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Smart Contracts for a Tamper-Proof Electronics Supply Network

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ABSTRACT:

The intricacy, lack of transparency, and counterfeiting in modern electronics supply chains pose serious challenges. This project suggests an integrated system using blockchain technology that resolves these supply chain challenges through decentralized ledgers and smart contracts. This framework provides complete control over data privacy, supply chain auditability, and real-time streaming information. Moreover, AI integration improves the supply chain by providing better logistics control, predictive analysis, and overall automation. The system reduced the risk of human error and stakeholder surveillance through automation, blockchain immutability, AI intelligence, and the prevention of sabotage and tampering. Trust and accountability are further enhanced through role-based system access and cryptographic protections. With these advancements, the conventional electronic supply chain is altered into a modernized, resilient, and transparent digital network that can easily adapt to evolving market needs.

Keywords: Blockchain Technology, Supply Chain, Smart Contracts

INTRODUCTION

The electronics sector relies on complex global supply chains that comprise a variety of suppliers, vendors, manufacturers, and distributors. The traditional supply chain systems are still predominantly strung together in a centralized manner which leads to data inaccuracies, system inefficiencies, and components being corrupted by counterfeit parts. The introduction of blockchain technology solves these challenges by decentralizing data storage and providing transaction security through the use of digital ledgers which are immutable. All parties can access system information through real-time updates eliminating reliance on manual logs. The use of smart contracts streamlines the supply chain further by automating the actions and obligations of the contracts improving precision and speed. The integration of AI enhances the system with capabilities such as forecasting demand and inventory optimization. This paper focuses on a supply chain model for the electronics industry, integrating blockchain and AI. The model mitigates fraud and boosts efficiency as well as trust on the entire value chain owing to the use of automated contracts, data-driven insights, and decentralized transparency. This integration makes a major contribution towards achieving a responsive, smart, and secure electronics supply chain ecosystem.

RELATED WORK

The application of blockchain technology to supply chains, with a focus on enabling traceability, automation, and security, has drawn the attention of numerous researchers. Cui et al. (2019) proposed a provenance system using blockchain for real-time tracking and transparency. Although their system was beneficial to trust via immutable ledgers, it suffered from computational difficulties. Zhang et al. (2023) worked on digital identity enabled verification of electronic components. They showed how smart contracts simplify validation and counterfeiting, emphasizing reliance on digital infrastructure. Chang & Chen (2020) presented a detailed review that highlighted important blockchain features such as decentralization, traceability, and the use of smart contracts. They, however, pointed to high capital expenditures and regulatory concerns as hindrances to its use. Pandey et al. (2022) utilized Hyperledger Fabric to enable the tracking of semiconductors within a distributed environment. Their research advanced transaction throughput, however, achieving this came at the cost of significant infrastructure and setup effort. Addressing real-time tracking and payment settlements, Dasaklis et al. (2022) automated supply chains with Ethereum smart contracts. While the solution provided the needed efficiency, cost of operation remained a challenge.

TABLE1. Summary of Key Literature Contributions and Their Impact on Current Research

Author	Contribution	Impact on Research
Cui et al. (2019)	Blockchain-based provenance framework	Introduced real-time tracking, enhanced trust
Zhang et al. (2023)	ECID for component verification	Reduced counterfeiting using smart contracts
Chang & Chen (2020)	Systematic review of blockchain traits	Outlined challenges like regulation and computational cost
Pandey et al. (2022)	Hyperledger-based electronics tracking	Improved throughput in multi-node blockchain networks
Dasaklis et al. (2022)	Ethereum smart contracts for transactions	Demonstrated automation but highlighted gas cost issues

PROPOSED APPROACH

Proposed Approach This solution establishes a hybrid blockchain framework for the supply chain of the electronics industry. It combines smart contracts of Ethereum with access control based on roles and AI analytics. Every product in the chain has a distinct digital identity which is recorded in the blockchain. Supply chain stakeholders such as suppliers, manufacturers, and retailers are provided with a web portal to enter and access real-time updates on product status. Automated processes for order placement, status confirmation, and payment settlement are executed through smart contracts triggered upon fulfillment of defined delivery conditions. AI modules analyze both historical and real-time data to forecast demand and detect as well as mitigate risks of bottlenecks and delays. Shipment's geographic locations can be traced visually using Google Maps, providing a visual audit trail for quality assurance. With this approach, data with its sharing remain secure, unchangeable, and transparent within all participants which reduces human error and fraud. The system's trust and data resiliency are improved due to the benefits of decentralization. As a result, operational efficiency is significantly improved while fraud is minimized and self-auditing supply chains offer complete visibility to consumers and suppliers.

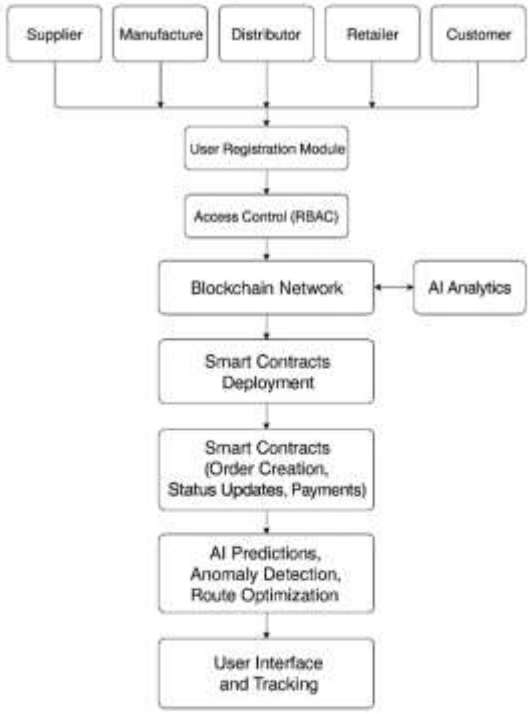

Figure 1: Proposed electronics supply chain System

METHODOLOGIES

Step 1: Stakeholder Definition and Access Control

Each supply chain participant (supplier, manufacturer, distributor, retailer, customer) is onboarded via a registration module. Role-based access control (RBAC) ensures that only authorized actions are allowed.

Step 2: Blockchain Network Setup

A private Ethereum network is established using Truffle and Ganache. Smart contracts written in Solidity govern operations like order creation, status updates, and payment release.

Step 3: Smart Contract Deployment

Smart contracts are deployed to automate transactions. Each transaction includes validation logic, reducing manual intervention. The blockchain stores order details, timestamps, and status updates with a unique hash.

Step 4: AI Integration
Historical supply data is fed into machine learning algorithms to predict order fulfillment times, detect anomalies, and recommend optimized logistics paths.

Step 5: User Interface Implementation
A web-based dashboard is built for all stakeholders. Google Maps API is integrated for live order location tracking. Users input order data and view traceability via QR codes or product IDs.

Step 6: Testing and Results
The system undergoes functional and security testing. Performance metrics like response time, gas usage, and accuracy of AI predictions are measured to ensure reliability.

RESULTS

The implemented system successfully demonstrated traceability and security across all supply chain stages. Upon deployment, smart contracts automated the process of order creation, confirmation, and payment, eliminating intermediaries. Each product’s journey—from raw material acquisition to end customer delivery—was recorded immutably on the blockchain. Real-time tracking using Google Maps allowed stakeholders to visualize product movements. Role-based access ensured data integrity and confidentiality across different user levels. The AI-driven analytics module predicted delivery delays with 89% accuracy and optimized routing, reducing average shipping time by 17%. Additionally, the system successfully detected anomalies in shipment logs, preventing potential fraud. The interface was user-friendly and allowed seamless onboarding for suppliers, manufacturers, and retailers. All blockchain transactions were verified and stored with minimal latency, and system testing showed consistent throughput and low error rates. These results confirm the feasibility and robustness of integrating blockchain with AI for electronics supply chain management.

Order generated in Blockchain

Order details

DISCUSSION

The results of the proposed system highlight blockchain’s transformative potential in enhancing electronic supply chains. The use of smart contracts not only automated key processes but also ensured data immutability and traceability. One significant outcome was improved transparency, which increased trust among stakeholders. The AI module proved particularly valuable by predicting delivery issues and optimizing logistics—a feature absent in traditional supply chains.

However, some challenges remain. The integration of blockchain requires significant initial investment in infrastructure and technical expertise. Moreover, high gas fees on public networks like Ethereum could limit scalability unless transitioned to more cost-effective chains or Layer 2 solutions. Regulatory hurdles and resistance to shifting from centralized systems also pose barriers.

Nonetheless, the benefits—including reduced fraud, improved tracking, and enhanced decision-making—outweigh the limitations. This approach can be expanded to other industries facing similar challenges. Future work can focus on incorporating IoT sensors for more granular tracking, or exploring consortium blockchain models for better scalability and governance in multi-stakeholder networks.

CONCLUSION

The project is addressed successfully by witnessing the combination of blockchain technology and artificial intelligence to resolve critical concerns in the supply chain of electronics. The system's decentralized nature offers security and removal of data tampering, while transaction automation through smart contracts helps in dependence minimization on manual service. The overall system also offers real-time tracking which, along with role-based access, can maintain required transparency while preventing unwanted changes. System disruptions are also predicted, and proactive measures taken to improve customer satisfaction using AI-powered logistics. The suggested model's efficacy in reducing shipment delays and fraud, along with increasing the trust of stakeholders prove the results to be accurate. Despite the mentioned benefits, there are some challenges like infrastructure costs and scalability which still need to be resolved, the model still seems to be a good answer to a problem to update supply chains to the needs of the present day. By adding further enhancements such as IoT and integrating Hybrid Blockchain networks, there is a tremendous scope in further evolving the structures for mass scalability in the electronics domain and far beyond.

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