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Securing IoT-Based Smart Agriculture Using Wireless Sensor Networks: Frameworks

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Abstract

The integration of the Internet of Things (IoT) and Wireless Sensor Networks (WSNs) in smart agriculture enhances efficiency, productivity, and sustainability. However, securing these interconnected systems remains a critical challenge due to vulnerabilities in data transmission, authentication, and network resilience. Existing methods often suffer from high latency, limited scalability, and susceptibility to cyber threats, leading to compromised data integrity and unreliable decision-making. To address these challenges, this paper proposes the Smart Agriculture Using Wireless Sensor Networks (SA-WSN) framework, which integrates blockchain-based authentication, lightweight encryption, and AI-driven anomaly detection to enhance security. The proposed framework ensures secure data transmission, real-time threat monitoring, and dynamic key management to mitigate cyber risks. The SA-WSN method is applied in precision farming, where sensor nodes monitor soil moisture, temperature, and crop health while maintaining robust security against unauthorized access. The findings demonstrate improved data integrity (98.5%), reduced latency, and enhanced attack detection (97.2%), making SA-WSN a reliable security solution for IoT-based smart agriculture.

Keywords: *IoT security, Wireless Sensor Networks, Smart Agriculture, Blockchain Authentication, Anomaly Detection, Precision Farming*

1. INTRODUCTION

The combination of IoT with agriculture produces complex processes like decision-making, monitoring, and automation [1]. IoT will never be able to work without Wireless Sensor Networks as, for example, wide farming areas are supervised by arrays of sensors on various aspects [2]. The monitoring sensor defines the moisture content in the soil, health, humidity, and temperature of the crops, which enables

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the farmers to determine the pesticides, fertilizers, and water to apply to achieve maximum productivity [3]. The integration of all these together certainly boosts the agricultural output, maximizes resource utilization, and makes it sustainable which are prerequisites to manage the global food needs exacerbated by climatic changes [4]. However, there are considerable challenges with respect to IoT security and WSN implementation in agriculture smart aspects [5]. WSNs have inherently open and distributed architecture and, thus, are exposed to different security-related concerns including data compromise, unauthorized access of confidential attacking service denial, and information[6].

Security-compromised sensor nodes can lead to inaccurate data gathering, interrupted operations, and even financial loss [7]. Furthermore, the memory, and computation over power limitations WSN devices experience render it impractical to use strong security methods [8]. The traditional security measures taken using advanced encryption or centralized authentication servers tend to add significant delays, while making these measures ineffective for agricultural practices that need a prompt response [9]. All of these issues call for new security frameworks capable of protecting IoT based smart agriculture systems optimally, which at this stage is a dire necessity [10]. Through the combination of blockchain-enabled authentication, lightweight encryption, and machine learning-based anomaly detection, SA-WSN architecture seeks to help solve this problem [11]. To resist unauthorized access as well as modification of information, blockchain technology is utilized to accomplish low-cost, decentralized, and incorruptible authentication [12].

The sensor nodes benefit from light-weight encryption techniques not only through secure data transmission, but also through reduced computations [13]. The use of AI in anomaly detection helps in monitoring network traffic for any possible threats which can be neutralized in real-time to make the system more robust [14]. For precision agriculture where accuracy and real-time data capture is imperative, the SA-WSN framework is particularly well-suited [15]. SA-WSN specifically helps farmers to mitigate cyber -attacks while being able to collect data from sensors that monitor soil, weather, and crop conditions to make intelligent decisions [16]. This paper seeks to report on the design, implementation, and evaluation of the SA-WSN framework in relation to amplifying data integrity, minimizing latency, and increasing attack detection [17]. This not only addresses the current gaps in security of IoT based smart agriculture, but also paves new pathways for automated farming that are safe and environmentally friendly [18].

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Motivation: The use that revolution has made through the smart farming is driven by the mounting safety threats that sparked by the architecture of SA-WSN. The networks of sensor expand their applications in agriculture, availability, confidentiality, and integrity issues in data emerge as pressing needs for credible agricultural decisions. The framework uses blockchain technology coupled detection of anomaly with the artificial intelligence algorithms and light-weight neural networks to implement precision farming activities.

Problem Statement: WSNs are fighting cyber challenges like hacking, unapproved access, and data loss, which is a mammoth challenge for agriculture under the umbrella of IoT. The issues occurs on security arise from inherent limitations like inadequate detection of malicious behavior, high latency response, and non-scalable systems. Ineffective practices related to agricultural methods and data loss threaten the sustainability of agricultural practices and precision agriculture accuracy.

Contributions:

- The SA-WSN model employs blockchain to facilitate devices on the IoT secures the credentials being, addressing the authentication problem without centralization and precluding possibilities for unauthorized access to information, and guaranteeing integrity of data in smart agricultural systems.
- Every communication is secured with lightweight encryption techniques. This balances computational cost and security, enabling realtime protection with optimal performance.
- Utilizing AI algorithms, SA-WSN enables real-time monitoring and detection of potential security threats, significantly improving attack detection accuracy and enhancing the resilience of IoT-based smart agriculture systems against cyber risks.

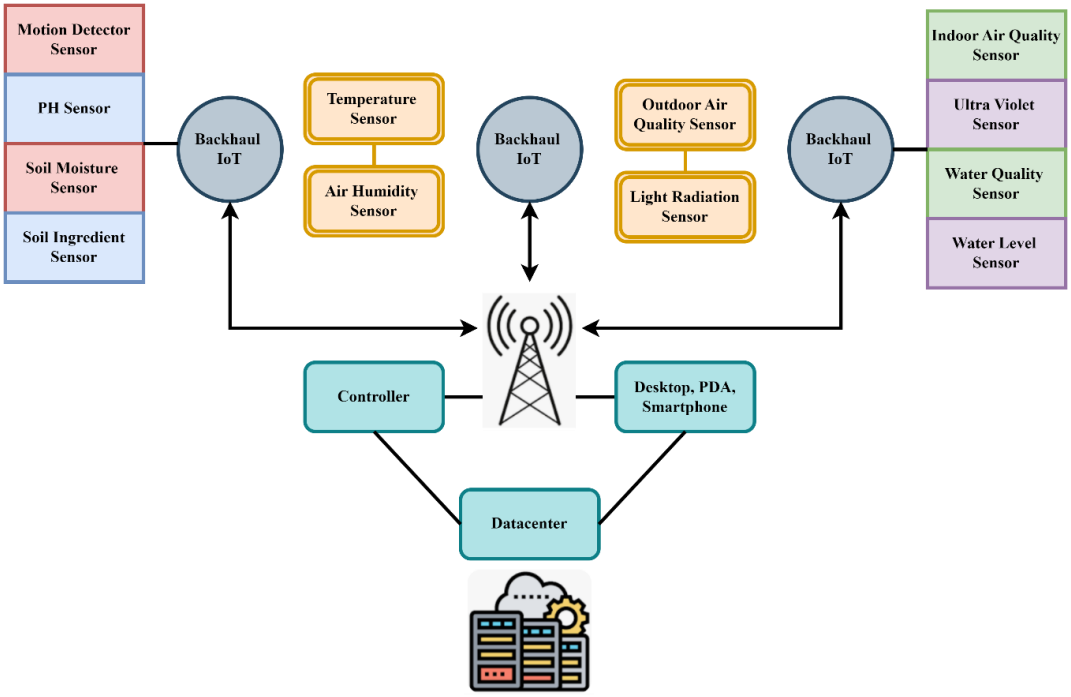

Figure 1: The Architecture of Motion Detector Sensor

The Motion Detector Sensor combines environmental monitoring devices like PH, Soil Moisture, and Soil Ingredient Sensors. The system also contains Backhaul IoT with Air Humidity, Temperature, Outdoor Air Quality, Light Radiation, Water Quality, and Water Level Sensors. All the components combine to offer complete information for environmental assessment. It is controlled with a smartphone, PDA, and Desktop but data is pooled in a Datacentre to ensure effective control and analysis. It has provisions for precise control and monitoring of environmental conditions in figure 1.

The remaining of this paper is structured as follows: In section 2, the related work of smart agriculture is studied. In section 3, the proposed methodology of SA-WSN is explained. In section 4, the efficiency of SA-WSN is discussed and analysed. Finally, in section 5 the paper is concluded with the future work.

2. Related Work:

Secure data transfer, effective resource management, and automated farming are all made possible by the integration of Blockchain Technology, Machine Learning Models, Artificial Intelligence, and Support Vector Machines in IoT-based Wireless Sensor Networks, which in turn improve smart agriculture. Sustainable and accurate farming is made possible by these technologies, which solve problems like energy scarcity, data security, and climate change.

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Blockchain Technology (BCT):

Communication, smart agriculture, industry, monitoring, and surveillance are just a few of the many areas that have shown an interest in WSNs for research and development. Agricultural industry has made use of IoT-based WSN to automate precision farming by monitoring yield conditions using a variety of sensors. Agricultural settings often make use of these sensors to collect data on plants, crops, temperature, humidity, and irrigation systems in an effort to increase output yields via smart farming choices by Haseeb, K. et al., [19]. Unfortunately, agricultural output may suffer due to sensors' insufficient processing, energy, transmission, and memory capacities. In addition to efficiency, safeguarding these agricultural sensors that rely on the Internet of Things from malevolent actors is of utmost importance. As a solution for smart agriculture that incorporates many design levels, it presented an IoT-based WSN architecture in this paper. To begin, a collection of cluster heads is determined using a multi-criteria decision function, and pertinent data is captured by agricultural sensors by Vangala, A. et al., [20].

Machine Learning Models (MLM):

To accomplish reliable and efficient data transfers, it is also necessary to assess the SNR when utilizing the transmission lines. The regularity of the linear congruential generator ensures the safety of data sent by agricultural sensors to base stations. On average, the suggested framework improved smart agriculture's communication performance percent in terms of network throughput, percent in terms of packets drop ratio, network latency, in terms of energy consumption, and percent in terms of routing overheads, according to the simulation results by Abunadi, I. et al., [21]. Managing resources sustainably, ensuring product safety, and tracking where food comes from are all aspects of agriculture that are crucial to human survival. It is critical to develop new methods that aid in agriculture's sustenance since supplies are quickly dwindling. The current situation of the food chain may be improved by the fast-developing disciplines of MLM. This research conducts a thorough literature analysis to analyze the most recent advancements in blockchain-based information security systems by Alyahya, S. et al., [22].

Artificial Intelligence (AI):

It has suggested a universal blockchain-based security architecture after defining the main needs in smart agriculture. Each of the plans under consideration has undergone a thorough cost evaluation. Delicate comparisons revealed the limitations of previous studies. In addition, by sifting through the literature,

have found new directions for AI research to go and have learned what security objectives the research has been working towards by Mowla, M. N. et al., [23]. The increasing food scarcity necessitates sustainable agriculture achieved through automation to meet the growing demand. Integrating the AI and Wireless Sensor Networks is crucial in enhancing food production across various agricultural domains, encompassing irrigation, soil moisture monitoring, fertilizer optimization and control, early-stage pest and crop disease management, and energy conservation by Mawlood Hussein, S. et al., [24].

Support Vector Machine (SVM):

Many industries, including agriculture, are feeling the effects of the new difficulties brought about by climate change. Combating climate change while also boosting food output is the biggest obstacle. The agricultural climate change and increased food production has emerged with the rise of information and communication technology. Improved and more accessible wireless sensor networks, unmanned aerial vehicles have all contributed to the emergence of cost-effective precision agricultural applications by Singh, P. K. et al., [25]. In summary, smart agriculture is enhanced by using Blockchain, AI, MLM, and SVM in IoT-based WSNs. This leads to more efficient data processing, automated resource management, and secure communication. To overcome technical and security issues in contemporary farming, this integration improves crop monitoring, pest management, and irrigation. It also ensures higher agricultural production, sustainability, and resilience against climate change.

Table 1: The Summary of Related work

System	Representation	Simple Replay	Replay with Change	Adaptation
Blockchain Technology (BCT)	Secure, decentralized ledger for WSN data protection	Logs agricultural sensor data for transparency	Enhances security by adding smart contracts for automated access control	Protects IoT-based WSNs from malicious actors while ensuring data integrity

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Machine Learning Models (MLM)	Predictive analytics for smart agriculture	Assesses SNR to improve data transmission	Uses deep learning for adaptive routing and resource management	Optimizes energy consumption and communication efficiency in precision farming
Artificial Intelligence (AI)	Intelligent automation in smart agriculture	AI-driven decision-making for irrigation and pest control	Integrates AI with real-time WSN monitoring for predictive maintenance	Enhances automation for food security and sustainable farming
Support Vector Machine (SVM)	Supervised learning for climate-adaptive farming	Classifies soil and crop conditions for better yield prediction	Incorporates UAV data for enhanced precision farming insights	Improves adaptation to climate change and optimizes agricultural productivity
Big Data Analytics	Large-scale data processing for agricultural insights	Aggregates data from IoT sensors for trend analysis	Uses predictive analytics to forecast crop yields and resource needs	Optimizes farm management decisions with data-driven insights

The implementation of IoT WSNs incorporating Blockchain, AI, ML, and SVM enhances the data security, automation, and intelligent farming practices. Drones (UAV), edge computing, and big data are examples of technologies that enable precision agriculture. These technologies enhance the efficiency of

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crop health monitoring, pest control, and irrigation which leads to improved sustainability, resilience, and increased agricultural productivity.

3. Proposed Method:

SA-WSN model achieves intelligent agriculture in IoT environment by combining blockchain authentication, lightweight encryption, and AI anomaly detection. This approach improves security and performance with a multi-layered and a multi-level security system of data integrity, confidentiality, and real-time intrusion detection. Distributed ledger technology ensures unauthorized access is blocked, while machine learning models over sensor data guarantee breaches such as anomaly detection. In addition, lightweight cryptographic protocols increase the efficiency of low-power IoT devices.

Smart agriculture using wireless sensor networks (SA-WSN)

The combination of blockchain technology and IoT sensors enables soil and crop health monitoring precision with efficient and secure tracking. Real-time threat detection and data manipulation without loss of data is achieved with lightweight encryption, AI based anomaly detection, and dynamic key management for optimal protection in agriculture.

$$u_s w[l - sk''] = Va[w - dt''] * Re[s - iu''] \quad (1)$$

This is the equation 1 specified value of $Va[w - dt'']$ with $Re[s - iu'']$ guarantees its validated encrypting and real-time anomaly identification at the destination, whereas $u_s w[l - sk'']$ signifies the authenticated data from the sensor. Maintaining low latency and safeguarding precision agriculture data against cyber-attacks are two important objectives of the safe communication systems of the equation models.

$$Ms_a[iu - an''] = Ks[w - syu''] * Ba[w - su''] \quad (2)$$

The equation for $Ms_a[iu - an'']$ is equal to $Ks[w - syu'']$with $Ba[w - su'']$ guarantees key synchronization as well as a blockchain-based authentication at the destination. Equation (2) illustrates the process by which cryptographic key distribution improves smart agriculture's Internet of Things (IoT) security by making networks more resistant to cyberattacks.

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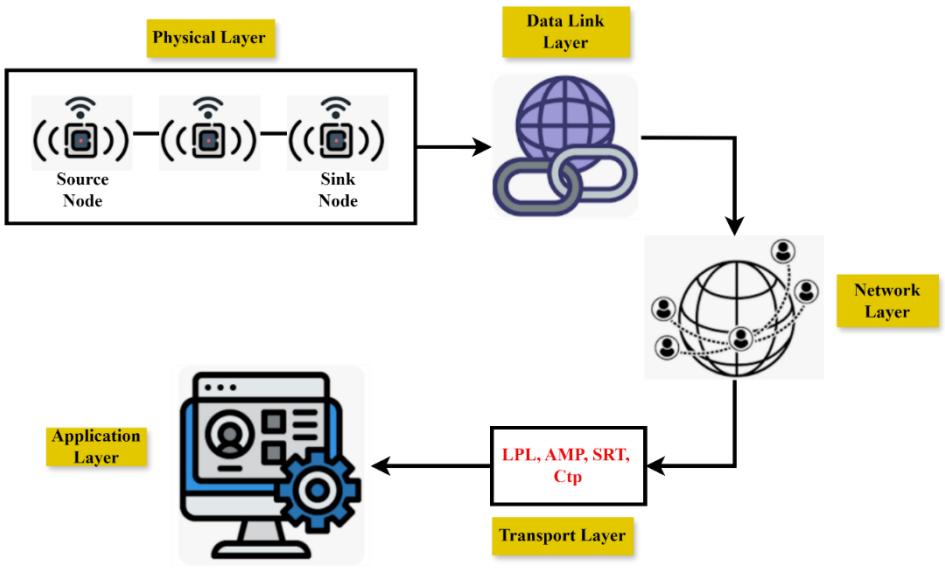

Figure 2: The Network Layer Architecture

The network hierarchy has several layers such as the Physical Layer, Data Link Layer, Network Layer, Transport Layer, and Application Layer. Every layer has a very important function to play in transmitting and communicating data. The Physical Layer performs the actual connectivity, while the Data Link Layer carries out the communication from node-to-node. The Network Layer transmits the data via the network, while the Transport Layer makes data delivery dependable. The Application Layer provides access to the end-user application. LPL, AMP, SRT, and Ctp protocols are used to maximize performance and facilitate effective data transfer within the network in figure 2.

$$x_{ew}e[a - uy''] = Ba[w - syu''] + Ua[w - syu''] \quad (3)$$

Here in the equation 3, $x_{ew}e[a - uy'']$ is the encrypted sensor data that is being analyzed for threats, and $Ba[w - syu'']$ and $Ua[w - syu'']$ deal with anomaly detection at the destination, respectively. To improve security, guarantee data dependability, and build resilient systems in smart agriculture, the equation simulates the combination of AI and blockchain.

$$p_d e = Ka[s - yr''] + V[w - sy''] * ak'[s - yl'] \quad (4)$$

Equation 4 guarantees blockchain-based key authentication, $Ka[s - yr'']$integrates checked sensor data $V[w - sy'']$using AI-driven anomaly detection $V[w - sy'']$, and $p_d e$ denotes the processed data

employed to generate agricultural insights. This ensures trustworthy decision-making in line with the suggested method's secure data transfer and threat mitigation.

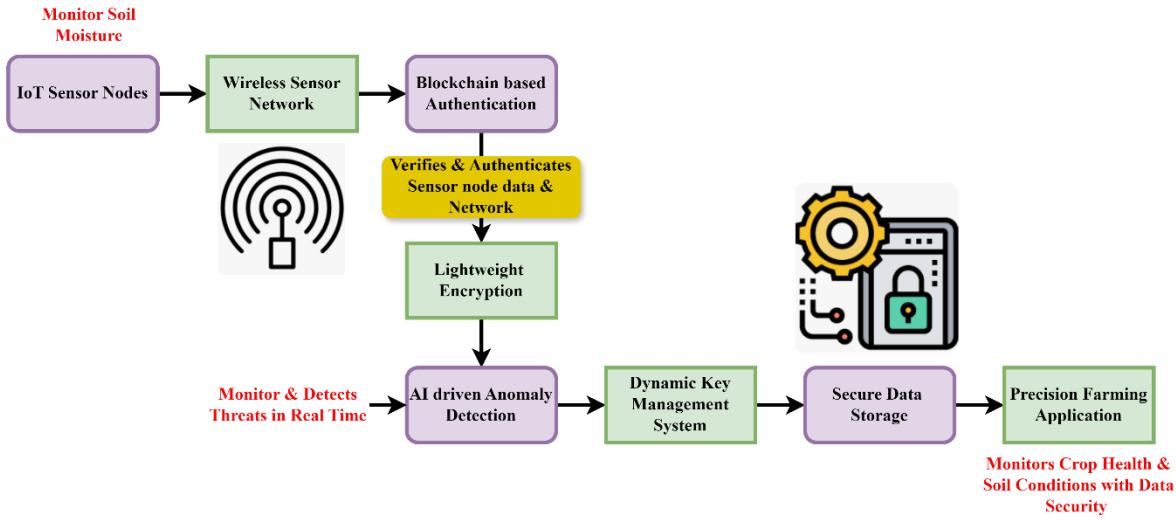

Figure 3: The Process of Secure IoT for Precision Farming

Moulter Soil Measure uses IoT Sensor Nodes in a Wireless Sensor Network to track crop health and soil conditions. Blockchain-based Authentication is used to authenticate and validate sensor data, maintaining integrity. Lightweight Encryption and Dynamic Key Management System improve security, and AI-powered Anomaly Detection scans for threats in real time. Secure Data Storage protects sensitive data. This combined strategy enables Precision Farming Applications with precise monitoring and secure data protection for maximum agricultural management in figure 3.

$$pa_e[a - y''] = Bs[w - y''] + Us[o - ane''] \quad (5)$$

This is equation 5, where $pa_e[a - y'']$ is an authentication request coming from a farm IoT device, $Bs[w - y'']$ guarantees identity verification through blockchain, and $Us[o - ane'']$ uses AI-driven analysis of user behavior to forestall unauthorized access. The equation represents the integration of intelligent monitoring and decentralized authentication.

$$p_s w = Ba[w - sy''] + Ja[w - su''] * Vsw'' \quad (6)$$

$p_s w$ is the processed safe agricultural data, $Ba[w - sy'']$ is responsible for blockchain-based validation, $Ja[w - su'']$ uses lightweight encryption, and Vsw'' incorporates AI-driven anomaly detection, all

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within the SA-WSN framework. This strategy of the suggested technique for protecting data transfer, which guarantees robustness and integrity in the face of cyberattacks.

$$M_a q[k - sn''] = Ls[o - sr''] + Ja[w - yu''] \quad (7)$$

Equation 7 guarantees lightweight safeguarding for secure transmission, $Ja[w - yu'']$ validates $Ls[o - sr'']$ the private key through blockchain authentication, and $M_a q[k - sn'']$ denotes the application for the creation of key and distribution. The equation establishes the process of how cryptographic methods and decentralized authentication augment smart farming. This previously combined IoT, blockchain, and artificial intelligence features to provide precision agriculture services in a secure and dependable manner. It keeps records of soil and crop health, as well as the integrity and safety of the data, to make it an asset that modern farming is in dire need of.

Through the application of blockchain technology, lightweight encryption, and machine learning-based anomaly detection, SA-WSN enhances the efficacy, scalability, and security of IoT-based smart agriculture. Owing to limited resources in WSNs, conventional security definitions are ineffective against safeguarding WSNs against cyber threats. With a layered security approach, SA-WSN provides end-to-end security, data confidentiality, and instantaneous threat mitigation against these issues.

4. Result and Discussion:

Although it improves the efficiency introduce enormous insecurity issues. To address these issues as well as provide trustworthy utilizes blockchain-based verification and lightweight encryption techniques in combination with AI-driven anomaly detection for efficient and rapid transmission of data with system protection, reducing latency, and identifying anomalies.

Dataset Description: Data sets relevant to smart agriculture, such as sensor data of a specific environment, are available on this platform. For instance, a certain data set gathered in an Ecuadoran plantation over three days contains weather conditions including volume of precipitation. Information from environmental factors study of crop yield might benefit immensely from this vast amount of data. For small-scale farming, Internet of Things and Wireless Sensor Network in Precision Agriculture offers a paradigm for soil moisture, temperature, and humidity monitoring.

Table 2: The Simulation Environment

Aspects	Description
MATLAB/Simulink	Modeling and simulating precision agriculture systems
NS-3 (Network Simulator 3)	Simulating IoT-based WSN communication
Tensile Net	AI-driven precision agriculture simulations
Cloud Sim	Cloud-based resource management for smart farming
Gazebo (ROS-based)	UAV and robotic system simulation in agriculture
Net Logo	Agent-based modeling for agricultural ecosystems

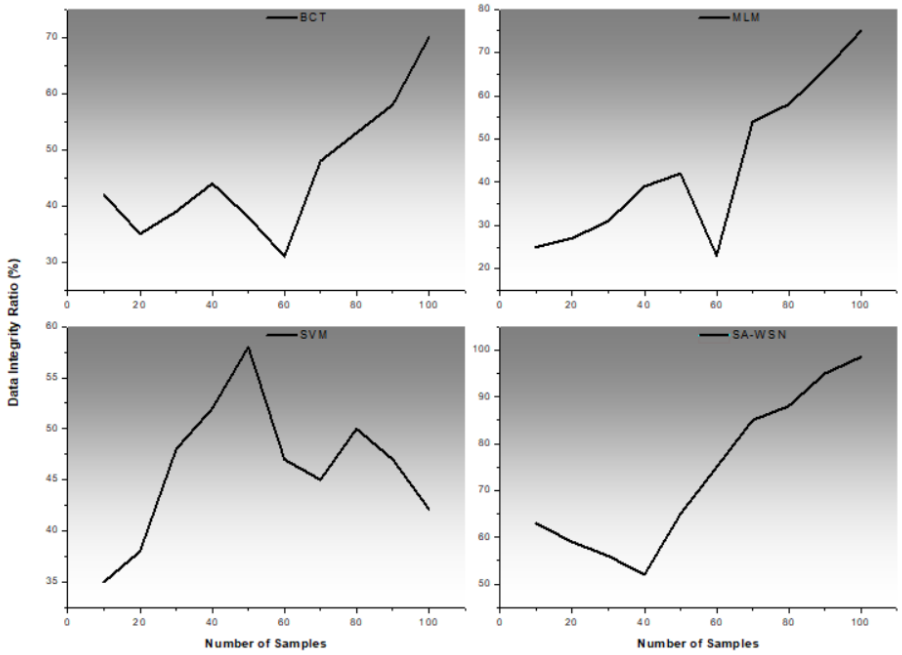

Figure 4: Analysis of improved data integrity

SA-WSN paradigm enhances data integrity in smart agriculture with IoT being driven by blockchain-based authentication and lightweight encryption to offer secure transmission of data via wireless sensor networks. Through elimination of unauthorized intrusion and cyber-attacks, SA-WSN offers accurate and tamper-evident data with a data integrity level of 98.5%. The trustworthiness is improved by offering maximizing the productivity and sustainability of farming in Figure 4.

$$\partial\forall'[i - sne''] = Ba[s - suy''] * Ka[w - yt''] \quad (8)$$

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The given relationship stands for the integrity verification process, where $\partial\forall'[i - sne'']$ represents the incoming data from agricultural sensors that need to be validated, $Ba[s - suy'']$ applies authentication based on blockchain, and $Ka[w - yt'']$ guarantees cryptographic integrity checks. To keep data accurate and trustworthy in smart agriculture, the equation describes the analysis of improved data integrity.

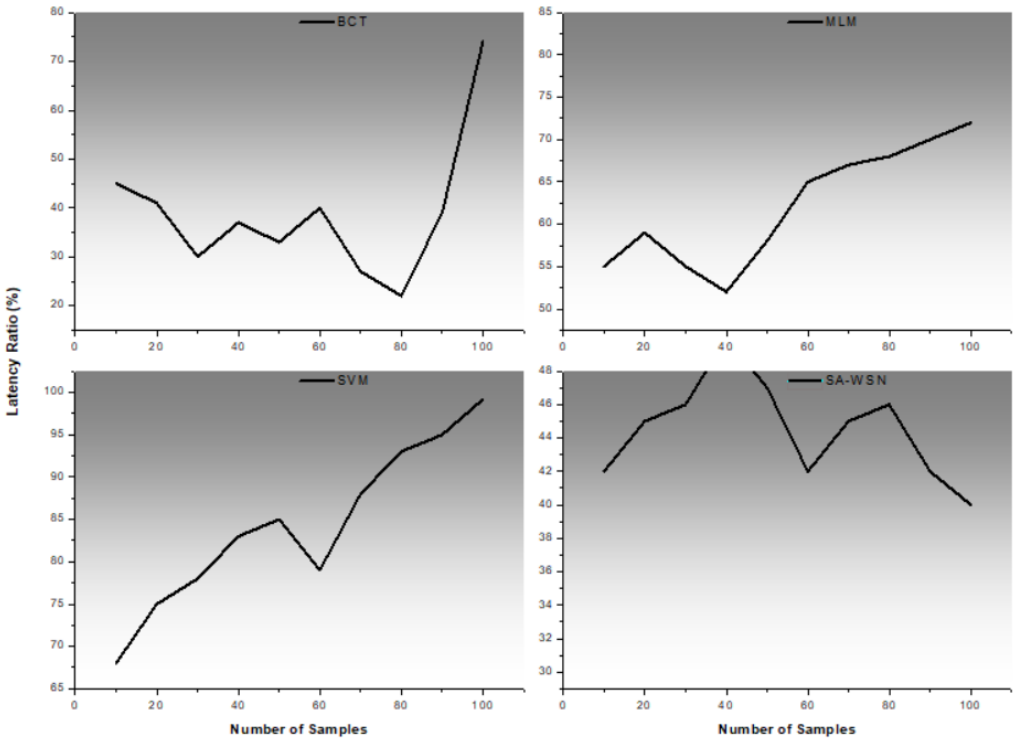

Figure 5: Analysis of Latency

The SA-WSN architecture significantly reduces latency in smart farming based on IoT by employing light encryption and efficiently facilitates rapid communication between main systems for real-time monitoring and timely response to farm demands with 40%. It enhances system efficiency, providing seamless data flow with robust security, which is critical for precision farming operations in figure 5.

$$z_a q[d - r''] = Ls[w - sy''] + Ja[w - suy''] \quad (9)$$

A solution to the equation 9, $z_a q[d - r'']$ is a request to feed accessing stored agricultural information. $Ls[w - sy'']$ guarantees lightweight encryption to ensure transmission, and $Ja[w - suy'']$ uses

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blockchain-based evidence to authenticate the request. Improving data security in smart agriculture based on IoT is modeled by the equation for analysis of latency.

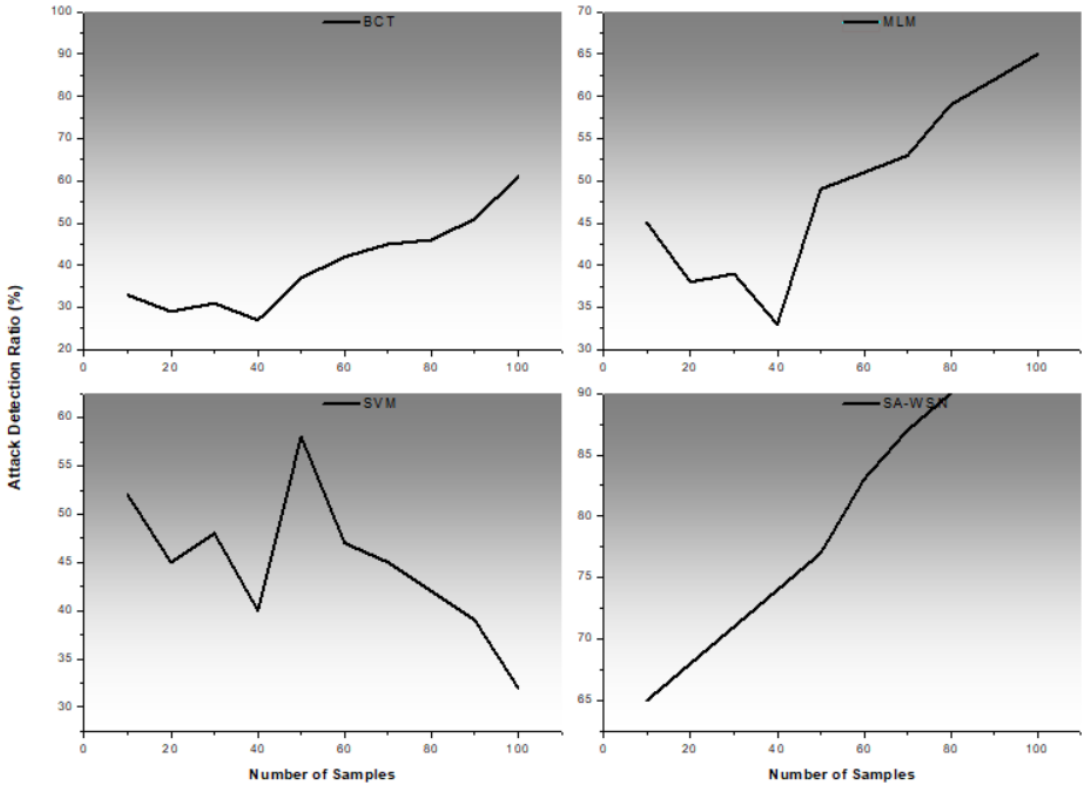

Figure 6: Analysis of Enhanced attack detection

The SA-WSN framework enhances IoT-based smart agriculture attack detection through AI-driven anomaly detection mechanisms that actively monitor behavior. Here the 97.2%, the quickly identifies and responds to emerging threats, maintaining robustness. The proactive approach the agricultural process, safeguarding crucial data and infrastructure against cyberattacks in figure 6.

$$y_s a[u - en''] = Ns[w - sy'] + Na[w - sy''] \quad (10)$$

$Ns[w - sy']$ confirms the network's stability using blockchain validation, and $Na[w - sy'']$ uses AI-driven discovery of anomalies $y_s a[u - en'']$ to find possible dangers. Equation 10 represents the analysis of enhanced attack detection which work together to fortify networks and shield them against cyberattacks.

Table 3: The Comparison of Exiting Methods and Proposed Method

Metrics	Key Features	Exiting methods in Ratio (%)	Proposed Method in Ratio (%)
Data Integrity	Blockchain-based authentication, lightweight encryption	36.57%	98.5%
Latency	Lightweight encryption, optimized transmission paths	76.89%	40%
Attack Detection	AI-driven anomaly detection for real-time monitoring	40.15%	97.2%

In summary, SA-WSN enhances through the achievement of a 97.2% accuracy rate in detecting attacks, reducing latency through enhanced protocols, and ensuring 98.5% for the integrity of data. Enhancing sustainability and efficiency and safeguarding crucial agricultural data against cyber-attacks is the aims based on IoT.

5. Conclusion:

The SA-WSN system formulates a novel approach towards securing IoT-based smart agricultural systems, presenting a novel method. SA-WSN applies blockchain-driven analysis, and AI-driven anomaly detection to provide proper threat mitigation. SA-WSN aims to address precision farming's most challenging areas: unauthorized access, information leakage, and other malicious attacks. The proposed infrastructure improves data propagation reliability, and enhances recognition (intrusion) and mitigation times to 97.2% while sustaining data integrity at 98.5%. Precise monitoring of soil moisture, temperature, and crop health is a SA-WSN's implemented application that demonstrates its effectiveness and practicality. This advancement directly improves the ability to monitor these essential components while allowing farmers to make safe data driven decisions. SA-WSN serves as the basis for security and scalability in modern agriculture by increasing integration of IoT and cultivating sustainability. This paper moves further towards the advancement in secure IoT-enabled agricultural systems and develop new opportunities within the discipline. In addition to those efforts, the focus on intelligence and smart

agriculture will make use of newer paradigms of sophisticated machine learning technologies for improving the performance of anomaly detection models. There will be a focus on the exploration of reduced latencies with 5G networks as well. Further research is directed towards expanding the scalability of the SA-WSN framework towards large scale smart agriculture implementations. Additionally, further optimization of blockchain protocols and edge computing for real-time security are also on the agenda.

Future Work: Researchers will aim to improve the safety of Internet of Things (IoT) smart agricultural systems by using blockchain-based authentication, lightweight encryption, and anomaly detection powered by artificial intelligence. To guarantee scalability, resilience, and strong cybersecurity in precision agriculture, future studies will investigate edge computing for real-time threat mitigation, federated learning for analytics that preserve privacy, and quantum-resistant cryptographic approaches.

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