Web 3.0 and NFTs enabled eWaste Management System for Smart City

Rohit Mathew Samuel[1], Jivthesh M R[1,2], Gaushik M R[1,2], Sai Shibu N B[1], and Sethuraman N Rao[1]

[1]Center for Wireless Networks and Applications (WNA), Amrita Vishwa Vidyapeetham, Amritapuri, India
[2]Tata Elxsi, Trivandrum, India
jivtheshm@gmail.com, saishibunb@am.amrita.edu, sethuramanrao@am.amrita.edu

***Abstract*—Electronic waste management is a critical issue in today's world that demands our immediate attention. The impact of improper management of e-waste, especially mobile phones and computers, can result in severe problems like health and environmental hazards and significant economic loss. With the global production of e-waste exceeding 7 million tonnes and expected to reach 300 million tonnes by 2025, it is imperative to develop a sustainable mechanism for its management. Governmental and non-governmental organizations are working to create better e-waste management solutions that will help reduce e-waste dumping and encourage recycling. Our solution involves using blockchain technology to ensure the transparency, traceability, and accountability of the e-waste management process. Additionally, we propose incentivizing society members through digital tokens or NFTs, promoting their active participation in e-waste reduction. Our proposed solution can create a sustainable and eco-friendly society by addressing e-waste management challenges. Blockchain technology and smart contracts will guarantee seamless and efficient e-waste management, promoting transparency and accountability. By incentivizing society members, we can encourage their active participation in reducing e-waste dumping and encourage recycling and refurbishing efforts. This paper also discusses the performance evaluation of smart contracts using a benchmark tool.**

***Index Terms*—e-waste management, Blockchain, AWS, Sustainability, NFT, Web 3.0**

I. Introduction

E-waste, consisting of electronic devices such as computers, cell phones, and televisions, pose a significant environmental and health hazard if not disposed of properly [1]. In many countries, the informal sector, comprising unregistered businesses or individuals operating outside the formal economy, plays a major role in the disposal of e-waste [2]. While the informal sector may use simple recycling procedures to extract valuable materials, it often lacks organization and adherence to environmental regulations [3], [4]. The formal sector must collaborate with the informal sector to ensure the safe and responsible recycling of e-waste. Proper cooperation between the two sectors can lead to the development of effective and efficient e-waste management systems that benefit the economy and the environment. We can create a sustainable solution to this critical issue by working together.

The improper disposal of electronic waste, or e-waste, poses a significant threat to the environment and public health. E-waste contains hazardous materials that can contaminate soil and water sources if not handled correctly. Unfortunately, the informal sector often manages e-waste irresponsibly, resulting in environmental damage and health risks. A standardized and transparent regulatory system for e-waste disposal is crucial to tackling this issue. Blockchain technology can provide a solution [5]. Blockchain technology can simplify supply chains and increase transparency and accountability by creating a distributed ledger that records transactions. This, in turn, can lead to a more sustainable and responsible platform for businesses, customers, and the waste management industry. Blockchain technology can help recycle and repurpose e-waste responsibly, creating a cleaner and more sustainable environment.

To address the issue of e-waste management, it is essential to have a comprehensive tracking and management system in place. Blockchain technology can create an efficient and transparent system that enables accurate tracking of e-waste from its source to its final disposal [6]. This can help ensure that e-waste is processed and disposed of safely and that there are no discrepancies in the disposal process [7].

In addition to accurate tracking, it is important to promote the responsible disposal of e-waste. This can be achieved through various measures, such as public awareness campaigns and financial incentives for proper disposal. Educating individuals and organizations on the hazards of improper e-waste disposal can encourage them to take responsibility for their waste and dispose of it properly [8], and [9].

Furthermore, promoting the reuse and recycling of e-waste can also help reduce its negative environmental impact. This can be achieved through initiatives encouraging the repair and repurposing of electronic devices and the extraction of reusable materials from e-waste [10]. By doing so, we can minimize the amount of e-waste in landfills and reduce the need for manufacturing new electronic devices.

Our proposed e-waste management system comprises AWS modules, DApps, system users, and collection centres. The AWS platform hosts the DApps and manages the blockchain. Users, including households, waste collectors, and industries, utilize the DApps to provide information about the e-waste they want to dispose of. This information is communicated to other system components using APIs.

Collection centres are equipped with device categorization systems that analyze the condition of the e-waste and de-

979-8-3503-0045-1/23/$31.00 © 2023 IEEE

2023 International Conference on Wireless Communications Signal Processing and Networking (WiSPNET) | 979-8-3503-0045-1/23/$31.00 ©2023 IEEE | DOI: 10.1109/WISPNET57748.2023.10134167

termine the best way to handle it. We use the Ethereum blockchain platform to provide users with rewards (in the form of NFTs or tokens) based on the recyclable value of their e-waste. These rewards are stored on IPFS, which is hosted on EC2.

Our proposed solution can help reduce health and environmental hazards associated with e-waste while ensuring economic sustainability. An efficient, cost-effective approach can lead to a more sustainable community. Incentivizing users to recycle their e-waste can encourage more responsible disposal practices and promote a circular economy. Our proposed e-waste management system employs advanced technologies to create a streamlined and effective process for managing e-waste, contributing to a more sustainable future.

The rest of the paper is organised as follows. Section II discusses state of the art and summarises the necessity for blockchain technology in ewaste management. Section III explains the proposed system architecture. Section IV discusses the smart contracts developed for the proposed system. Section V explains the performance evaluation of the developed smart contract using the hyperledger caliper tool. The paper is concluded in VI.

II. State of the Art and Related work

Neha Gupta et al. proposes a new way to handle EWM using smart contracts based on the blockchain. Smart contracts will help producers, importers, retailers, and recyclers of EEEs work together better [11]. It will let the government control the collection and recycling of electronic waste. It will also reduce the difference between the organised and unorganised sectors, clarifying the whole process. A prototype of the presented system was also developed using Solidity and Ganache. This framework can help enforce the proper implementation of e-waste management laws in India.

Karishma Chaudhary et al. discuss creating an Ethereum-based smart contract blockchain architectural platform called "e-waste lens" to help India deal with e-waste better [12]. The unique thing about the blockchain architectural framework is that it allows stakeholders in the e-waste management chain to track and monitor the movement of e-waste in real time. This makes it easier to find people not following the rules for effective e-waste management.

Swagatika Sahoo et al. proposes a new smart e-waste management system that uses blockchain technology and smart contracts to consider forward and reverse supply chains [13]. This lets the proposed system cover the whole life cycle of e-products, from when they are made (as new products) to when they are thrown away (as e-waste) and recycled back into raw materials. It also solves some problems and limits that existing blockchain-based systems have. Also, a prototype implementation of the system using Solidity on the Ethereum platform was shown as proof of concept. An experiment was done to show that it is possible and works well in terms of execution gas cost.

Gouri S. Nair et al. shows the proposed smart waste management platform's architecture [14]. A routing algorithm for the garbage collection robot is also talked about. The algorithm aims to find the shortest way to get to all the trash cans. The proposed platform is meant to address the United Nations Sustainable Development Goals.

Some of the research questions we aim to address are as follows:

1) How can blockchain technology be used to improve the tracking and disposal of e-waste, and what are the associated benefits and drawbacks?
2) What technological innovations can be used to improve e-waste management, such as new methods for recycling or repurposing e-waste or new devices that can reduce e-waste in the first place?
3) What is the potential impact of using NFT incentives for e-waste recycling in terms of increasing participation and improving the efficiency of the recycling process?
4) How do different user groups (e.g., households, waste collectors, industries) respond to NFT incentives for e-waste recycling, and what factors influence their decision-making?

Our paper addresses these issues by proposing a solution incorporating blockchain technology, smart contracts, and NFT incentives to promote responsible e-waste disposal practices while addressing the existing research gaps.

III. Proposed system for Blockchain-enabled e-waste Management

As shown in figure 1, the proposed system consists of four major components. The first component is the AWS modules. This component comprises the AWS EC2, Amazon Managed Blockchain and Forecast platforms.

A. Amazon Web Services - Cloud Solutions

1) AWS EC2: Amazon Elastic Compute Cloud, also known as Amazon EC2, is a component of Amazon Web Services (AWS) Cloud that offers scalable computing capability. By utilising Amazon EC2, one could eliminate the need to make an initial hardware investment, helping users build and deploy apps more timely. Amazon Elastic Compute Cloud allows users to deploy as few or as many virtual servers as users require, set encryption and connectivity, and manage storage. Users don't need to analyze traffic when using Amazon EC2 because they can scale up or down to manage demand variations or popularity spikes.

2) Amazon Managed Blockchain: Amazon Managed Blockchain is a completely managed solution by Amazon that enables anybody to deploy blockchain infrastructure with only a few clicks. The burden associated with creating a private blockchain network or creating nodes to connect to a public blockchain network is eliminated with Amazon Managed Blockchain. Users can rapidly establish blockchain networks that span several AWS accounts using Amazon Managed Blockchain. This enables users to process transactions and share information without a centralised authority. When you utilize Amazon Managed Blockchain instead of self-hosting the blockchain network, users won't have to manually deploy

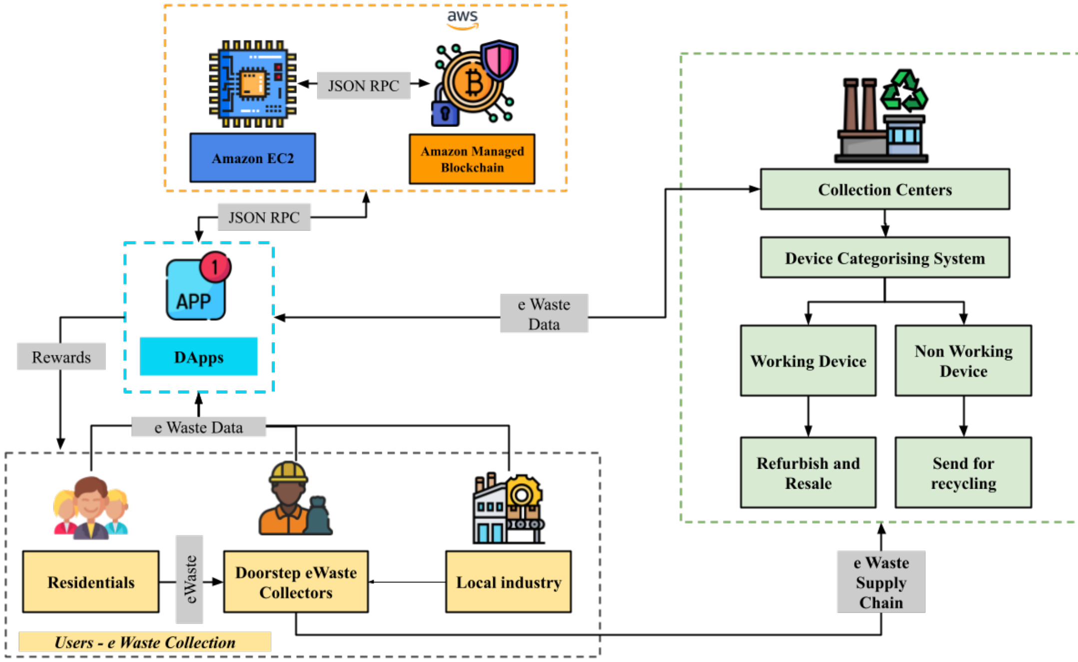

Fig. 1. Proposed system architecture

hardware, configure software, or set up networking and security components like you would if you hosted your blockchain. Network participants can vote to add or remove network members using the voting API provided by Managed Blockchain. Managed Blockchain offers the ability to create and configure numerous blockchain peer nodes to the newly joined member to process transaction queries and save a replica of the ledger after the member has been added. Additionally, Managed Blockchain will monitor the network and immediately replace any malfunctioning nodes.

B. Decentralized Applications

Decentralized applications (DApp) are computer programmes or applications that are digital and that operate on a blockchain or peer-to-peer (P2P) network of computers rather than on a single computer. DApps, which are often developed on the Ethereum platform, have the potential to be developed for a wide variety of uses, some of which include the gaming industry, the financial sector, and social media. DApps, or decentralised applications, are similar to cryptocurrencies because a single entity does not control them. DApps can provide social media networks, games, other forms of entertainment, and applications that aid productivity. To this point, Ethereum has proven to be the platform of choice for decentralised applications. When the network was first conceived, one of its key objectives was simplifying the development of DApp. Users of DApps may experience increased peace of mind if they are aware that the application developers cannot regulate how it is used, at least not in the traditional sense. For instance, the developers of a DApp for a social network do not have the authority to delete a post or block a user. They can also not sell users' data to other entities because decentralised applications operate independently once published.

C. Users and e-waste Collection Process

The user is responsible for separating their waste into hazardous and nonhazardous categories and disposing of it in designated smart bins. These bins are equipped with sensors that can track the amount of waste and schedule pick-ups at appropriate intervals. When it is time for the bins to be collected, a doorstep e-waste collection team will visit the user's location to retrieve the waste. The team will load the collected materials, including electronic waste such as old electronics or appliances, into specialized carriers for transport to a recycling centre. At the recycling centre, the waste materials will be taken to a storage area where they will undergo the process of segregation. This involves separating the different types of materials present in the waste, such as metals, plastics, and glass. The materials will then be disassembled, with the usable components extracted and the remainder sent for further processing or disposal.

D. Recycling Centers

After the electronic waste has been collected from customers and delivered to a recycling centre, it is first categorized based on its characteristics. This may include whether the devices are still functional or not. If the devices are deemed suitable for refurbishment, they are further classified and sold on markets for used or refurbished products. If the devices are intended for recycling, they are classified and sent to product manufacturers or vendors who can use the materials to make new products. If the devices are considered for disposal, they are classified and sent to appropriate disposal sites. Once the collected electronic waste has undergone the refurbishment or recycling process, it is ready to be sent to the e-waste supply chain, where it can be sold or used to produce new products.

IV. Smart contracts for eWaste Management System

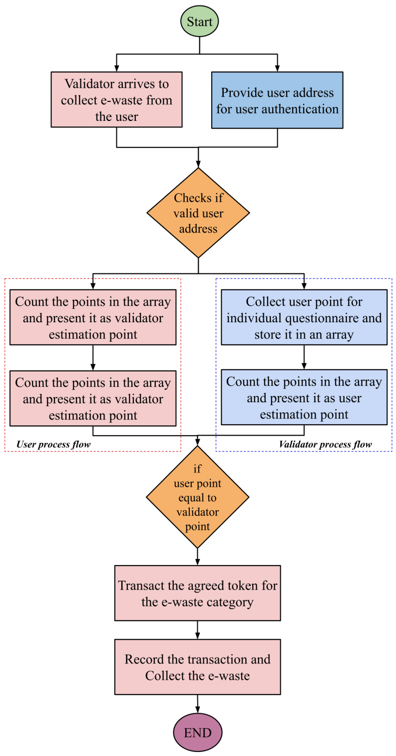

Fig. 2. Smart contract logic

Smart contracts [15], [16] are algorithms that define how transactions should be executed. This section discusses the smart contracts developed for e-waste management using blockchain technology. Figure2 demonstrates the logic of the smart contract we developed. The smart contract consists of various functions for a set of predefined tasks. This section explains each of these functions and their expected outcomes.

```
function newUser(address userAddress, uint userid, string memory username) public returns(bool success) {
    users[userAddress].id = userid;
    users[userAddress].name = username;
    users[userAddress].set = true;
    return true;
}
```

Fig. 3. Smart Contract Function to store incoming messages

The new User function shown in figure 3 in the smart contract is used to register new users on the platform. When new users want to join the platform, they must provide their user address, user ID, and user name as input arguments to the newUser function. This function then maps the user data to a unique address identifying the user within the smart contract. This also includes a Boolean set variable that ensures that points are not awarded to addresses not registered in the smart contract. This is to prevent unauthorized users from receiving points on the platform. By requiring users to register and be mapped to a unique address, the smart contract can ensure that only registered users can earn points and participate in the platform.

```
function user_Points(address userAddress, uint point) public returns(bool success){
    if(users[userAddress].set){
        userAnswer.push(point);
        return true;
    }

}
```

Fig. 4. Smart Contract Function to calculate user points

The userpoints function shown in figure 4 of the smart contract is used to award points to users who participate in the platform. This function takes the user address and a point value representing the points as input arguments. The points are awarded for each question the user answers correctly in the e-waste quality assessment process. The points that a user earns are stored in an array called userAnswer. This array tracks the points each user has earned over time. The userAnswer array is indexed by the user's address so that the points for each user can be easily accessed and updated as needed. When the userpoints function is called each time, a user answers a question correctly in the e-waste quality assessment process. The function adds the points for the correct answer to the user's total points scored in the userAnswer array.

```
function userEstim(address userAddress) public returns(bool success){
    uint count = 0;
    uint total_score;
    if(users[userAddress].set){
        for(uint i = 0; i < userAnswer.length; i++){
            if(userAnswer[i] == 1){
                count = count+1;
            }
        }
        total_score = count*10;
        users[userAddress].userEstPoints = total_score;
        return true;
    }
}
```

Fig. 5. Smart Contract Function to estimate user points

The userEstim function shown in figure 5 of the smart contract calculates the total score awarded to a user based on their performance in the e-waste quality assessment process. This function takes the user's address as the input argument and counts the total number of points the user has earned by answering questions correctly. The total score is calculated by adding all the points the user has earned in the assessment process. This total score is then assigned to the state variable userEstPoints, which represents the points awarded to the user for their e-waste. The userEstPoints state variable is used to track the total points that a user has earned over time.

```
function Validator_Points(address userAddress, uint point) public returns(bool success){
    if(users[userAddress].set){
        valAnswer.push(point);
        return true;
    }
}
```

Fig. 6. Smart Contract Function to calculate Validator's point

The ValidatorPoint function shown in figure 6 of the smart contract awards points to users participating in the e-waste collection process. This function takes the user's address and a Boolean value representing the points as input arguments. The points are awarded by the person who collects the e-waste based on their assessment of the quality of the waste.The points that a user earns are stored in an array called valAnswer. This array tracks the points each user has earned through the e-waste collection process. The valAnswer array is indexed by the user's address so that the points for each user can be easily accessed and updated as needed. The ValidatorPoint function is called each time a user's e-waste is collected and assessed for quality. The function adds the points for the e-waste to the user's total points scored in the valAnswer array.

```
function compare(address userAddress) public returns(bool success){
    if(users[userAddress].userEstPoints == users[userAddress].validEstPoints){
        users[userAddress].tokenEL = true;
        return true;
    }
}
```

Fig. 7. Smart Contract Function to compare user estimated and validator estimated point

The compare function in the smart contract is used to compare the points awarded to a user by the e-waste quality assessment process (user estimation points) with the points awarded to the user by the e-waste collection process (validator estimation points). This function takes the user's address as the input argument and uses it to retrieve the user's points from the userAnswer and valAnswer arrays. Once the points have been retrieved, the compare function compares the user estimation points with the validator estimation points. If the user estimation points are equal to or greater than the validator estimation points, the function sets the Boolean tokenEL variable to true for the user's account. If the user estimation points are less than the validator estimation points, the function sets the tokenEL variable to false for the user's account. The tokenEL variable marks the token eligibility for the user's account. If the tokenEL variable is true, it indicates that the user can receive a token as a reward for participating in the platform. If the tokenEL variable is false, it indicates that the user is not eligible to receive a token.

A. Smart Contract Implementation using Truffle suite and Web3

The proposed machanism involves using a decentralized application (DApp) to facilitate the collection and recycling of e-waste. When users want to dispose of their e-waste, they can use the DApp to book a date for a collector to come and pick up the waste. Before the e-waste is collected, the user is asked to answer a series of questions about the quality of the waste to determine the opportunities for its reuse. The user answers these questions by selecting 1 for true or 0 for false. Based on the user's answers, points are awarded to the user to reflect the quality of the e-waste. Once the date for the e-waste collection has been arranged, the collector comes to pick up the waste and visually confirms its quality. The collector then asks the same series of questions as the user and awards points based on the answers. The points awarded by the collector (validator points) are recorded on the blockchain along with those awarded by the user (user points). If the validator points are equal to or greater than the user points, the user can receive a crypto token reward for participating in the platform. The user can then accept the validator's point reward offer, complete the transaction, or reject the offer and choose not to dispose of their e-waste. If the validator points are less than the user points, the user is not eligible for a token reward.

```
 1. To add new user
 2. User points
 3. Validator points
 4. To compare validator and user points
 5. To exit
3
   --- Validator ---

Enter the User address to validate :0x0B46d22501384Ed9b65f873D45797A9F174f5dc4

Based on the questions award 1/0 points
question 1: 1
question 2: 1
question 3: 1
question 4: 0
question 5: 0
--- Scores are recorded ---

 1. To add new user
 2. User points
 3. Validator points
 4. To compare validator and user points
 5. To exit
4
   --- Comparing points---

Enter the User address to compare the scores :0x0B46d22501384Ed9b65f873D45797A9F174f5dc4

User score :50
Validator score :30

--- product mark differ and not eligible for the estimated token ---

 1. To add new user
 2. User points
 3. Validator points
 4. To compare validator and user points
 5. To exit
5
---- collection completed ----
```

Fig. 8. Terminal output of smart contract implementation using truffle suite and web3

Figure 8 displays the smart contract described in the process is implemented using the Truffle suite and web3. The final step involves the collector adding the decision and any remarks to the blockchain and exiting the DApp.

B. NFT Distribution

To distribute NFT to users, we used Remix IDE, an Ethereum test network that can be accessed through the web and used to develop, test and validate smart contracts. To construct smart contracts for the minting of NFTs, distribution of NFTs, and managing users, we used the Remix IDE, which was connected to the Ethereum Rinkeby Test Network. The smart contracts were initially deployed in Remix IDE to test the minting of NFTs, distribution of NFTs, and management of users. The smart contract implemented in Remix IDE may be seen in figure 9. The red highlight represents the function of mining an NFT stored in IPFS, and the green highlight represents the NFT transfer function.

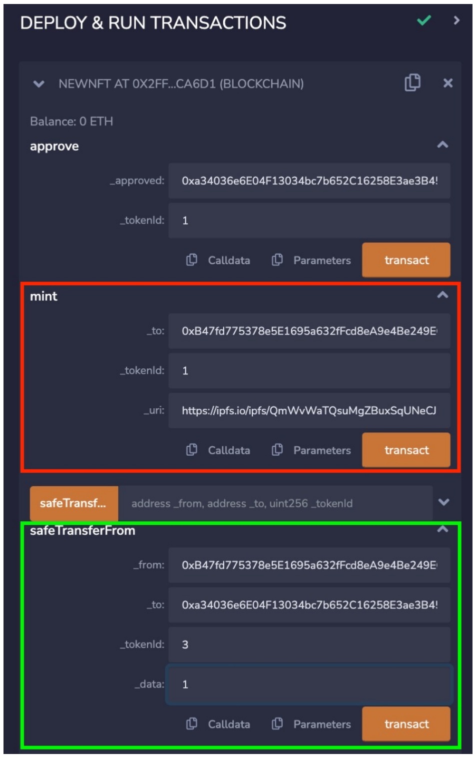

Fig. 9. Minting and transferring NFTs using Smart Contracts in Remix IDE

We stored NFTs and user data using the IPFS distributed file system. Text, images, and videos can all be stored here. Using the desktop client compatible with Ubuntu OS, we produced NFTs in the photo format (jpg) and then uploaded them to IPFS. The NFTs we uploaded to IPFS is depicted in Figure 10. IPFS offers a URL for every one of these NFTs to access.

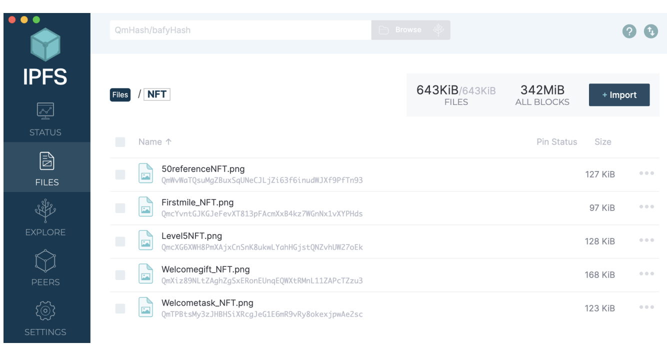

Fig. 10. NFTs stored in IPFS

V. Performance Evaluation of Smart Contract using Hyperledger Caliper Tool

We used the Hyperledger Caliper benchmarking tool run a series of tests to evaluate the performance of the smart contracts. First, we install Hyperledger Caliper on a Macbook Air with a 16GB M1 configuration. We used different workloads to simulate different scenarios and assess the system's performance under various conditions. Table I summarises the configuration for the system under test.

TABLE I
System under test

Device	OS	Memory	Storage	CPU
Macbook Air M1	MacOS Ventura 13.1	16 GB	500 GB SSD	M1

We started by setting up the necessary dependencies and configuration files for Hyperledger Caliper. This includes installing Node.js and setting up a configuration file that specifies the Ethereum network and smart contract we want to test. Then use the Caliper command line interface to run the performance tests. This involves specifying the type of test you want to run (e.g. "throughput" or "latency") and the parameters for that test (e.g. the number of concurrent users or the duration of the test). The next step is to analyze the results of the performance tests. Hyperledger Caliper generates detailed reports with metrics such as transaction throughput, average transaction latency, and error rates. These metrics help in identifying bottlenecks or inefficiencies in the smart contract. Table II summarises the performance evaluation results for functions in our smart contract that we developed for the proposed application.

TABLE II
Performance evaluation table

No of workers	Functions	Send Rate (TPS)	Throughput (TPS)	CPU (Avg)	Avg Latency (s)
15	new User	23.1	22.6	0.14	19.79
15	user_Points	23.0	22.4	0.15	15.41
15	Validator_Points	24.8	23.2	0.19	14.19
20	newUser	19.8	18.7	1.30	6.60
20	user_Points	22.2	21.1	0.57	17.84
20	Validator_Points	2.3	2.0	0.11	N/A

From Table II, it can be observed that when the number of workers increases, the transmission rate and throughput decrease. In the case of CPU utilization, increasing the number of workers leads to an increase in CPU consumption. This is because each worker will require CPU time to complete their work, and adding more workers will increase the overall demand for CPU resources. Similarly, latency refers to the time it takes for a request to be processed by the system. In our case, latency is lower when the number of workers is higher. The results of the tests showed that the smart contracts performed well and met the requirements for efficiency and scalability. The system handled a significant number of transactions without compromising its performance or speed.

VI. Conclusion

The management of e-waste is a critical issue that requires immediate attention. The increasing use of electronic devices and the toxic nature of e-waste necessitate proper management to prevent harm to the environment and public health. With its ability to create a transparent and immutable ledger, blockchain technology has emerged as a promising solution to address the challenges associated with e-waste management.

Our proposed blockchain-based solution for e-waste management leverages the potential of NFT incentives and smart contracts to encourage users to dispose of their electronic devices responsibly. By incentivizing users with NFT rewards, we can create a more effective and efficient system for e-waste management. Moreover, the use of smart contracts can automate the e-waste management process, ensuring that it is transparent and efficient. Our proposed blockchain-based solution for e-waste management can potentially transform how we handle e-waste. By promoting responsible disposal practices and incentivizing users with NFT rewards, we can create a more sustainable and cleaner environment for ourselves and future generations.

However, there is still a need for further research on the scalability and effectiveness of blockchain-based solutions for e-waste management, especially when combined with NFT incentives and smart contracts. The benchmark test results demonstrate that this approach can effectively and efficiently manage e-waste while promoting environmental sustainability. However, further research is needed to explore the scalability and effectiveness of blockchain-based solutions for e-waste management in real-world scenarios. Additionally, we plan to develop a machine learning-based e-waste prediction system to enhance our proposed solution's efficiency further.

VII. Acknowledgement

We sincerely thank our beloved Chancellor and world-renowned humanitarian leader, Dr. Mata Amritanandamayi Devi(AMMA), for her inspiration and motivation towards all our endeavours.

References

[1] M. S. Hossain, S. Al-Hamadani, and M. T. Rahman, "E-waste: A challenge for sustainable development," *Journal of Health and Pollution*, vol. 5, pp. 3–11, 12 2015.

[2] S. R, R. P, V. S, K. R, and G. M, "Deep learning based smart garbage classifier for effective waste management," 06 2020, pp. 1086–1089.

[3] G. Rishma and R. Aarthi, "Classification of waste objects using deep convolutional neural networks," in *ICDSMLA 2020*, A. Kumar, S. Senatore, and V. K. Gunjan, Eds. Singapore: Springer Singapore, 2022, pp. 533–542.

[4] B. Debnath, A. Das, S. Das, and A. Das, "Studies on security threats in waste mobile phone recycling supply chain in india," in *2020 IEEE Calcutta Conference (CALCON)*, 2020, pp. 431–434.

[5] A. N. Mahesh, N. B. S. Shibu, and S. Balamurugan, "Conceptualizing blockchain based energy market for self sustainable community," in *Proceedings of the 2nd Workshop on Blockchain-Enabled Networked Sensor*, ser. BlockSys'19. New York, NY, USA: Association for Computing Machinery, 2019, p. 1–7. [Online]. Available: https://doi.org/10.1145/3362744.3363345

[6] S. S. Narayanan Babu and B. Sukumar, "Architecture and proof of concept design for community marketplace using blockchain technology and fuzzy intelligence — narayanan babu — international journal on communications antenna and propagation (irecap)," *Architecture and Proof of Concept Design for Community Marketplace Using Blockchain Technology and Fuzzy Intelligence — Narayanan Babu — International Journal on Communications Antenna and Propagation (IRECAP)*, Feb 2022.

[7] S. Mohammed and U. Sindhu Vaardini, "Analysis on the growing problems of e-waste and implementation of a circular economic approach to managing e-waste," in *2021 International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA)*, 2021, pp. 1–5.

[8] Z. Zheng, S. Xie, H. Dai, X. Chen, and H. Wang, "An overview of blockchain technology: Architecture, consensus, and future trends," in *2017 IEEE International Congress on Big Data (BigData Congress)*, 2017, pp. 557–564.

[9] N. Gupta and P. Bedi, "E-waste management using blockchain based smart contracts," in *2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, 2018, pp. 915–921.

[10] S. Shahid, Z. Saddique, E. F. Qayyum, and E. Jamil, "A review on the methods of recycling e-waste, implementable in pakistan," in *2019 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, 2019, pp. 1–6.

[11] N. Gupta and P. Bedi, "E-waste management using blockchain based smart contracts," in *2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, 2018, pp. 915–921.

[12] P. Yadav, D. Verma, P. Padmanabhan, and K. Chaudhary, "Blockchain: a game changer in electronic waste management in india," *International Journal of Integrated Supply Management*, vol. 1, p. 1, 01 2021.

[13] S. Sahoo and R. Halder, *Blockchain-Based Forward and Reverse Supply Chains for E-waste Management*, 11 2020, pp. 201–220.

[14] G. S. Nair, D. P V, J. K, N. Giriraj, and S. S. N B, "Architecture, concept and algorithm for data analytics based zero touch waste management in smart cities," in *2021 Second International Conference on Electronics and Sustainable Communication Systems (ICESC)*, 2021, pp. 851–856.

[15] P. Kumar, "A buyer and seller's protocol via utilization of smart contracts using blockchain technology," in *Advanced Informatics for Computing Research*. Singapore: Springer Singapore, 2019, pp. 464–474.

[16] Priyanka, "An efficient and novel buyer and seller's distributed ledger based protocol using smart contracts," in *Distributed Computing and Internet Technology: 16th International Conference, ICDCIT 2020, Bhubaneswar, India, January 9–12, 2020, Proceedings*. Springer-Verlag, 2020, p. 349–363.