Blockchain-Based Device Lifecycle Tracking: Enhancing Sustainability and Transparency

***Abstract*—The rapid proliferation of electronic devices has raised concerns about electronic waste(e-waste) management, device lifecycles, and their environmental impact. In response,this research project presents a comprehensive solution for tracking the lifecycle of electronic devices using blockchain technology. By leveraging the transparency, security, and immutability offered by blockchain, our solution aims to enhance sustainability practices,improve user awareness, and promote responsible device disposal.This project bridges the domains of blockchain technology and device lifecycle management,examining how blockchain's decentralized ledger can revolutionize the tracking of device ownership, usage history, repair records, and end-of-life disposal. Through a thorough literature review, we explore the state of existing research in blockchain technology,device lifecycle tracking, and the intersection of these areas.**

***Index Terms*—Blockchain, Device Lifecycle Tracking, Sustainability, Electronic Waste, Smart Contracts, Transparency, User Adoption,E-waste Management,Disposal,Regulatory Compliance**

I. Introduction

Electronic devices have evolved into integral components of contemporary life, reshaping the landscape of communication, productivity, and daily routines. Their significance lies in their capacity to enhance connectivity, increase efficiency, grant immediate access to information, and offer entertainment, making them inseparable from our daily existence. The outbreak of the COVID-19 pandemic played a pivotal role in amplifying the reliance on electronic devices, elevating them to essential tools for remote work, online education, and maintaining social connections. The widespread implementation of lockdowns and social distancing measures underscored the indispensability of smartphones, computers, and tablets for communication, information retrieval, and entertainment. Concurrently, the upsurge in demand for e-commerce and online services expedited the adoption of these electronic companions.

However, the heightened integration of electronic devices into our daily lives has introduced a myriad of challenges, notably in the realms of electronic waste (e-waste) management and regulatory compliance. E-waste encompasses discarded electronic devices such as smartphones, laptops, and other gadgets, and when not adequately handled, it poses substantial environmental and health risks. According to data from the United Nations Environment Program (UNEP, 21 November 2022), the world is annually generating 54 million metric tons of e-waste, comprising computers, mobiles, smartphones, and related accessories. This figure is expected to double by 2050, presenting severe issues and concerns for humanity if not addressed promptly [1]. Additionally, there are mounting apprehensions about cybersecurity, exemplified by recent reports in the Times of India regarding Chinese mobile manufacturer Vivo, which allegedly sold over 13,500 phones sharing the same International Mobile Equipment Number (IMEI). This raises significant cybersecurity concerns as having identical IMEI numbers for multiple phones can jeopardize data security and integrity [2]. The increasing prevalence of challenges stemming from inadequate electronic device tracking underscores the urgency for a comprehensive solution. In response, we propose the development of an advanced system for end-to-end tracking of electronic devices utilizing blockchain technology. This proposed system introduces a robust and transparent ledger that seamlessly monitors the entire lifecycle of electronic devices, encompassing their journey from the manufacturing phase through to their eventual disposal. By deploying this system, we seek to ensure the integrity and authenticity of data, thereby alleviating critical issues associated with e-waste management, cybersecurity, and regulatory adherence. This research paper delves into the intricacies of our proposed system, detailing its architecture, functionality, and potential to revolutionize the management of electronic devices in an increasingly interconnected world.

II. Literature Survey

The literature survey underscores the critical concern of e-waste management, with data revealing the alarming growth in electronic waste production. Notably, the United Nations Environment Program (UNEP) highlights the production of approximately 54 million metric tons of e-waste annually, necessitating an urgent need for effective e-waste management.[1] Moreover, the survey brings to the forefront a real-life issue involving the sale of smartphones with duplicate IMEI numbers, exemplified by a recent report on Vivo's sale of over 13,500 such phones [2]. This underscores the critical demand for a robust device tracking system. To address these challenges, your project's innovative solution design harnesses blockchain technology, as originally introduced in Nakamoto's seminal whitepaper[3], and further informed by the practical insights shared by Mougayar and Swan. This blockchain-based approach offers a secure, transparent, and efficient means to comprehensively track electronic device lifecycles, ensuring data integrity, and presents a transformative solution to real-world problems associated with e-waste management and device authenticity.[4]

III. Methodology

Blockchain is a distributed and decentralized digital ledger technology that underlies many cryptocurrencies, such as

Bitcoin. It is designed to record and store transactions across a network of computers in a highly secure, transparent, and immutable manner. The significance of using blockchain technology in our project, "Device Lifecycle Tracking Using Blockchain," is multifaceted and crucial for addressing the challenges associated with tracking electronic devices effectively. Here's an overview of the key significance of blockchain in our project:

1. Data Immutability: Blockchain's primary feature is its immutability. Once data is recorded on the blockchain, it becomes nearly impossible to alter or tamper with. This is immensely valuable when tracking the lifecycle of electronic devices, ensuring the historical data's accuracy and trustworthiness.

2. Transparency: Blockchain operates on a decentralized network, where all participants maintain a copy of the ledger. This transparency allows stakeholders to access and verify the complete history of each device. This feature builds trust among participants, whether they are manufacturers, consumers, or regulatory bodies.

3. Security: Blockchain employs robust cryptographic techniques to secure data. Transactions are cryptographically linked, and access to data is permissioned. This security is vital in safeguarding sensitive information, especially in the context of device tracking, where data security is paramount.

4. Decentralization: Traditional tracking systems often rely on centralized databases or authorities, which can be vulnerable to single points of failure or breaches. Blockchain's decentralized nature eliminates this risk, enhancing the resilience and reliability of the tracking system.

5. Smart Contracts: Smart contracts are self-executing agreements with predefined rules. In your project, they can be used to automate processes like ownership transfers, warranty validation, and compliance checks. These automated processes reduce the need for intermediaries and enhance efficiency.

6. Regulatory Compliance: In industries where compliance with regulations is critical, blockchain simplifies adherence by providing a transparent and immutable record of all transactions and activities. This audit trail can significantly ease the process of demonstrating regulatory compliance.

7. Trust and Accountability: Blockchain's characteristics contribute to trust and accountability within the device tracking system. Participants can have confidence in the accuracy of the recorded data, and accountability is established through the transparent and tamper-resistant ledger.

In summary, the significance of using blockchain in your project lies in its ability to revolutionize the way electronic devices are tracked and managed. It ensures data accuracy, accountability, and trust in the entire device lifecycle, from manufacturing to disposal. This is especially valuable in an era where electronic devices play an increasingly central role in our daily lives, and effective tracking and management are essential for sustainability, security, and regulatory compliance.

A. Device Lifecycle Tracking: End-to-End Workflow

In the context of "Device Lifecycle Tracking Using Blockchain," let's explore the end-to-end workflow of how electronic devices are tracked throughout their lifecycle, from manufacturing to disposal.

1.Device Initialization: Unique Digital Twin: Each electronic device, such as a smartphone, laptop, or tablet, is assigned a unique digital identity (a digital twin) on the blockchain. This identity is generated during the device's manufacturing phase.

2.Manufacturing and Distribution: Transaction Recording: As devices are produced and distributed, transactions are recorded on the blockchain. These transactions contain essential information about the device, including its make, model, serial number, and manufacturer details. Significance: This stage establishes a tamper-resistant record of the device's origin and journey through the supply chain. It ensures the authenticity of the device for all stakeholders

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3.Ownership Transfer: Ownership Transfer: When a device changes hands, such as when a consumer sells a device to another individual, the ownership transfer is initiated on the blockchain. A smart contract validates the transaction and updates the device's history. Significance: This feature enables transparent and secure ownership transfers, reducing the risk of stolen or counterfeit devices entering the market.

4.Device Usage and Repairs: Repair Records: When a device requires maintenance or repairs, authorized service centers log the details on the blockchain. This includes repair dates, service center information, and actions taken. Significance: Users can verify the legitimacy of service centers and validate warranty status. It also enhances accountability and trust in device repairs.

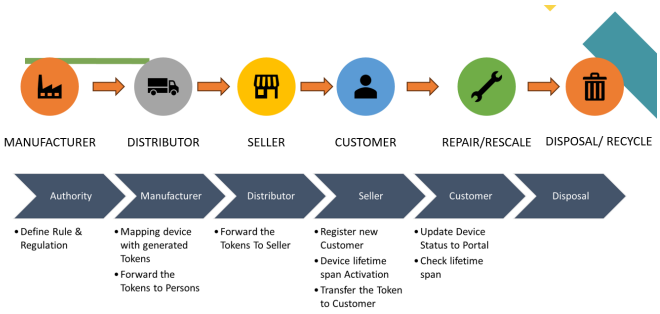

Fig. 1. Workflow of the System

5.End-of-Life Disposal: Disposal Transactions: Responsible disposal events are recorded on the blockchain when devices reach the end of their lifecycle. This includes recycling, environmentally safe disposal, or resale to e-waste management companies. Significance: The blockchain ensures that electronic devices are disposed of in an environmentally responsible manner, in compliance with regulations, reducing e-waste and its associated risks.

6.Regulatory Compliance: Data for Regulatory Authorities: Manufacturers can easily extract data from the blockchain to demonstrate compliance with environmental and e-waste management regulations to regulatory authorities. Significance: The system simplifies regulatory reporting, reduces the risk of non-compliance, and helps manufacturers adhere to regional and global regulatory requirements.

The creation of smart contracts, principally in Solidity, is at the core of our system. These agreements include activities such as adding devices, changing device information, and monitoring lifecycle events. Access is only granted to authorised users thanks to the incorporation of reliable access control methods. At this point, thorough testing is carried out, including unit and integration testing.Due to the project's revised scope, we kept the blockchain platform we had previously selected and incorporated the improved smart contracts into the current system. Real-time communication between the frontend and the blockchain is supported through optimised transaction handling and event listening.To fit the revised project scope, we extended our prior frontend development work. User authentication, role-based access control, and user interface elements were improved to better meet the new standards, making it easier to add devices, update data, and monitor lifecycle events.

B. Scenarios

Real-Life Problem: Duplicate IMEI Numbers in Smartphone Sale
Let's illustrate how "Device Lifecycle Tracking Using Blockchain" can address a real-life problem, such as the case where Vivo was reported to have sold 13,500 phones with the same IMEI (International Mobile Equipment Identity) number. This issue can create several problems, and our system offers a solution:

Vivo, a smartphone manufacturer, unknowingly or knowingly, sold 13,500 smartphones with identical IMEI numbers. IMEI numbers are meant to be unique identifiers for each mobile device, crucial for network operations, security, and tracking. Duplicate IMEI numbers can lead to various issues, including network disruptions, security vulnerabilities, and potential legal consequences for the manufacturer.

Proposed Solution:

Unique Device Identifiers on Blockchain: In our system, each device is assigned a unique digital twin on the blockchain. This digital twin includes the device's IMEI number and other identifying information. The blockchain ensures that IMEI numbers are never duplicated, as any attempt to use an existing IMEI number is immediately detected.

Secure Manufacturing Records: During the manufacturing phase, our system records the unique IMEI numbers for each device, linking them to their respective digital twins. This creates a secure and tamper-resistant record of IMEI assignments.

Distribution and Sales Tracking: When these devices are distributed to retailers and sold to consumers, every transaction is recorded on the blockchain. Any attempt to sell devices with duplicate IMEI numbers would be flagged as fraudulent in the system.

Ownership Transfer Verification: If a consumer purchases a smartphone with a unique IMEI, they can easily verify the IMEI's authenticity and uniqueness through the blockchain.

Detection and Resolution: In the case of Vivo's issue with 13,500 phones sharing the same IMEI, the system would have detected this irregularity during the sales and distribution phase. The blockchain would immediately flag this issue, and necessary actions could be taken to rectify it.

Significance of Our System:
Our system prevents the distribution and sale of devices with duplicate IMEI numbers, reducing the risk of network disruptions and security vulnerabilities. It establishes accountability and transparency in the supply chain, providing a tamper-resistant record of device origins and histories. It safeguards manufacturers from potential legal consequences, ensuring regulatory compliance.

In this real-life example, "Device Lifecycle Tracking Using Blockchain" is a proactive solution to prevent problems related to duplicate IMEI numbers, providing a secure and reliable method for device tracking and management. It offers a trustworthy means to authenticate devices and protect consumers from potential issues stemming from the misuse of IMEI numbers.

C. Smart Contract Code

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.0;

contract DeviceLifecycle {
    struct Device {
        uint256 id;
        string name;
        string manufacturer;
        string purpose;
        address owner;
        bool isSold;
    }

    mapping(uint256 => Device) public devices;
    uint256 public deviceCount;

    event DeviceAdded(uint256 id, string
        name, string manufacturer, string
        purpose, address owner);
    event DeviceSold(uint256 id, address
        previousOwner, address newOwner);

    function addDevice(string memory _name,
        string memory _manufacturer, string
        memory _purpose) public {
        deviceCount++;
        devices[deviceCount] =
            Device(deviceCount, _name,
            _manufacturer, _purpose,
            msg.sender, false);
        emit DeviceAdded(deviceCount, _name,
            _manufacturer, _purpose,
            msg.sender);
    }

    function sellDevice(uint256 _deviceId,
        address _newOwner) public {
        require(_deviceId <= deviceCount &&
            _deviceId > 0, "Invalid device
            ID");
        Device storage device =
            devices[_deviceId];
        require(msg.sender == device.owner,
            "Only the owner can sell the
            device");
        device.owner = _newOwner;
        device.isSold = true;
        emit DeviceSold(_deviceId,
            msg.sender, _newOwner);
    }
}
```

IV. Figures, Outputs and Table

SrNo.	Year	Percentage of E-waste	No. of countries involved
1	2014	44%	61
2	2017	67%	67
3	2019	71%	78

TABLE I
Overall E-waste Generated

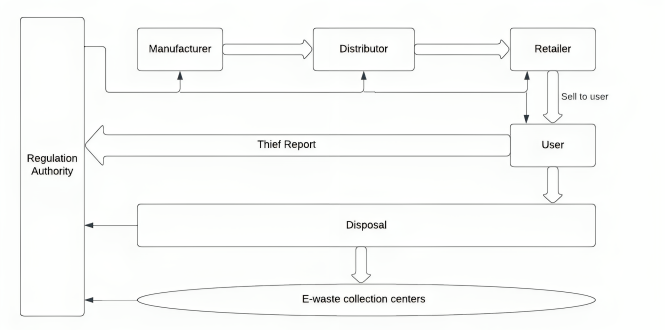

Fig. 2. Overall Architecture of the System

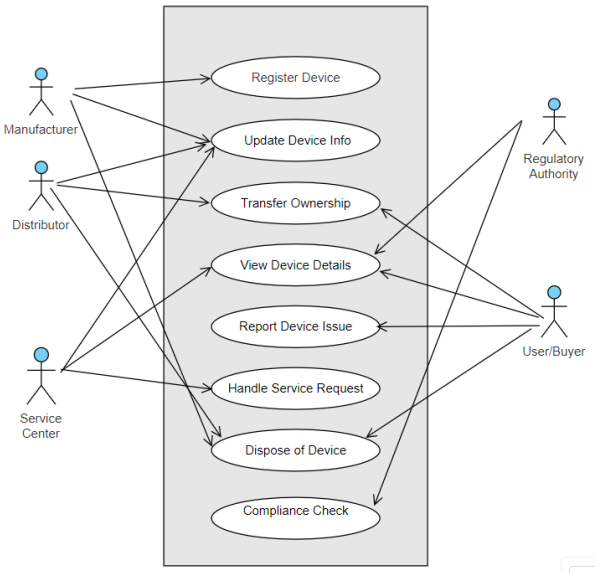

Fig. 3. Use Case Diagram

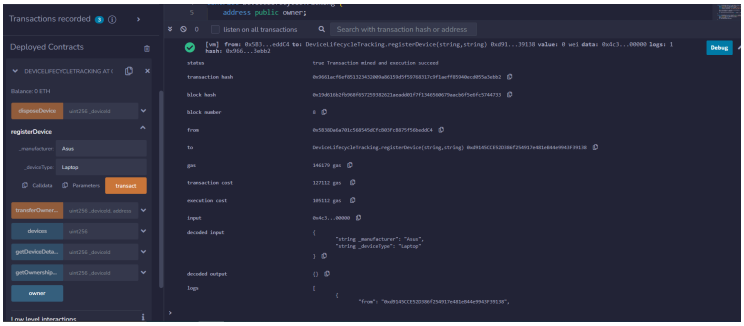

Fig. 4. Transaction

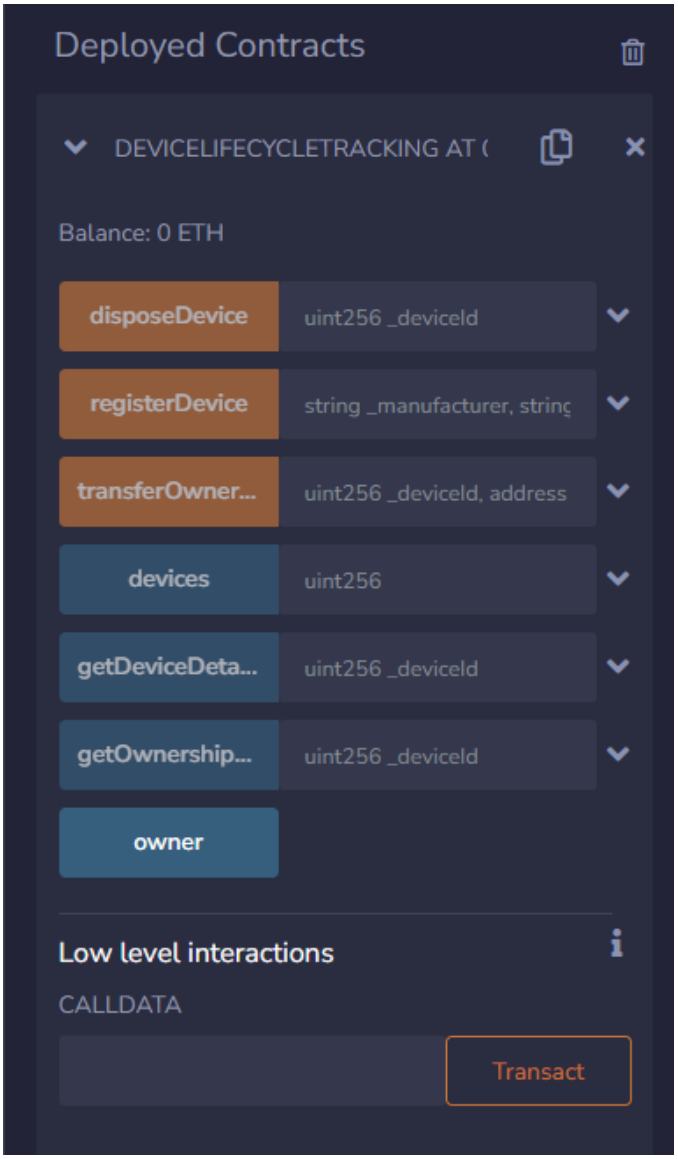

Fig. 5. Blockchain Smart Contract

V. Future Scope

In the future, the ”Device Lifecycle Tracking Using Blockchain Technology” programme will focus on research and innovation, collaboration, scalability, worldwide acceptance, regulatory lobbying, and educational initiatives. The initiative can grow to include a wider variety of electronic gadgets, encourage ethical recycling, and lessen electronic waste. Through the creation of international standards, it may be adopted on a global scale. The project will keep serving as a centre for cutting-edge research and development, propelling breakthroughs in blockchain technology and ecological sustainability. Campaigns for education can enlighten the public, manufacturers, and legislators, and policy advocacy can encourage ethical behaviour. Stakeholders, researchers, and legislators must work together to create a more inventive and sustainable future where environmental responsibility and technology coexist together.

VI. Conclusion

Our initiative, ”Device Lifecycle Tracking Using Blockchain Technology,” stands out as a ground-breaking and comprehensive response in a period characterised by rapid technology breakthroughs and rising environmental sustainability concerns. We have set out to address important difficulties in the lifecycle management of electronic devices by thorough planning, creative technological integration, and steadfast devotion to environmental responsibility.

The importance of this project rests in its capacity to address a wide range of problems with a single, comprehensive answer. Device lifetime tracking exemplifies our dedication to environmental stewardship, resource conservation, and responsible consumption and is more than just a cutting-edge technology solution.

The project ”Device Lifecycle Tracking Using Blockchain Technology” is a visionary path towards a future that is more sustainable and accountable. We have established the groundwork for dramatic change via our commitment to pushing the envelope of technology and environmental awareness. We want to shape a future where technology and sustainability coexist peacefully, creating a lasting legacy of innovation and responsible consumption. We invite stakeholders, researchers, and politicians to work with us on this. Together, we can transform how we interact with technology and open the door to a better, more sustainable future.