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RESEARCH ARTICLE

Exploring IoT-Blockchain Integration in Agriculture: An Experimental Study

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ABSTRACT The incorporation of Internet of Things (IoT) technology with agriculture has transformed several farming practices, bringing unparalleled simplicity and efficiency. This article explores the robust integration of IoT and blockchain technology(BIoT) in agricultural operations, offering insight into the resulting BIoT system's design. This study investigates the potential benefits of merging the IoT and blockchain technologies in agriculture. A system for tracking plant growth using sensors and blockchain-integrated IoT has been developed and analyzed. Through empirical investigation, the report highlights greater efficiency, transparency, and security as significant benefits of BIoT architecture. A cost analysis is also conducted, showing that the system is cost-effective. The paper also proposes a mathematical formula for the calculation of infrastructure cost. It also looks at the problems of integrating BIoT in agricultural contexts, such as technological complications and the need for stakeholder participation. The findings indicate that the IoT can potentially revolutionize agricultural practices drastically, but its practical implementation would need careful consideration of technological, economic, and societal considerations. Empirical analysis is conducted to analyze the latency, throughput, and transaction scalability. The paper concludes with research suggestions, emphasizing the significance of interdisciplinary collaboration and the consequences of BIoT deployment in agriculture.

INDEX TERMS Blockchain, Internet of Things, cost analysis.

I. INTRODUCTION

The share of agriculture and allied sectors in India contributed to the country's Gross Value Added (GVA) at 17.8 percent for 2019-20, according to the economic survey 2020-2021 [1]. One of the commercial crops grown in south India is sandalwood [2]. Agroforestry is intentionally growing trees such as sandalwood along with other crops. Agroforestry practices have been encouraged as they provide social and economic stability for individual farmers with the added benefit to the ecology [3], [4]. The report by Thomson [5] predicts that the local demand for sandalwood will be a minimum of 250 tons in 2040 since the government has amended the Karnataka Forest Act 2001 and legalized sandalwood cultivation.

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However, farmers face many hurdles during the growth monitoring, harvesting, and post-harvest stages, like inadequate funding, difficulty in agricultural loan procurement, pest and disease control, expensive labor charges, market uncertainty, theft, and assurance of quality or organic products. The technological advancement like the Internet of Things (IoT) can provide a solution to the problems faced by farmers in agroforestry [6], [7]. An IoT architecture allows for the effortless incorporation of heterogeneous devices that perform diverse tasks [8], [9]. One of the eminent sectors where IoT has immensely contributed is precision agriculture, at various stages of pre-harvest, during harvest, and post-harvest, as depicted in Figure 1. There are numerous ways in which smart sensing can enhance various agricultural practices; it can optimize resource management, ensure food safety, provide a transparent food supply chain, farmer and crop insurance, and hassle-free land registry [10],

FIGURE 1. IoT at Various Stages of Agribusiness: Pre-harvest,harvest and Post-Harvest.

[11], [12], [13]. Customers also prefer transparency and knowledge of the food they consume in terms of organic crops [14]. In the pre-harvest stage, IoT facilitates sensing and actuating activities to monitor soil quality, pesticides, and heavy metal residues. IoT devices can also monitor weather, which leads to smart irrigation and efficient resource management. IoT can monitor crop health and detect weeds [15], [16]. During the harvest stage, the crop yield prediction, labor charges, crop and farmer insurance calculation, records of harvested products, and disaster management are carried out [13]. The tracking and tracing of the post-harvest products provide for a transparent and trusted supply chain and warehouse management.

A. CHALLENGES IN IOT

While IoT has much to contribute in numerous ways to agriculture, there are still hurdles. Based on a centralized authority, the current IoT architecture faces bottlenecks, single point of failure, security issues, and scalability challenges. As the number of devices and data increases, the central authority becomes overwhelmed, leading to delays in data processing and hindering overall performance. Centralized IoT architectures are also vulnerable to security breaches, allowing hackers to access sensitive data from connected devices. Scalability challenges arise as the number of IoT devices increases, making it challenging to expand the IoT ecosystem without upgrading the central infrastructure [7], [17], [18].

B. BLOCKCHAIN RESOLVING IOT CHALLENGES

The distributed architecture of the blockchain is perceived as a promising strategy for dealing with some of the challenges posed by IoT architecture. Experts and researchers advocate for a more decentralized and distributed IoT architecture to address these issues. However, the integration of blockchain technology with the IoT presents challenges such as scalability, latency, data size and storage, energy efficiency, interoperability, security concerns, cost, and regulatory compliance issues. Cost is a significant barrier for large-scale IoT deployments [19], [20], [21], [22]. The use of blockchain in IoT can eliminate the single point of failure and provide a sufficient mechanism for securely storing and processing IoT data [20], [23]. Table 1 summarizes how blockchain can contribute to resolving some of the challenges faced by IoT.

TABLE 1. Blockchain solution to IoT challenges.

Sr. no	Challenge in IoT	Blockchain Solution
1	Centralized architecture	Decentralized Architecture: Eliminates central point of failure and bottlenecks, also providing increased fault tolerance and system scalability [23].
2	Identity issues	Blockchain can offer trustworthy distributed device authentication and permission for IoT applications. [24], [25].
3	Security and privacy issues	All participating nodes can view valid transactions encrypted by private key. Optimization of security protocols [26].
4	Legal issues	Transparent transactions can be validated [23].
5	Reliability	Sensor data traceability and accountability improve IoT reliability [27].

C. KEY OBJECTIVES

This paper aims to understand the various architectural challenges of IoT and Blockchain integration with an empirical analysis of various evaluation parameters.

The key objectives of this research are

1) To propose an architecture model for agroforestry end-to-end supply chain.
2) To implement the crop growth monitoring system using IoT and blockchain technology in the agroforestry scenario.
3) To compute a mathematical model for cost on blockchain for the implemented crop growth monitoring system.
4) To experimentally analyze the proposed architecture for latency, throughput, and transactional scalability.

The objectives will be justified via a proof of concept implementation and mathematical derivations.

D. KEY CONTRIBUTION

The key contributions are as follows:

1) Conducted a thorough analysis of the architectural challenges associated with blockchain and IoT frameworks. These difficulties are crucial since they are essential to creating a framework for the BIoT (Blockchain-Integrated IoT).

2) Proposed an architectural framework that seamlessly combines the IoT and blockchain technologies to address a very specific issue: agroforestry. It provides a focused answer for improving agroforestry practices, resource management, and production optimization.
3) A working prototype implementation with various sensors, each serving specific functions and data collection purposes, with a focus on crop growth monitoring
4) A smart contract is written to establish a predetermined threshold that specifies when data should be added to the blockchain.
5) A mathematical cost analysis for a crop growth monitoring system.
6) Evaluation of latency, throughput, and transactional scalability of the Blockchain IoT system.

E. PAPER ORGANIZATION

The paper is organized into various sections. The current section I discusses the importance of agroforestry and the advantages of IoT in agriculture. It also elaborates on the challenges faced by traditional IoT architecture and deliberates on how blockchain helps to overcome some of the challenges. The key objectives and contributions are also listed in this section. Section II, discusses the basics of blockchain technology; this is important so that the readers have a better understanding of the proposed framework. Section III literature review explores the various works of IoT blockchain integration, with a particular emphasis on the architectural obstacles when merging these two technologies. Identified research gaps by compiling a table with key information from the articles and identifying the advantages and limitations. The next section, IV elucidates the proposed architectural model designed for the end-to-end supply chain in agroforestry, providing a thorough examination of its core components and operational features. Section V provides insight into the implementation details and data collection methods of the prototype. The various components used and the smart contract are discussed in detail. The infrastructure cost analysis is presented in Section VI. The various case studies conducted for the experiments and the results of the experiments are evaluated in Section VII. In the final section, VIII work done is summarised and analyzed potential future initiatives. This critical section not only outlines the important findings and concepts of this study but also provides the framework for future research and inquiry.

II. PRELIMINARIES

Blockchain is a distributed digital ledger technology that stores transactions and information securely. It is the technology behind cryptocurrencies and has applications in several fields, including finance, supply chain management, healthcare, and voting systems. The underlying network is a peer-to-peer configuration, eliminating the need for a central authority, thus increasing security and transparency. Security is achieved through cryptographic techniques that make it nearly impossible to modify or delete data once a block of data has been added to the blockchain. Immutability ensures the integrity and reliability of historical records. Blockchain can implement self-executing contracts called smart contracts, eliminating the need for intermediaries and reducing the risk of disputes. Consensus mechanisms such as Proof of Work (PoW) and Proof of Stake (PoS) validate and agree on the content of each new data block. Public blockchains like Bitcoin and Ethereum offer complete transparency, while private blockchains limit access and control, making them suitable for business applications that require more privacy

A. ARCHITECTURE OF BLOCKCHAIN

The layered architecture for blockchain incorporates 5 layers: The hardware and infrastructure layer, the data layer, the network layer, the consensus layer, and the application layer [28].

1) The hardware and infrastructure layer: The blockchain base layer is a peer-to-peer(P2P) network, with a vast network of computers collaborating as peers. These computers also participate in the computation, validation, and storage of transactions within a shared ledger. This results in a distributed database that preserves records of all data, transactions, and information. In the P2P network, each computer is a node responsible for transaction validation, the organization of transactions into blocks, and dissemination throughout the network. Once a consensus is reached, nodes securely integrate the verified block into the blockchain, updating their local ledger copies.
2) The data layer: Within the blockchain's data structure is a linked list structure that consists of two fundamental parts: pointers and a linked list of blocks. These blocks are connected, with each block having data and links to its predecessor. The Merkle tree, a binary tree of hashes that includes the Merkle root as well as crucial information like the previous block's hash, date, nonce, block version number, and current difficulty objective, ensures the security, integrity, and tamper-proof nature of blockchain technology. Digital signatures are essential for ensuring data integrity and verifying the sender's identity.
3) The network layer: The network layer controls inter-node communication and transaction propagation. It maintains the network's present state by ensuring effective communication, synchronization, and propagation. Distributed nodes work together to fulfill common goals, such as transaction processing. Full and light nodes, for example, perform various roles such as mining, consensus rule enforcement, and transaction validation.
4) The consensus layer: The consensus layer validates blocks, organizes them in the right sequence and maintains agreement among all participants. This layer, which operates within a distributed peer-to-peer

network, develops a set of agreements between nodes in order to maintain decentralization.

5) The application layer: The application layer consists of smart contracts, chaincodes, and decentralized apps (dApps). This layer is where end users interact with the blockchain network via various applications. Scripts, APIs, user interfaces, and frameworks are all part of this domain. These apps are intended to communicate with the blockchain network, which is the underlying technology.

III. LITERATURE REVIEW

A comprehensive literature review was conducted to understand the current research trends in the field of agriculture with BIoT architecture. Surveys like [13], [23], and [29], showcase that IoT and blockchain integration is a focus area right now. However, there is very little focus on the various architectures for integrating IoT data into the blockchain.

Novo [30], describes a blockchain and IoT architecture to improve device management. A management hub acts as an interface between IoT devices and the blockchain, converting information in CoAP messages into JSON-RPC messages that blockchain nodes can interpret. However, only a specific management hub is allowed for access control. Mondal et al. [31] developed an RFID-based blockchain and IoT architecture for creating a transparent food supply chain. The micro-controller and blockchain structure allow food items to be traced and stored in an immutable block, providing transparency and keeping up-to-date shelf life.

Hang and Kim [32] proposed a decentralized scheme that offers a secure and quick information transfer.The IoT blockchain network in docker made use of hyperledger playground to design smart contracts and couch DB to store values. IoT device server had been deployed on the Raspberry PI with temperature and humidity sensors. The blockchain web app was hosted on Apache WebApp. The IoT device used was not part of the blockchain network, and IoT servers served as a gateway. A revolutionary strategy was proposed for designing and deploying a decentralized IoT platform to handle scalability, identity, and data security problems. However, the IoT server acted as a centralized entity for requesting transactions to the blockchain.

Dorri et al. [33] proposed a new architecture for verifying and validating incoming transactions. Implementation was done on NS3 simulator incorporated with crypto++ security library. The IoT devices were a part of the blockchain network. The architecture decreases blockchain packet and computational overhead by 90% in a network of 200 nodes, facilitating blockchain adoption for low-resource accessible IoT devices.

Hang et al. [34] examined the use of blockchain in conjunction with a traditional system in order to preserve agriculture data from a fish farm in a tamper-proof manner. Modules for the fish tank and water pump were emulated, and a Rest API was designed to control the modules. The smart contract was deployed on the hyperledger fabric network. IoT devices used were not a part of the blockchain network and the REST server acted as a gateway. A generic model for the integration of legacy fish farms with the blockchain via REST API was proposed. However, the traditional section remains vulnerable to cyber-attacks.

Pincheira and Vecchio [35] proposed an IoT and blockchain architecture for ensuring data integrity. The architecture incorporated blockchain at the sensor level, creating a trustworthy data flow that smart contracts may leverage to realize unique decentralized IoT applications. However, the gateway module used can still pose a potential single point of failure.

Awan et al. [36] discussed a novel combo smart model for smart agriculture considering blockchain and IoT. Eleni Symeonaki et al. [37], introduced a cloud-based middleware framework, to tackle the challenges associated with precision farming. Zhang et al. [38] built a traceability system for IoT data. Three systems with CentOS 8.0 for three different chains were used. Hyperledger fabric with four peer nodes and one orderer node was used to deploy the smart contract. CouchDB was used as the database. All data had been verified and was traceable. The use of a double chain ensured high reliability however it could increase the cost of the system.

Torkya and Hassaneinb [39], outlined the challenges regarding the IoT performance in precision agriculture networks and categorized them along with the potential solution that blockchain can offer as follows:

1) Blockchain and Sensing Challenge: The difficulty of successfully adding various sensors to the blockchain network. Using blockchain, clear communication rules can be established between sensors and blockchain nodes to enhance the data flow.
2) Blockchain and Energy Consumption Challenge: IoT devices are required to be low-energy devices, but due to wireless communication, the energy efficiency is most often not met. The blockchain's distributed nature of processing transactions will be an efficient management of energy resources, minimizing wastage.
3) Blockchain and Network Complexity Challenge: Blockchain technology can help address the challenges of communication for IoT farming by facilitating secure, standard-based, and decentralized data acquisition and management.
4) Blockchain and bandwidth and latency Challenge: The bandwidth and latency issues in IoT-driven precision agriculture networks are a significant concern. Blockchain technology can address these issues by distributing workload closer to endpoints, optimizing bandwidth utilization, and reducing latency.
5) Blockchain and Limited Data Storage Challenge: The increasing usage of IoT-powered precision agricultural networks need effective data storage and management. Real-time data monitoring, high availability, scalability, security, and low latency are all issues for current cloud-based storage systems.

Blockchain-based storage overcomes these constraints by enabling IoT endpoints to analyze and alter data in real time.

Analysis of the research papers with focus on the architecture which integrates IoT and blockchain, is conducted in the following subsection.

A. ARCHITECTURAL CHALLENGES ASSOCIATED WITH BLOCKCHAIN AND IOT FRAMEWORKS

For a deeper understanding of key components in the integration of IoT with blockchain technology, the literature review findings are consolidated into Table 2. This table provides an examination of key aspects, including the placement of IoT devices, the role of gateway components, and other essential supporting elements.

The placement of IoT devices is a crucial factor when discussing architectural problems. It entails making a fundamental choice about whether IoT devices should be deployed as edge nodes or at the consensus layer of the blockchain network. The decision is critical because it fundamentally affects how these devices participate in and play a role in the network. In the consensus layer, for an architecture where IoT devices actively participate in the transaction process, IoT devices have a direct impact on the verification and validation of transactions. As opposed to this, when IoT devices work as edge nodes, their main duty is to gather data and send it to smart contracts.

When IoT devices function as edge nodes, the gateway component becomes a vital component. This element makes sure that data is transferred securely and easily from these edge devices to the blockchain network. It serves as a link, facilitating the exchange of information while preserving the security and integrity of the data. The architectural framework consists of a number of other elements in addition to where the IoT devices should be placed and what the gateways should do. These include the data storage that are essential for storing and managing the enormous amounts of data produced by IoT devices. Additionally, IoT nodes' integration into the larger system and performance optimization are greatly aided by specialized features designed specifically for them. The literature analysis also explores the drawbacks of each architectural strategy, indicating the potential difficulties and restrictions that must be taken into account when implementing IoT and blockchain integration. It is evident from the literature review that IoT and blockchain integration fall into two different categories. One involves IoT devices actively participating in the blockchain network, increasing the consensus process and adding to the generation of new transactions. The second involves gathering IoT-generated data, which is then sent to the blockchain through a predefined gateway. These two methods offer various strategies to deal with special needs and use cases within the IoT and blockchain environment. From the literature review, it can be observed that the integration of IoT with blockchain can happen in mainly two ways, one in which the IoT device are actively part of the blockchain network and contribute to new transactions. The other is where in the IoT data is collected and sent to the blockchain via some gateway.

IV. PROPOSED GENERIC ARCHITECTURAL FRAMEWORK FOR AGROFORESTRY

In this section, a generic framework for agroforestry is proposed, as depicted in Figure 2.

The framework includes a number of stakeholders, each with a distinct role. First and foremost, selected government-approved depots, provide farmers with authentic saplings. The issuance of certificates and the safe storage of all associated documents on a blockchain are done to guarantee the veracity of these transactions. Farmers, land records are verified before they are registered on the framework. The use of sensors for crop growth data is crucial within the framework. These sensors monitor crop growth and transmit that data to the blockchain. The information gathered is necessary to verify the use of organic fertilizers and pesticides responsibly and the adherence to organic farming practices.

Independent harvesters using specialized equipment are a part of this framework, for the cutting of the trees. By querying the blockchain, farmers can confirm the legitimacy and accreditation of these harvesters, increasing trust during the harvesting process. The framework also includes a production unit that ensures chemical-free and sustainable manufacture of agricultural goods. This is in line with the rising demand for ecologically friendly farming methods and organic farming techniques, all of which are documented transparently on the blockchain.

An essential component of this agricultural system is the engagement of the government. According to the policy in place, the government receives a part of the earnings from agricultural activity. This monetary support is essential for a number of agricultural efforts, including growth and infrastructure improvements. A certain percentage of the profit earned by the farmers, to be given to the government, is calculated in the smart contract and all transactions are recorded in the blockchain; this is in order to ensure fair trade practices. Customers can scan a QR code to gain access to a detailed account of the complete production cycle, which enables them to follow the progress of agricultural goods from the planting of saplings to the harvest and processing. This degree of openness encourages consumer confidence in the final product's quality and authenticity, which can be a powerful selling point for these agricultural goods.

This multi-stakeholder agricultural framework leverages blockchain technology to ensure transparency, authenticity, and sustainable practices throughout the entire agricultural supply chain. By involving government bodies, farmers, harvesters, and consumers, it creates a robust system that benefits all participants while contributing to the overall development of the agricultural sector.

TABLE 2. Consolidated literature on various architectures for BIoT.

Sr. no	Author	Year	Tools	IoT in Network	Gateway	Components	Advantages	Limitations
1	Oscar Novo [30]	2018	Ethereum, Solidity, Javascript, LibCOAP.	NO	Management hub	Wireless sensor networks, Managers, Agent nodes, Smart contracts, blockchain network, Management hubs	New access management solution	Management Hub becomes the central point of failure.
2	Saikat Mondal et. al [31]	2019	C,Spyder Python 3.7	YES	NA	SensorID, Terminal, Agent node, Manager, Blockchain network	Transparency and traceability of food items	Verification by only one terminal. Storage in a resource-constrained device.
3	Lei Hang& Do-Hyeun Kim [32]	2019	Hyperledger playground, Couch DB, Raspberry PI, Temperature and humidity sensors, Apache WebApp.	NO	IoT server	Device owner, IoT server, App client, IoT network, Blockchain network	Increased scalability, identity management, and data security	The IoT server acts as a centralized entity for requesting transactions to the blockchain.
4	Miguel Pincheira & Massimo Vecchio [35]	2020	Python 3.6, Ethereum blockchain	YES	NA	Device module, Gateway module, Blockchain module.	Blockchain at the sensor level, thus a trustworthy data flow.	The Gateway module still poses a potential single point of failure.
5	Lei Hang et. al [34]	2020	Rest API, Hyperledger fabric network.	NO	REST server	End-user, blockchain network, fish farm, data storage.	A generic model for integration of legacy fish farm with blockchain via REST API.	Vulnerable to cyber-attacks.
6	Sabir Hussain Awan et. al [36]	2021	NA	YES	IPFS decentralized server	IoT devices, Blockchain, Retail.	Transparent, trustworthy tracking.	No verification and validation of incoming transactions and newly committed blocks
7	Xinghua Zhang et. al [38]	2022	CentOS 8.0, Hyperledger fabric, CouchDB	YES	NA	NA	All data is verified and traceable. Since double chain it ensures high reliability.	The use of two chains, may increase the cost of the system.
8	Ali Dorri et. al [33]	2022	NS3 simulator.	YES	NA	Transmission layer, Verification layer, Normal node, Verifier node, and Backbone node.	Decreases computational overhead by 90%.	NA

V. WORKING PROTOTYPE IMPLEMENTATION

This section delves into the implementation of the suggested framework for tracking plant growth, which is essential for ensuring the best agricultural practices. The Raspberry Pi is deployed as a key component of the suggested architecture, acting as the collection point for sensor data. Then, a specialized smart contract is executed on the blockchain node after this data has passed via a gateway module Figure 3

The crop growth monitoring was focused upon, due to the huge amount of data which is generated from the sensors. Thus providing an overview of the blockchain technology used and also emphasizing the importance of it for achieving successful plant development monitoring. We build a strong basis for gathering and transmitting sensor data using the Raspberry Pi, giving real-time insights into plant growth. Furthermore, the use of proposed smart contracts and blockchain technology demonstrates the cutting-edge strategy used to guarantee accuracy, transparency, and traceability throughout the monitoring process. The various components of the architecture are:

1) Embedded device Module
   The Raspberry Pi is a key component of the proposed system since it effortlessly integrates a variety of sensors for data collection. Specifically, soil moisture sensors and the DHT11 temperature and humidity sensor, are integrated with the Raspberry Pi. The Python Adafruit library was used to program these sensors, enabling them to acquire data on a regular basis at predetermined intervals. Sensor data was

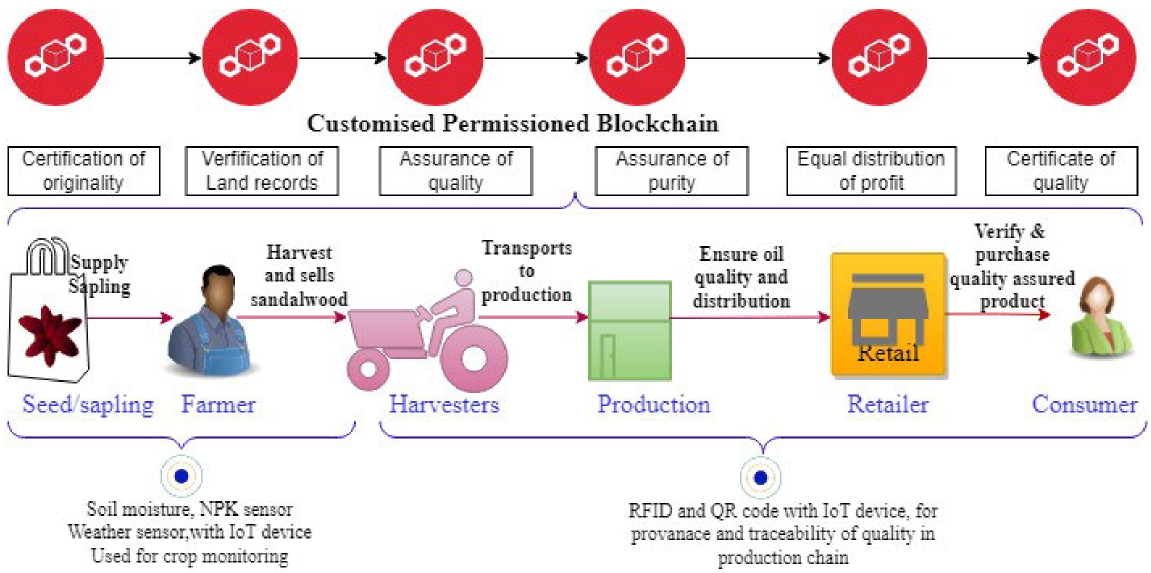

FIGURE 2. Proposed framework for agroforestry end to end supply chain.

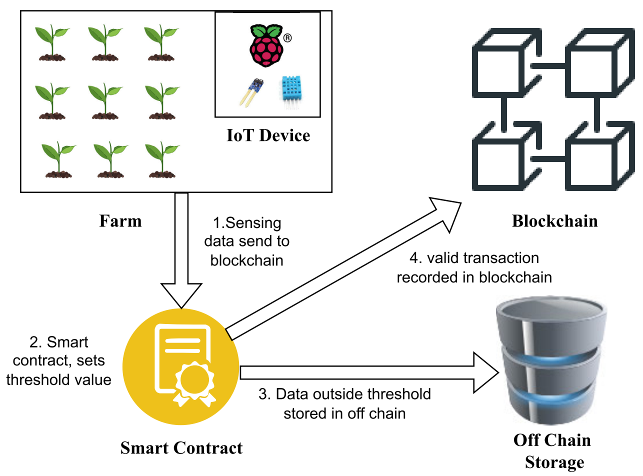

FIGURE 3. BIoT architecture for plant growth monitoring.

sensed and maintained on the Raspberry Pi, one month data was 20MB. We used a server-client communication mechanism to make sure that this crucial sensor data was transmitted without interruption. The use of this methodology allowed the collected data to be sent securely to the blockchain node, where it underwent additional processing and analysis. Table 5 provides a thorough explanation of each component's job and features, for a detailed grasp of the system's components and their specifications.

2) Blockchain module: The technology used to develop the blockchain network is summarised in Table 4. Ethereum private network, Ganache 2.5.4 was used to deploy the smart contracts written in solidity. The operating system is Ubuntu 20.04.4 with 3.00GHz processor 8GB RAM. The visual code studio was used as the IDE.

TABLE 3. Components of Raspberry-based IoT device server.

Sr. No	Component	Description
1	Hardware	Raspberry Pi4 Model B Rev 1.1
2	Memory	1 GB
3	Operating System	Raspbian GNU/Linux V10
4	Resources	DHT11 sensor, soil moisture sensor and ADC
5	Programming Language	Python
6	Library and Framework	Adafruit,digitalio

TABLE 4. Components for blockchain module.

Sr. No	Component	Description
1	CPU	Intel® Core™ i5-7400 CPU @ 3.00GHz
2	Memory	7.7 GiB
3	Operating System	Ubuntu 20.04.4 LTS
4	Blockchain	Ethereum- ganache-2.5.4
5	Node	v16.7.0
6	IDE	Visual studio code-1.68.1
7	Bechmark Tool	Hyperledger Caliper

3) Smart Contract: A smart contract manages all the policies in the blockchain.A manager node is the owner of the smart contract.The smart contract checked the readings for a threshold value. Two functions are written in the smart contract one to check the temperature and the other to check the soil moisture level. If the values cross the threshold, the smart contract was triggered and data was written into the blockchain. The retrieve function is used to retrieve

the value of the transaction. The algorithm 1, outlines the smart contract written in solidity for monitoring plant growth data.

A. DATA COLLECTION AND RESULTS

Data on temperature and humidity was collected using a DHT11 sensor and soil moisture data was collected using a soil moisture sensor. Analog to digital converter was used to convert the soil moisture readings. The experimental setup is shown in Figure 4.

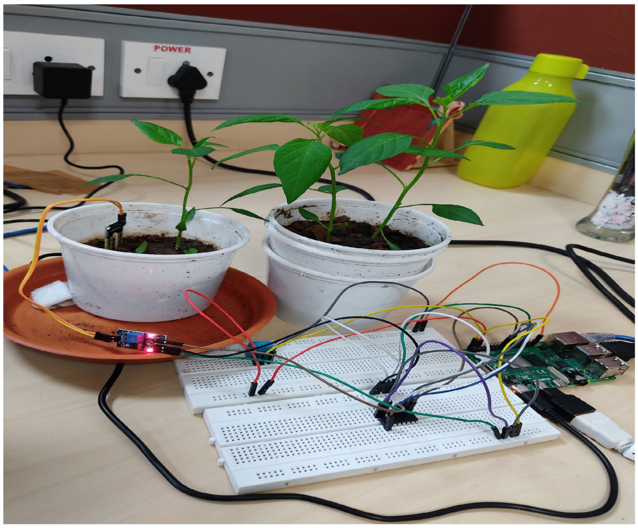

FIGURE 4. Experimental Setup.

Data was observed in the lab setup, between the temperature of 26 and 50 degrees Celsius. The average per-day transactions was 1955, the standard deviation was 1422. Adding and subtracting one std deviation to mean value, found the majority of the data falls into this range (mean +/− Std deviation).

VI. INFRASTRUCTURE COST ANALYSIS

The overall infrastructure cost analysis is important, for agroforestry policies in South India, as it plays a crucial role in deciding if incorporating technology like blockchain and IoT is even feasible. This assessment makes sure that the suggested infrastructure for agroforestry is still economical. To encourage fair access to these transformative tools and to foster agricultural efficiency and prosperity without risking the financial stability of the farming communities engaged in agroforestry.

For computing the infrastructure cost the following components were considered

1) Embedded module(EM): Module connected to end sensors, responsible for collecting environment data.
2) Manager account(MA): Smart contract account owner.
3) Consumer Account(CA): Query the blockchain for stored values.

Per-day averages average transactions, were used for cost analysis. Thus defining the cost of smart agricultural system as F_{cost} which supports average transactions Tx. The two functions StoreTemp and StoreMoisture writes transactions to blockchain, thus only these two are considered for cost calculations T_{cost} and M_{cost}. There is a one time contract deployment cost SC_{cost} thus the various cost involved are:

- SCD_{cost} when F=0 (for initial contract deployment).
- Tx_{cost} total cost of all transactions written into blockchain.

the total cost for a month can be represented by Equation 1

$$F_{cost} = \begin{cases} SC_{cost} = SCD_{cost}, & \text{if } F_{cost} < 0 \\ Tx_{cost} = T_{cost} + M_{cost}. \end{cases} \tag{1}$$

To extend this for public blockchains, the cost is incurred only when changes are made to the ledger. To analyze the cost, the following notations are used:

- N is the number of days
- τ_t Cost when there is temperature change
- τ_m Cost when there is moisture change
- τ_{sc} cost of deploying smart contract

The total cost for a month on public blockchain can be represented by Equation 2

$$\tau_{total} = \tau_t + \tau_m + \tau_{sc} \tag{2}$$

where

- τ_{total} is the total cost of the system
- τ_{sc} is a constant which has non zero value for N=1 and zero otherwise.

A. HARDWARE COST ANALYSIS

The hardware cost for deploying BIoT framework, each unit IoT device consists of Raspberry Pi4 Model B, DTH11, Soil moisture and MCP3008 IC. The cost of each device in Indian rupes at the time of the experimentations in provided in Table 5 below.

TABLE 5. Hardware cost.

Sr. No	Component	Price
1	Raspberry Pi4 Model B	3000 INR
2	DTH11	650 INR
3	Soil moisture	60 INR
4	MCP3008 IC	329 INR

B. COMPELETE FRAMEWORK COST

In the blockchain module each transaction requires a certain amount of transaction fees. Table 6 provides the gas incurred for each transaction. To translate cryptocurrency to fiat currency, the average value of the cryptocurrency is needed. The list of parameters for approximately 1 acre of land for cost evaluation of crop growth monitoring is provided in table 7.

The total cost for the entire framework with hardware is given by equation 3:

$$\tau = \tau_{total} * P_{(c)} + D * \tau_{device} \tag{3}$$

Algorithm 1 Smart Contract for Plant Growth Monitoring

Require: address of Smart contract deployer, IoT device registration
  Call storeData function
  while Values within ThreshHold **do**
    if If balance available **then**
      Transaction committed
      Smart contract state updated to committed.
    else
      transaction failed
      Smart contract state reverted.
    end if
  end while

TABLE 6. Gas needed for transactions.

Sr. no	Transaction	Gas in gwei
1	Deploy contract	96177
2	Store_Temp	41438
3	Store_Moisture	41428
4	total	924837

TABLE 7. Parameters for cost calculation.

Sr. no	Parameter	description	Value
1	D	No. of IoT devices	4
2	$P_{(c)}$	One month Avg cryptocurrency	1,02,072.92INR
3	Temp_tx	No. of temperature transaction	10
4	Moisture_tx	No. of moisture transaction	10
5	τ_{total}	Cost of contract deployment and measurements	924837gwei
7	τ_{device}	Cost one device	4039INR

By substituting the values in the equations, the total cost for the crop growth monitoring is 16256.4 INR. This is the initial setup cost; once the hardware is set up, the monthly cost for blockchain transactions is nearly 20 INR.

VII. SMART CONTRACT PERFORMANCE: CASE STUDY ON PUBLIC BLOCKCHAINS

Various experiments were conducted on the implemented prototype, specifically focusing on the smart contract and its two write functions, Store Temperature (StoreTemp) and Store Moisture(StoreMoisture). The algorithm's performance on a public blockchain was evaluated by defining a series of distinct use cases with varying key parameter specifications. These use cases assisted in observing and analyzing the blockchain platform's performance against throughput, latency, and scalability metrics.

1. Throughput: Calculates the number of successful transactions per second from the first transaction deployment time. It is an important performance metric for blockchain systems that is frequently measured in transactions per second (TPS). Higher throughput means a blockchain network can process more transactions or smart contract executions in a given time frame, making it more scalable and efficient.

2. Latency: Transaction latency is determined as the time spent between the deployment of a transaction and its successful completion. It is measured in seconds.

3. Scalability: Transaction scalability is the ability to handle an increasing number of transactions as its workload progresses.

Hyperledger caliper tool was used to analyze the various metrics. This study provides details into the proposed blockchain framework's real-world functioning and the consequences of its performance in a public blockchain environment, contributing to a better understanding of its practical implementation.

A. STUDY THE EFFECT OF WRITE OPERATIONS ON THE THROUGHPUT OF THE BLOCKCHAIN NETWORK

The purpose of this case study was to thoroughly examine how changes in transaction rates affect the overall throughput performance of the blockchain network. A systematic approach was followed, to accomplish this. Transaction rates were set as 10, 50, 100, 150, 200, 250, 300, 350, 400, 450, and 500 transactions per unit of time. A total of 2,000 transactions, were fixed. the study included the simultaneous execution of the write functions associated with the smart contracts StoreTemp and StoreMoisture.As can be observed in the graph provided in the Figure 5 both the functions have similar throughput. As the transaction rate increases the throughput also increases gradually, up until the transaction rate is 250; from there the throughput becomes constant and remains around 45 to 47 TPS.

B. STUDY THE EFFECT OF WRITE OPERATIONS ON THE LATENCY OF THE BLOCKCHAIN NETWORK

The purpose of this case study was to examine the latency rates of the blockchain network for a fixed number of 2,000 transactions. Transaction rates were set as 10, 50, 100, 150, 200, 250, 300, 350, 400, 450, and 500 transactions per unit of time. Both the write functions associated with the

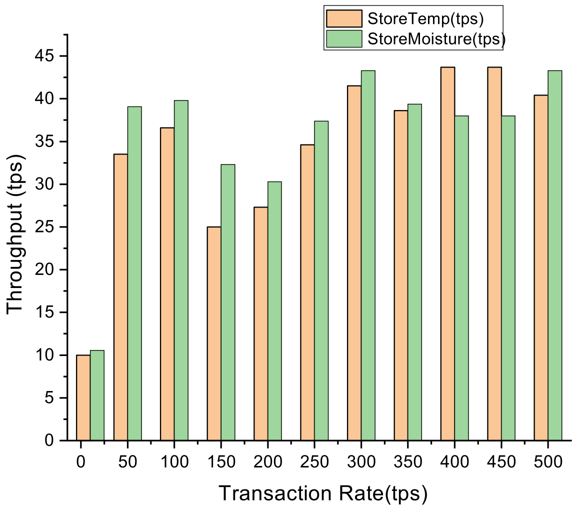

FIGURE 5. Average Throughput for StoreTemperature and StoreMositure functions where number of transactions were fixed to 2000.

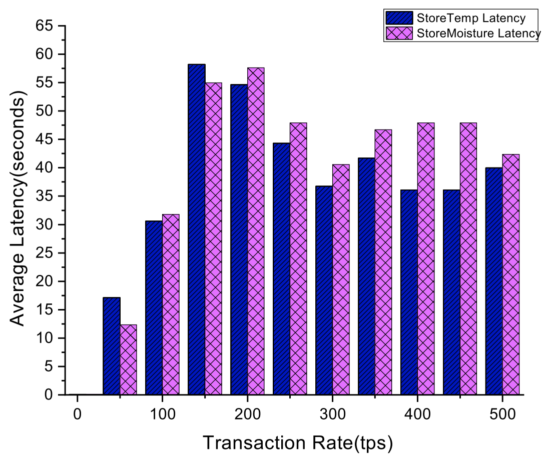

FIGURE 6. Average latency and Throughput for StoreTemperature and StoreMositure functions.

smart contracts StoreTemp and StoreMoisture were deployed simultaneously. From the graph in Figure 6 the latency sharply increases when the throughput is around 200 TPS and after that stays almost constant at around 50 - 55 seconds for StoreMoisture function and 40 to 45 seconds for StoreTemp.

C. STUDY THE EFFECT OF VARYING NUMBERS OF TRANSACTIONS ON THE THROUGHPUT AND LATENCY OF THE BLOCKCHAIN NETWORK

In this case study, a range of transaction quantities are including 10, 50, 100, 500, 1000, and 2000 transactions, while simultaneously implementing both smart contract functionalities. The primary goal of this experiment was to investigate the effects of increasing transaction amounts on two key performance metrics: average throughput and average latency.

The graph in Figure 7, shows a definite trend. The average throughput increases significantly as the number of

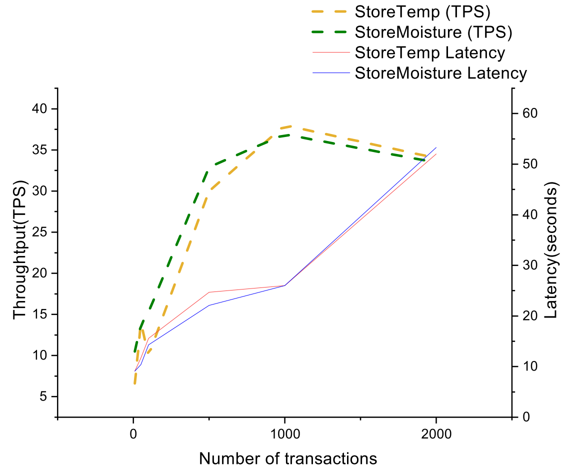

FIGURE 7. Average latency and Throughput for StoreTemperature and StoreMositure functions.

transactions increases. This shows that as transaction traffic increases, the blockchain network's transaction processing capability improves. Concurrently, latency appears to be increasing, implying that transaction completion times tend to increase with increased transaction volumes. Figure 8,

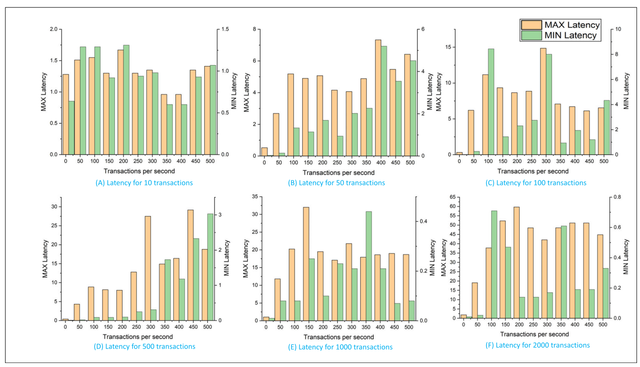

FIGURE 8. Consolidated graph of transactional latency for various numbers of transactions of Store Moisture.

presents consolidated graphs of all the different numbers of transactions and maximum and minimum latency for a better understanding of StoreMoisture. It can be observed that as transactions increase the latency also increases, in Subgraphs A,B and C. After the number of transactions is increased beyond 500 transactions, in Subgraphs D,E and F the minimum latency decreases, and remains constant at around 4 to 8 seconds. However the maximum latency, steadily keeps on increasing across all number of transactions.

Figure 9, presents consolidated graphs of all the different numbers of transactions and maximum and minimum latency for a better understanding Of StotreTemp. The minimum latency, gradually increases, until it reaches 500 transactions in subgraph D, where it suddenly rises high, consequently reducing for the next fixed transactions.

Thus, the proposed smart contract for crop growth monitoring, shows that beyond a certain number of transactions,

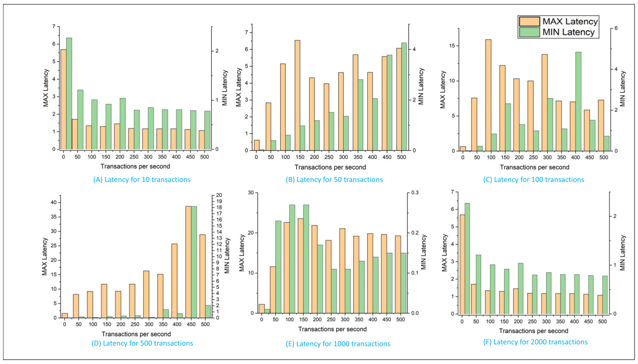

FIGURE 9. **Consolidated graph of transactional latency for various number of transactions Of Store Temperature.**

the latency remains constant. Therefore making practical implementation feasible

VIII. CONCLUSION AND FUTURE WORK

The contributions to this study included a thorough investigation of the architectural issues inherent in the integration of blockchain and IoT frameworks. This study helped to provide a better understanding of the IoT blockchain architecture. The IoT device can be a direct member of the blockchain with limited functionalities or connect to the blockchain via a gateway. It's a tradeoff between security and resource management. Specifically for agricultural applications, researchers need to remember the huge amounts of data collected for various environmental parameters. To build an efficient BIoT architecture for agriculture identification of all the components and the nature of the data being produced needs to be done. Time-sensitive data needs to be processed at the earliest and only necessary data can be stored into the blockchain, thus reducing the storage requirements.

This work also proposes a novel architectural framework that seamlessly integrates IoT and blockchain technologies, with a special focus on tackling agroforestry's unique issues. This framework provides a customized solution for improving agroforestry practices, resource management, and production optimization. To back up the proposed architecture, a working prototype that included a range of sensors, each with a distinct role for accurate data collecting, with a major focus on crop growth monitoring, was implemented. In addition, a smart contract to set predetermined thresholds for data inclusion on the blockchain, assuring data veracity and integrity, was proposed.

Finally, the blockchain-IoT system's latency, throughput, and scalability, offering vital insights into its real-world performance, was evaluated. Collectively, these contributions enhance the subject of BIoT by providing practical solutions for agroforestry and setting the framework for larger applications in the integration of blockchain and IoT technology.

The future work is the study of IoT architecture when the IoT device participates in the consensus of the blockchain, a comparative study between the two architectures can be conducted to determine which is well suited for agricultural practices.

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