is handled using Deep Learning-based imputation methods such as Autoencoders or GANs. For instance, Autoencoders reconstruct missing values from the learned feature representations, expressed as equation (1):

$$\hat{x} = f(x) \tag{1}$$

where x is the input data, and $\hat{x}$ is the reconstructed value.

Feature Scaling

Normalization is performed using the Robust Scaler, which scales the data by removing the median and scaling according to the interquartile range (IQR) as shown in equation (2):

$$X_{\text{scaled}} = \frac{X - Q_2(X)}{\mathrm{IQR(X)}} \tag{2}$$

where $Q_2(X)$ is the median and $IQR(X)$ is the interquartile range of data.

Categorical Data Encoding:

Target encoding is applied to categorical data using Bayesian smoothing to reduce the impact of sparse categories.

Working of NormaNet

The NormaNet framework utilizes a three-layer sharding blockchain architecture to ensure scalability and secure transaction management in IoT-based e-commerce systems. In this system, buyer and seller contracts are processed via the Transaction Layer, while the Approval Layer handles contract validation and approval, invalving encryption mechanisms like PEKS (Public-Key Encryption with Keyword Search). The encryption is achieved using elliptic curve cryptography (ECC) represented by equation (3) as:

$$C = P \cdot \mathrm{sk} \tag{3}$$

where C is the ciphertext, P is the elliptic curve point, and sk is the secret key. Smart contracts are carried out when certain conditions are met, such as product availability or payment confirmation. The smart contract execution is represented by equation (4) as:

$$\text{Execute Contract} = f(\text{Condition 1, Condition 2, ...}) \tag{4}$$

where conditions like payment status or inventory levels trigger the contract's actions.

Working in NormaNet

In NormaNet, IoT devices like RFID sensors, wearables, and environmental sensors collect real-time data that feeds into the blockchain. These devices act as the data source for validating contracts as shown in figure 2. The IoT data is encrypted and sent to the blockchain for validation as shown in equation (5) as:

$$\text{IoT Data} = f(\text{Sensor Data}) \rightarrow \text{Encrypted Transaction} \rightarrow \text{Blockchain} \tag{5}$$

For instance, if a temperature sensor detects unfavorable conditions, it automatically triggers an update in the blockchain contract. This system also utilizes edge computing**,** where data is processed locally an IoT devices, reducing bandwidth and improving latency. The time for local processing is modeled as equation (6) as:

$$T_{\text{hoal}} = T_{\text{procosing}} + T_{\text{coummuicaliun}} \tag{6}$$

where $T_{\text{penceswing}}$ is the local computation time, and $T_{\text{commumication}}$ is the time to transmit data to the blockchain.

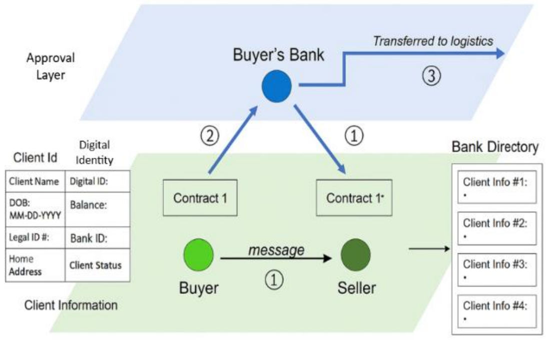

Figure 2: E-Commerce Contract Generation and Approval Process in the Proposed NormaNet Framework.

Resource Management in IoT

In addition to transaction management, NormaNet integrates rescource management by utilizing loT sensors to monitor system resources such as CPU, memory, and bandwidth. These resources are dynamically adjusted based on demand to maintain high system performance. The total resource usage is given by equation (7) as:

$$R_{\text{lotal}} = R_{\text{CPU}} + R_{\text{mumury}} + R_{\text{hamelwiduh}} \quad (7)$$

where each component represents the resources consumed by the processing, memory, and communication tasks, ensuring efficient handling of large-scale transactions in the loT ecosystem. This optimization ensures the scalability and efficiency of the NormaNet framework.

Results and Discussion

The results of the NormaNet framework show its superior performance compared to existing blockchain solutions like Ethereum and IOTA. With a remarkable 113.69 TPS, it outperforms Ethereum's 15 TPS and IOTA's 65 TPS, ensuring high throughput for IoT-based e-commerce transactions. Its transaction latency of 0.0088 seconds is significantly faster than Ethereum (0.4 seconds) and IOTA (0.12 seconds), making it highly efficient for real-time processing. NormaNet's energy consumption per transaction (0.15 Wh) is much lower than Ethereum (0.8 Wh) and IOTA (0.25 Wh), optimizing power use for IoT devices. Additionally, it maintains 100% supervision accuracy, ensuring reliable validation of transactions, and supports up to 50 IoT devices, providing strong scalability.

Performance Metrics of the Proposed Framework

The performance of the NormaNet framework is evaluated using the following metrics:

Transactions per Second (TPS):

This metric measures the throughput of the system, i.e., how many transactions the framework can process per second. Higher TPS values indicate the system's ability to handle a large number of concurrent transactions, which is essential for scalability in loT-based e-commerce systems and is given in equation (8)

$$\text{TPS} = \frac{\text{Number of Transactions}}{\text{Total Time Taken}} \quad (8)$$

Transaction Latency:

Transaction latency measures the time taken for a transaction to be processed from initiation to completion. Lower latency indicates faster processing and more efficient response times, which is crucial for real-time e-commerce environments and is given in equation (9) as:

$$\text{Latency} = \frac{\text{Time of Completion}}{\text{Time of Initiation}} \quad (9)$$

Energy Consumption per Transaction (Wh)

This metric evaluates the power efficiency of the system. It measures how much energy is consumed by the system for each transaction. Reducing energy consumption is vital for loT devices with limited power resources given in equation (10) as:

$$\text{Energy Consumption} = \text{Power}\,(\mathrm{W}) \times \text{Time}\,(s) \quad (10)$$

Supervision Accuracy:

This metric evaluates the accuracy of the supervision layer in identifying valid and fraudulent transactions. It measures the effectiveness of the system in ensuring legal and authorized transactions, contributing to data integrity and is given by equation (11) as:

$$\text{Accuracy} = \frac{\text{Correct Transactions}}{\text{Total Transactions}} \times 100 \quad (11)$$

Scalability (loT Device Count):

Scalability measures the system's ability to handle an increasing number of loT devices while maintaining performance. A scalable system can support a growing loT infrastructure without significant degradation in transaction throughput and is given by equation (12) as:

$$\text{Scalability} = \frac{\text{Number of Devices}}{\text{Transaction Processing Time}} \quad (12)$$

Proposed Framework Evaluation

The NormaNet framework achieves an impressive 113.69 TPS, demonstrating its ability to handle high transaction volumes as shown in table 1. The transaction latency for loT devices is very low at 0.0088 seconds, ensuring fast processing. The energy consumption per transaction is 0.15 W, indicating efficient use of power for loT devices. The framework ensures 100% supervision accuracy, ensuring reliable validation and supervision of transactions. Finally, NormaNet scales well, supporting up to 50 loT devices, ensuring robustness as the loT ecosystem expands.

Table 1: Performance Metrics of the NormaNet Framework.

Metric	Value
Transactions per Second (TPS)	113.69 TPS
Transaction Latency (loT Devices)	0.0088 sec
Energy Consumption per Transaction (Wh)	0.15 Wh
Supervision Accuracy (%)	100%
Scalability (loT Device Count)	50 Devices

Performance Comparison

In comparison to Ethereum and IOTA, NormaNet outperforms both in TPS, with 113.69 TPS compared to Ethereum's 15 and IOTA's 65 as shown in table 2. It also exhibits the lowest transaction latency of 0.0088 seconds, making it significantly faster than both Ethereum (0.4 sec) and IOTA (0.12 sec). Furthermore, NormaNet is highly energy-efficient, consuming just 0.15 Wh per transaction, which is better than Ethereum (0.8 Wh) and IOTA (0.25 Wh). NormaNet also provides superior supervision accuracy at 100%, ensuring reliable legal supervision, unlike Ethereum (92%) and IOTA (85%). Lastly, NormaNet supports up to 50 loT devices, scaling better than Ethereum (20 devices) and IOTA (30 devices).

Table 2: Performance Comparison of the NormaNet Framework with Ethereum and IOTA.

Metric	*NormaNet*	*Ethereum*	*IOTA*
Transactions per Second (TPS)	113.69	15	65
Transaction Latency	0.0088 sec	0.4 sec	0.12 sec
Energy Consumption (Wh)	0.15	0.8	0.25
Supervision Accuracy (%)	100%	92%	85%
Scalability (loT Devices)	50 Devices	20 Devices	30 Devices

Discussion

The NormaNet framework provides a highly scalable, secure, and energy-efficient solution for loT-based e-commerce transactions. Its performance in terms of TPS, latency, energy consumption, and supervision accuracy demonstrate its robustness in handling real-time, large-scale transactions. By leveraging three-layer sharding and PEKS for security and privacy, NormaNet addresses key challenges faced by existing blockchain systems, such as Ethereum and IOTA especially in the context of loT environments. The framework is optimized for resource-constrained loT devices, ensuring efficiency without sacrificing performance.

Conclusion and Future Works

In conclusion, the NormaNet framework offers an innovative solution for secure, scalable, and efficient loT-based e-commerce transactions. With 113.69 TPS, 0.0088 sec latency, 0.15 Wh energy consumption, and 100% supervision accuracy, it significantly improves upon existing solutions like Ethereum and IOTA. Future work will focus on further optimizing the scalability to support more than 50 loT devices, reducing energy consumption even further, and integrating advanced machine learning techniques for predictive analytics in transaction management. The development of a fully decentralized logistics and payment system based on NormaNet will be explored as a next step in enhancing the framework's realworld applicability.

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