A Blockchain-Based IoT-Enabled E-Waste Tracking And Tracing System

Prof. Manjiri Karande[1], Mr. Vaibhav Gawaye[2], Mr. Suhas Wankhade[3], Mr. Rohan Sarkate[4], Mr. Mayur Hirole[5]
[1, 2, 3, 4, 5] Dept of Computer Engineering
[1, 2, 3, 4, 5] Padm. Dr. V. B. Kolte College of Engineering, Malkapur

Abstract- *The rapid growth of electronic devices has led to an exponential increase in electronic waste (e-waste), posing significant environmental and health risks. Traditional methods of managing and tracking e-waste are often fragmented, inefficient, and lack transparency. To address these challenges, we propose a blockchain-based Internet of Things (IoT)-enabled e-waste tracking and tracing system. The system integrates IoT sensors and blockchain technology to provide real-time monitoring, secure data management, and transparent tracking of e-waste from collection to disposal. IoT devices, such as RFID tags and environmental sensors, are embedded in e-waste items, enabling automated collection and transmission of data, including the condition, location, and recycling status of the items. This data is securely recorded on a blockchain, ensuring immutability, traceability, and transparency. The decentralized nature of blockchain eliminates the need for intermediaries, reduces the risk of fraud, and enhances accountability throughout the e-waste lifecycle. The proposed system aims to optimize e-waste management processes, improve recycling rates, and reduce the adverse impact of e-waste on the environment. Furthermore, it offers stakeholders, including manufacturers, recyclers, and regulatory authorities, a reliable and efficient platform for monitoring and ensuring the responsible disposal and recycling of electronic waste.*

Keywords- Blockchain, smart cities, security, e-waste, traceability, IoT, Ethereum etc

I. INTRODUCTION

The global surge in electronic device usage has resulted in a dramatic increase in electronic waste (e-waste), which has become one of the fastest-growing waste streams worldwide. Improper disposal and management of e-waste can lead to severe environmental and health hazards, including the release of toxic substances like lead, mercury, and cadmium.

Traditional e-waste management systems are often fragmented, lacking transparency, and are vulnerable to inefficiencies and fraudulent practices. This creates challenges in ensuring the responsible recycling and disposal of e-waste. To address these issues, a blockchain-based Internet of Things (IoT)-enabled e-waste tracking and tracing system offers a promising solution. By leveraging the power of IoT devices and blockchain technology, this system provides a comprehensive, secure, and transparent framework for managing the entire lifecycle of e-waste. IoT sensors, such as Radio Frequency Identification (RFID) tags, GPS, and environmental monitoring devices, are used to track and collect data on e-waste items, including their type, condition, and location. Blockchain technology ensures that this data is securely recorded and immutable, offering a transparent and auditable record of every transaction and movement of e-waste throughout the supply chain. This decentralized, tamper-proof ledger eliminates the need for intermediaries, reducing operational costs and the risk of fraud. Moreover, it enables real-time monitoring and better decision-making by all stakeholders, including manufacturers, recyclers, regulators, and consumers. The integration of IoT and blockchain in e-waste management not only enhances efficiency and accountability but also promotes sustainability by improving recycling rates and ensuring that e-waste is disposed of in an environmentally responsible manner. This system presents a significant step forward in the transition toward a circular economy, where resources from electronic waste can be recovered and reused, minimizing the negative impact on the environment. In the contemporary digital era, the proliferation of electronic devices has become an integral part of our daily lives, contributing to unprecedented technological advancements. However, the rapid evolution of electronics has given rise to a parallel challenge– the generation of electronic waste, commonly known as e-waste. The improper disposal of electronic devices poses severe environmental and health hazards due to the presence of hazardous materials. Recognizing the urgency of addressing this issue, our project, the E-Waste Management System, aims to provide a comprehensive solution to the burgeoning problem of electronic waste. This initiative endeavors to establish an efficient and sustainable system for the collection, recycling, and responsible disposal of e-waste, aligning with global environmental goals and local regulatory frameworks. Managing e-waste is currently one of the major challenges of urban cities. E-waste is more difficult to manage than conventional waste since it contains toxic chemicals, radioactive materials, and storage devices that might lead to privacy and security issues. If the storage devices are not disposed of appropriately, they may fall into the hands of adversaries who acquire storage devices in bulk and scan them for sensitive information. Through this process, they can extract important data, such as encryption keys, crypto wallets, social security numbers, blueprints of important buildings, and even classified information of the governments. Therefore, electronic devices require evidence-based tracking, tracing, destruction, and recycling. Internet of Things (IoT) is one of the building blocks of smart cities and can play a crucial role in the collection and tracking of e-waste.

II. LITERATURE REVIEW

- **A. J. Jara et. al. (2011):** The generation of electronic waste (e- waste) is determined as a substantial element of solid waste administration. However, encountering e-waste in landfills is not recommended as a result of its unsafe chemicals along with hefty steels. The presence of beneficial steels like gold plus copper highlights the significance of reliable waste administration. While some industrialized nations apply contemporary family e-waste administration methods Malaysia has actually not completely applied lawful structures for house e-waste. To sustain the idea of sustainability in smarter cities reliable administration of house e-waste is vital. This research discovers the application of wise collection systems in the Malaysian e-waste monitoring as well as reusing market.
- **Mithila et. al. (2023):** The arising field of IoT-based wise e- waste administration includes the combination of modern technology as well as ecological sustainability. Digital waste postures a worldwide obstacle, with possible negative results on both the atmosphere as well as public health and wellness. In this research, we present a wise e-waste monitoring system using IoT gadgets plus sensing units for tracking, arranging, plus disposal of e-waste.
- **Sumaiya et. al. (2023):,** The Net of Points (IoT) is playing a crucial duty in establishing cutting-edge applications for wise cities with garbage administration being a details location that take advantage of numerous IoT parts like RFIDs coupled with sensing units. To resolve the requirement for an effective coupled with economical garbage collection system, this paper presents a unique approach an smart garbage design for wise cities using a crossbreed hereditary formula (GA)-- unclear reasoning engine. The system wisely reviews, accumulates and also refines details with a blurry thinking engine, dynamically establishing just how to handle waste collection.
- **Niful et.al. (2023):** The incorrect disposal of digital waste money (e-waste) offers substantial ecological plus wellness dangers on an international range, motivating significant worries. Exact category of e-waste photos is necessary for efficient administration as well as reusing initiatives. This paper presents the E-Waste Vision Dataset a detailed collection including 8 unique courses of digital gadget pictures. Additionally, the paper provides EWasteNet an unique two- stream strategy for specific e-waste photo category capitalizing on a data-efficient picture transformer (DeiT). The very first stream uses a Sobel driver for side discovery, while the 2nd stream uses an Atrous Spatial Pyramid Pooling as well as focus block to order multi-scale contextual info.
- **Atta Ur Rehman et. al. (2023):** The rising international problem of digital waste recycling needs effective surveillance plus traceability of digital tools as well as connected company deals amongst stakeholders. Present centralized systems do not have openness, permanence together with safety and security, preventing detailed protection of the e-products life process as well as managing big quantities of information produced in supply chain procedures. In feedback, this paper recommends a blockchain-based IoT-enabled system that uses wise agreements to tape-record customer activities on an dispersed journal making certain openness, traceability, along with safety and security.

III. SYSTEM ARCHITECTURE

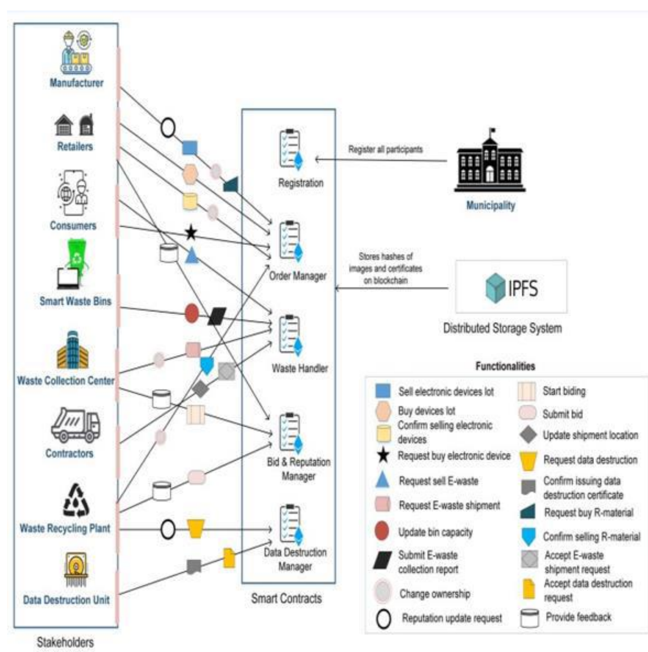


Figure 1: Proposed System Architecture

IV. EXISTING SYSTEM

The proposed system architecture of the Blockchain-Based IoT-Enabled E-Waste Tracking and Tracing System integrates key technologies IoT and blockchain to provide an efficient, transparent, and secure solution for managing e-waste. The architecture consists of several components working in conjunction to ensure real-time tracking, secure data storage, and improved accountability across the e-waste lifecycle.

1. IoT Devices (Edge Layer)

The IoT devices form the edge layer of the architecture and are responsible for the collection and transmission of real-time data related to the e-waste. These devices are embedded in e-waste items at various points of their lifecycle (from collection to disposal). Key IoT devices include:

- RFID Tags: Each e-waste item is tagged with a unique RFID tag that stores the item's identity and relevant information, such as type, manufacturer, model, and initial condition.
- Sensors (Environmental and Location): Environmental sensors monitor the condition of the e-waste, detecting parameters such as temperature, humidity, and potential hazardous material emissions. GPS sensors track the geographical location of the e-waste during transportation and recycling.
- Barcode/QR Code Scanners: Additional scanning devices can be used to validate and register data from the e-waste items at various checkpoints.

These IoT devices generate data continuously, which is transmitted to the central processing system for further analysis and recording.

2. Data Aggregation and Processing Layer

The data aggregation layer collects, filters, and processes data received from the IoT devices. It includes:

- Gateway Devices: These act as intermediaries between the IoT devices and the blockchain network. They collect data from IoT sensors and preprocess it (e.g., filtering noise, converting data formats).
- Edge Computing: In some cases, edge computing is utilized to perform initial processing of the data locally, enabling faster responses and reducing the load on central servers. This layer may filter and verify the incoming data for consistency and accuracy before it is sent to the blockchain.

The processed data is then ready to be transmitted to the blockchain for secure storage and tracking.

3. Blockchain Layer

The core of the proposed system architecture is the blockchain layer, which ensures transparency, security, and immutability of e-waste data. Key elements include:

- Blockchain Network: A decentralized blockchain network is used to store all e-waste-related data. The network is composed of multiple nodes, which ensure that data is replicated across the system, making it tamper-resistant. Each transaction (e.g., movement, recycling, disposal) related to an e-waste item is recorded as a block in the blockchain.
- Smart Contracts: Smart contracts automate processes such as verification, tracking, and triggering actions when certain conditions are met. For example, a smart contract could be used to automatically trigger a reward or penalty if an e-waste item is recycled or disposed of according to specific guidelines.
- Consensus Mechanism: A consensus mechanism (e.g., Proof of Stake or Proof of Authority) is employed to validate transactions on the blockchain, ensuring that the data entered by IoT devices is correct and that no unauthorized tampering occurs.

The blockchain layer ensures that all e-waste transactions are securely stored, auditable, and traceable by all stakeholders in the system.

4. Cloud and Data Storage Layer

The cloud and data storage layer provides scalable infrastructure for storing data that is not directly placed on the blockchain. This includes large data sets such as detailed environmental sensor logs, e-waste analytics, and historical data. It serves as a backup storage and provides additional computational power for advanced data processing and analysis.

- Data Analytics: Cloud-based tools can be used for data analytics and reporting, providing insights into e-waste trends, recycling rates, and potential inefficiencies in the system.
- Data Redundancy: A redundant cloud storage ensures that data is safe and available even if the blockchain network faces issues.

5. User Interface (UI) and Access Control Layer

The user interface layer allows stakeholders to interact with the system through a web or mobile application. Various stakeholders such as manufacturers, recyclers, consumers, and regulators can access relevant data based on their roles:

- Manufacturers: Monitor e-waste produced by their products and ensure proper recycling or disposal.
- Recyclers: Track the e-waste items received for recycling, ensuring the materials are handled according to regulations.
- Regulators: Access transparency into the e-waste management process, ensuring compliance with environmental standards.
- Consumers: Track the recycling status of their electronic products and view the responsible disposal process.

Access to data is controlled through a permissioned access control system, where different users have different levels of access to information based on their role in the system.

6. Monitoring and Reporting Layer

This layer is responsible for generating reports and notifications to all stakeholders based on the data stored in the system. Reports include:

- Real-time status of e-waste items: The tracking status, location, condition, and recycling progress of e-waste.
- Compliance reports: Ensuring that the e-waste management practices align with environmental regulations and industry standards.
- Alerts and notifications: Automated alerts sent to stakeholders if any e-waste item deviates from expected tracking patterns or if irregularities (such as improper disposal) are detected.

IV. ALGORITHMS

Creating an algorithm for a Blockchain-Based IoT-Enabled E-Waste Tracking and Tracing System involves integrating the functionalities of Internet of Things (IoT) devices with blockchain technology to enable the real-time monitoring and secure tracking of electronic waste (e-waste) from its generation to recycling or disposal. The algorithm can be broken down into several stages that focus on data collection (via IoT), validation (via blockchain), and tracing (via a decentralized ledger). Here's a step-by-step breakdown of a conceptual algorithm:

1. IoT Device Integration for E-Waste Collection

The first step in the system is integrating IoT devices to collect data about the e-waste items (e.g., location, weight, type of waste, etc.). These devices can be sensors, GPS trackers, or RFID tags attached to the e-waste. Data Collection Process are IoT Sensor Data & RFID/QR Code

Example IoT Data Collected: Type of e-waste (e.g., cell phone, laptop, etc.), Geographical location (GPS coordinates), Timestamp of collection, Quantity of e-waste, Condition of the device (working, non-working)

2. Data Transmission to Blockchain Network

The IoT device will send the collected data to a blockchain network for validation and permanent storage. The blockchain will ensure that the data is immutable and transparent. blockchain Process are Smart Contracts, Transactions & Data Validation

Example Blockchain Structure:

- Block 1: Timestamp, IoT sensor data (e.g., location, weight, type), GPS location, RFID scan ID.
- Block 2: Timestamp, updated IoT sensor data, GPS location, RFID scan ID.

This chain of blocks represents a chronological sequence of e-waste tracking.

3. Secure and Transparent E-Waste Tracking

The blockchain serves as a decentralized ledger, allowing all stakeholders (e.g., collectors, transporters, recyclers, and regulators) to view the status and location of the e-waste at any time. blockchain process are Access Control & Immutable Records

4. Traceability and Auditing

A piece of e-waste is collected by a registered waste collector (via an IoT device). It is tracked on the blockchain from the point of collection to the recycling center. At every step, relevant stakeholders (transporter, recycler, auditor) verify the authenticity and completion of the process. blockchain process are Real-Time Traceability & Audit Trail

5. Smart Contracts for Automation

Smart contracts can automate key actions within the system, such as:

- Automated Payment: When e-waste reaches the recycling center, the smart contract automatically triggers a payment to the recycler, depending on the amount and type of e-waste.
- Environmental Compliance: Smart contracts could enforce rules regarding e-waste recycling to ensure compliance with regulations. For example, if a transporter does not deliver e-waste to a certified recycler, a smart contract can flag this as a violation.

6. Reporting and Data Visualization

For all users (e.g., stakeholders in the supply chain), the system should offer visualizations and reports based on the data stored on the blockchain. blockchain process are Stakeholder Dashboard & Regulatory Compliance Reports

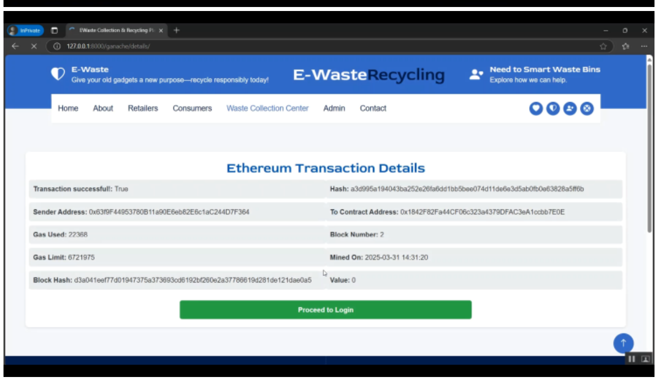
Pseudocode for Blockchain-Based IoT-Enabled E-Waste Tracking and Tracing System:

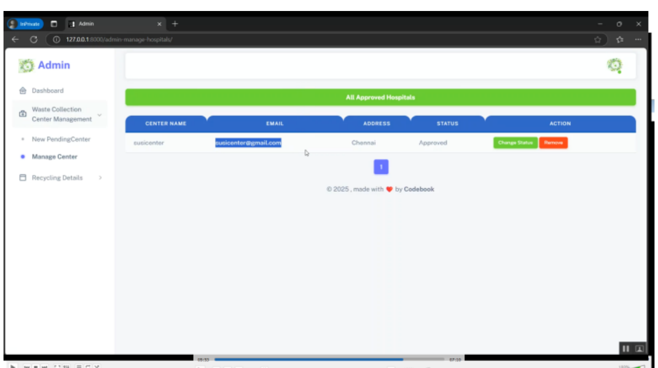
```
// Initialize system parameters
initializeBlockchainNetwork()
initializeIoTDevices()
initializeSmartContracts()
initializeDatabase()
// Main loop for monitoring IoT devices and e-waste
while (systemIsActive()) {
  // Step 1: Collect data from IoT sensors
  eWasteData = collectIoTData()

  // Step 2: Verify and validate IoT data (e.g., RFID scan, GPS location)
  if (isValidData(eWasteData)) {
    // Step 3: Create a new transaction in the blockchain network
    blockchainTransaction = createBlockchainTransaction(eWasteData)
    // Step 4: Send data to blockchain network for permanent record
    if (sendToBlockchain(blockchainTransaction)) {
      print("E-Waste Data Successfully Added to Blockchain")
    } else {
      print("Blockchain transaction failed")
    }
    // Step 5: Update the e-waste data in the local database
    updateLocalDatabase(eWasteData)
    // Step 6: Trigger smart contract actions (e.g., payment, compliance check)
    smartContractActions(eWasteData)
  } else {
    print("Invalid IoT data. Skipping transaction.")
  }
  // Step 7: Allow system to periodically check for updates in real-time
  waitForNextDataCollection()
}
// Function to initialize the Blockchain Network
function initializeBlockchainNetwork() {
  connectToBlockchain("Ethereum or Hyperledger Network")
  initializeBlocks()  // Creates the genesis block and other initial configurations
}
// Function to initialize IoT devices
function initializeIoTDevices() {
  // Register sensors such as GPS, RFID, weight, temperature, etc.
  configureIoTSensors(["GPS", "RFID", "Weight", "Temperature"])
}
// Function to initialize Smart Contracts
function initializeSmartContracts() {
  deploySmartContract("WasteTrackingContract")
}
// Function to collect IoT data from sensors
function collectIoTData() {
  eWasteData = {
    "timestamp": getCurrentTime(),
    "location": getGPSLocation(),
    "rfidID": scanRFID(),
    "weight": measureWeight(),
    "temperature": getTemperature(),
    "type": detectWasteType()  // (E.g., phone, laptop, TV)
  }
  return eWasteData
}
// Function to validate the collected data
function isValidData(eWasteData) {
  // Validate if the data is complete and correct
  if (eWasteData["location"] == null || eWasteData["rfidID"] == null) {
    return false
  }
  return true
}
// Function to create a blockchain transaction
function createBlockchainTransaction(eWasteData) {
  transaction = {
```

```
        "timestamp": eWasteData["timestamp"],
        "location": eWasteData["location"],
        "rfidID": eWasteData["rfidID"],
        "weight": eWasteData["weight"],
        "temperature": eWasteData["temperature"],
        "type": eWasteData["type"]
    }
    return transaction
}
// Function to send data to blockchain
function sendToBlockchain(transaction) {
    // Create a new block for the transaction and append to blockchain
    newBlock = createNewBlock(transaction)
    return addBlockToBlockchain(newBlock)
}
// Function to update the local database (for real-time tracking)
function updateLocalDatabase(eWasteData) {
    // Store e-waste data for local reference (optional: to allow offline access)
    database.store(eWasteData)
}
// Function to trigger Smart Contract actions
function smartContractActions(eWasteData) {
    // Trigger action based on type of e-waste or stage in the process
    if (isRecyclingStage(eWasteData["location"])) {
        // Trigger payment or recycling confirmation smart contract
        executeSmartContract("RecyclingPayment", eWasteData)
    } else if (isFinalized(eWasteData["type"])) {
        // Mark e-waste as finalized and ensure compliance
        executeSmartContract("FinalizeWaste", eWasteData)
    }
}

// Function to check if data is in the recycling stage
function isRecyclingStage(location) {
    // Assume location or stage can be identified (e.g., recycler or final disposal)
    return location == "RecyclingCenter"
}
// Function to check if e-waste is finalized
function isFinalized(wasteType) {
    // Assume some e-waste types are finalized (e.g., fully processed items)
    return wasteType == "Recycled"
}
// Function to execute a Smart Contract
function executeSmartContract(contractName, eWasteData) {
    // Execute predefined smart contract actions
    if (contractName == "RecyclingPayment") {
        // Trigger payment to recycler or transporter
        paymentAmount = calculatePayment(eWasteData)
        triggerPayment(paymentAmount)
    } else if (contractName == "FinalizeWaste") {
        // Mark the e-waste as finalized in the system
        markWasteAsFinalized(eWasteData)
    }
}
// Function to calculate payment for recycling services
function calculatePayment(eWasteData) {
    // Example: calculate payment based on weight or type of e-waste
    payment = eWasteData["weight"] * 0.1    // Example calculation
    return payment
}
// Function to trigger payment to recycler or transporter
function triggerPayment(paymentAmount) {
    // Transfer funds to the recipient via blockchain (e.g., Ethereum)
    blockchainPayment(paymentAmount)
}
// Function to mark waste as finalized
function markWasteAsFinalized(eWasteData) {
    // Update the waste status as "finalized" in the system
    updateWasteStatus(eWasteData["rfidID"], "Finalized")
}
// Function to simulate a wait time between data collection cycles
function waitForNextDataCollection() {
    // Wait for the next data collection (e.g., 1 minute)
    sleep(60000)
}
// Function to simulate blockchain block creation
function createNewBlock(transaction) {
    // Create and return a new block containing the transaction data
    block = {
        "previousBlockHash": getLastBlockHash(),
        "transactionData": transaction,
        "blockHash": generateBlockHash(),
        "timestamp": getCurrentTime()
    }
    return block
}
// Function to add a block to the blockchain
function addBlockToBlockchain(block) {
    // Append the block to the blockchain network
    blockchain.add(block)
    return true
}
```

```
// Utility functions
function getCurrentTime() { return currentTimestamp() }
function generateBlockHash() { return hash("block data") }
function getLastBlockHash() { return blockchain.lastBlock().blockHash }
function sleep(ms) { // Sleep for `ms` milliseconds }
```

V. RESULT





VI. CONCLUSIONS

The integration of Blockchain and IoT technologies into the management of e-waste offers a powerful solution for improving the transparency, accountability, and efficiency of e-waste tracking and tracing throughout its lifecycle. This system provides several key benefits that address the growing challenges in e-waste disposal and recycling. A Blockchain-Based IoT-Enabled E-Waste Tracking and Tracing System offers a transformative approach to managing e-waste, addressing key challenges like fraud, inefficiency, and environmental impact. By combining the transparency and immutability of blockchain with the real-time capabilities of IoT, the system has the potential to create a more sustainable and accountable e-waste management ecosystem. As technological, regulatory, and industry adoption continues to grow, this solution can play a crucial role in reducing the negative effects of e-waste on our environment and public health, ultimately contributing to a more circular economy.

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