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Custom Block Chain Based Cyber Physical System for Solid Waste Management

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Abstract

The aim of this paper is to develop an intelligent cyber-physical system for the waste management in a locality which will not only keep records of the use of the trash bins in the but also ensure they have an additional blockchain based verification system which will ensure the proper working even in the presence of an adversary. The proposed system is an ensemble of the database server, blockchain server, embedded system based clients and an android app. This is inspired by the recent global trend in smartphone popularity which has piqued interest in the above mentioned division. The advent of smartphone popularity helps us to create an ideal system for a plethora of reasons such as processing capability and native storage etc. Furthermore, blockchain technology, introduced by Satoshi Nakamoto in 2009 ensures decentralization and security of transactions due to its use of cryptographic hash functions and public key cryptographic system. To further excite the situation, India recently revised its solid waste management policy in 2016 after 16 long years. All of the above factors together pointed to creation of a smart waste management system to prevent further exacerbation of India's existing waste management crisis.

Keywords: cyber-physical systems, blockchain, solid waste management, embedded systems, intelligent systems

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1. INTRODUCTION

Solid Waste management is a global issue but it's a major problem in developing countries like India due to lack of sophisticated systems and inefficient working of organizations like municipal corporations which work in this

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field. Its consequences are even more pronounced in underdeveloped nations. It has been observed that such systems fail to keep pace with social and economic development in many regions. The factor which makes it a crucial problem is the adverse effect on public health, environment, and economy in the absence of these systems. The chief cause of the increase in municipal solid waste is overpopulation, urbanization, industrialization, and economic growth.[1] According to one report, 43% of funds for waste management are unused in India because at the base level things are not working properly.[2] Despite the significant development in social, economic and environmental areas, solid waste management systems in India have remained relatively unchanged. The informal sector has a key role in extracting value from the waste with approximately 90% of residual waste currently dumped rather than properly landfilled. In India, Ministry of Environmental and Forests (MoEF) manages the rules and regulations regarding the waste management and handling but its compliance is variable and limited and one the biggest reasons is lack of awareness among people in urban as well as suburban areas [3]. One way to handle this problem is the introduction of an intelligent system in the scenario which is not only capable enough to keep records of the use of garbage disposal places but will also ensure that the place is properly maintained by a municipal officer who is responsible to handle that area. The collected data will help us to study the behavior of people and the spread of diseases in a locality which were caused due to unhygienic surroundings. Like any other cyber-physical system for our system also internet connection is so crucial [4]. In India, from last few years Internet availability is skyrocketed which allow us to deploy our system in large of the part of the country.

2. RELATED WORK

The technology which is an important component in the backend in cryptocurrencies is slowly making its way into waste management. Several initiatives have seen the potential of incorporating blockchain technology. One such initiative is Plastic Bank [5] which is a Canada based global recycling venture. It pays the people in exchange for plastic waste using blockchain-secured digital tokens which can be used at stores to purchase goods through their app [5]. This model allows investors to monitor their investments. Another effective use of blockchain in managing waste which is making an appearance is French Railways, Société Nationale Des Chemins de Fer Français (SNCF). SNCF's subsidiary AREP uses blockchain to collect detailed information on station bins [6]. This data will make it possible for station managers to see what providers have done and when. This allows them to improve waste management and optimize sorting. One of the most influential initiatives from India is SwachhCoin [7] which is also making the news. Apart from these initiatives, the de facto standard for smart waste management is trash bins with microcontrollers to open and close lids as well as inform the authorities regarding the status of trash bins with solar panels to make it dependent on renewable energy. These trash bins collect data regarding and stores in the cloud. These are definitely good systems but these systems lacks intelligence.

3. BACKGROUND

There are some aspects of the project which are needed to be discussed before discussing our solution. These aspects are as follow:

3.1. Waste Management Rules in India

After 16 long years India has revised its policy on Solid Waste Management [8]. According to the rules, it is now the responsibility of the generators to segregate the waste into three categories namely Wet, Dry and Hazardous waste. Waste generator now has to pay a 'User Fee' to the waste collector and a 'Spot Fine' has been introduced for littering and non-segregation. Its quantum will have to be decided by the local bodies [9]. Waste processing facilities now have to be setup by all local bodies with population 1 million or more within the next 2 years. India had earlier introduced its initial set of E-Waste Management laws in 2011 which was then improvised in 2016 [8]. The first quarter of 2018 made those laws more stringent. Accountability for assortment and channelization of e-waste has been given to producers, manufacturers, importers, dealers, retailers, and refurbishes of EEEs. Authorization to those particular stakeholders will be given provided their phase-wise assortment targets of e-waste are met. Assortment targets refer to amount of e-waste that has to be collected by the producer/retailer within the stipulated

time period. Provision of deposit-refund scheme for customers was conjointly made available by the government [8]. In order to stall the outpour of e-waste into the unorganized sector government has also directed stakeholders to deposit e-waste at government approved centers and recycling units with relevant documents carried by transporter during this transportation process [8]. Proper execution of these new rules has been a difficult task for the government. Inadequate record keeping by industries makes e-waste estimation within India a more difficult task. Consumers continue to provide their waste EEEs to rag pickers instead of producers/retailers in return for a small amount of money due to lack of incentives. Only a miniscule quantity (5%) of all e-waste reaches formal recyclers whereas remaining (95%) is processed by informal sector. Lack of e-waste coming to the formal sector forces several governments authorized assortment centers to operate at a much lower capacity [6]. This leads the stakeholders to resort to unfair means to reach their collection targets protect their license to control. Additionally, transporters act as outpour points of collected e-waste into unorganized sector. Lack of transparency with e-waste movement has resulted in few formal players investing in EWM in India.[8] In a report that was published last year by Ministry of Environment and Forest several other points are mentioned. Main attraction for revision of these rules was to extend them to urban and industrial areas.

3.2. BlockChain

Blockchain technology is the core concept behind all cryptocurrency systems. This concept was originally introduced by Satoshi Nakamoto in the year 2009 [10]. Blockchain is a growing list of records which can conjointly be referred to as blocks which are joined using cryptography techniques. Each block contains the cryptographic hash value of previous block, information and the time stamp. This system was developed as an alternative to existing monetary systems but unlike traditional monetary systems, this system is decentralized due to absence of transaction validating centralized authority [11]. In cryptocurrency systems these blocks store the verified transactions and the corresponding chain if a blockchain is formed. A replica of each blockchain is present at each node in the system. Each node can initiate as well as verify the group action. For a system to act as a node it must possess a wallet. On acquiring the wallet, each node receives a pair of keys which contain its public and private key [11]. A public key uniquely identifies the node within the network, known to everyone within the network and is used to initiate any transaction within the network [12][13][14]. Considering the case of Bitcoin, the wallet maintains no record of quantity of cash owned by a node but keeps the blockchain of all transactions in which the node is included. It acts as validation for a node that it owns a certain definite amount of money [10].

There are certain transaction models that are used by cryptocurrencies. Bitcoin makes use of UTXO model. An unspent transaction output (UTXO) is an output of a blockchain transaction that has not been spent. In other words it is used as an input in a very new transaction. All UTXO given as inputs must satisfy the prerequisite to have the same receivers and hence the amount should add up to the amount that node is attempting to send. The creator digitally signs it using its private key to preserve the integrity of freshly generated transaction. Private Key is private to the node i.e. it is not shared across the network. This transaction is then broadcasted to neighboring nodes which check its integrity and validity by verifying whether inputs follow UTXO or not. Copy of the blockchain available at every node is used to trace the origin of specified UTXO. Once veracity of the transaction is identified, it is added by the nodes to its memory pool and is passed on to the neighboring nodes [15][16][17].

These transactions are picked by miners and grouped together into a single block. Miners refers to nodes responsible for appending new blocks to blockchain and these blocks contain cryptographic hash value of previous block, information along with the time stamp. The block can be hashed by using hashing algorithms such as SHA256 which outputs a 64 digit hexadecimal number [10]. SHA256 has a desirable property of a strong avalanche effect which means that even a single modification within the data bits can result in a drastically modified hash value. Appending a new block to blockchain requires calculation of hash value of block which is made extremely difficult by imposing restrictions that hash value has to be below a particular threshold. However, block content is static and hence a variable is added within the block. And value of variables is adjusted each time to calculate hash value of the block. This method can be termed as the Mining of Cryptocurrency [11]. Once mining of the block is complete, it is passed on over the network to be confirmed by other nodes and miners present in the network. Once

majority of the participating peers agree on veracity of the new block it is appended to the blockchain. Modification of blocks which are a part of the blockchain requires large computational power and speed. If an adversary attempts to alter a block it would lead to modification of hash of altered block and would not match the hash present in the subsequent block [11]. Due to the presence of invalid hash in contents hash of the subsequent block also becomes invalid and as a result the entire subsequent block becomes invalid. Hence, to avoid this adversary must compute new valid hashes of all blocks which follow the modified block before appending a new block to the blockchain. The above task is extremely computation intensive and can succeed only if a majority of miners contribute mining power to bring down the network (51% attack) [18][19]. Execution of complex calculations to create each and every block eliminates the requirement of a centralized authority for establishing trust and to prevent fraud. The concept of public key cryptosystem is the underlying support system of blockchain. Blockchain provides a decentralized and an extremely secure way of storing information and as a result it is a preferred system in numerous industries as well as public domain projects [10][15] .

3.3. Cyber-Physical Systems

A cyber-physical system is a mechanism which is controlled or monitored by computer based algorithms and is tightly coupled with the internet and its end users. The physical and software components are deeply interconnected with each operating on varied temporal and spatial scales in a cyber-physical system. They exhibit multiple and distinct activity modalities and interact with each other in an exceeding ton of the way which varies with context. There exist several examples of cps such as smart grid, autonomous mobile systems, medical monitoring, process management systems, robotics systems and automatic pilot avionics. CPS is the brainchild and a product of intermingling of multidisciplinary approaches which includes theory of mechatronics, cybernetics, and process and design science. The process control is generally named as embedded systems. In embedded systems computational elements tend to be more strenuous instead of the link between computational and physical elements. CPS and IoT are similar as they share basic architecture but CPS involves a higher level of combination and coordination of computational and physical elements [6].

The applications of CPS are found to be extremely useful across diverse fields such as aerospace, chemical processes, recreation, civil infrastructure, energy, manufacturing, automotive, transportation, healthcare, and consumer appliances. A fully functioning CPS is often designed to be a network of interacting elements with physical input and output rather than as standalone devices, which is the case with numerous embedded systems. The concept of CPS is closely tied to fundamentals of robotics and sensor networks coupled with intelligence mechanisms full of computational intelligence. The recent technical advancements in the sciences and engineering have led to the betterment of the link between computational and physical constituents with the help of intelligent mechanisms which has led to increase in adaptability, autonomy, efficiency, functionality, reliability, safety, and usability of cyber-physical systems. The class of cyber physical system deployed in our project can be categorized under Mobile cyber physical systems. In this category of cyber physical systems, physical system under study has inherent property of mobility. Several examples of mobile physical systems include mobile robotics and electronics transported by humans or animals [4].

The recent boom in popularity of smartphones has piqued interest in mobile cyber physical system division. Platforms of smartphones help us create an ideal cyber physical system for a plethora of reasons which primarily include possession of important computational resources such as processing capability and native storage, possession of multiple sensory input and output devices like touch screens, cameras, GPS chips, speakers, microphone, light-weight sensors, proximity sensors as well as multiple communication mechanisms, such as Wi-Fi, 4G, EDGE, Bluetooth which are used to interconnect devices to either the internet or to each other. The role of high level programming languages also cannot be neglected in rapid advancement of CPS. Rapid development of mobile cps node software, like Java, Objective C, JavaScript, Python, etc. as well as the readily-available application distribution mechanisms, like Google Play Store and Apple App Store has paved the way for CPS. For tasks that require additional resources which are unavailable on local device, a common mechanism for rapid implementation of smartphone-based mobile cyber-physical system nodes makes use of networking feature to link the device with

either a server or cloud environment. This enables complex processing tasks to be carried out which would not have been possible locally.

4. DETAILS OF PROPOSED SYSTEM

In this paper we are going to present a method to improve the situation of the solid waste management in India. In recent time the reach of Internet has increased in country. According to one report of Telecom Regulatory Authority of India (TRAI), India had 1.012 billion active mobile connections in January 2018 [20]. Due to availability of these resources, it makes it easier to implement to scale up our proposed system. The system is created in such a way that it the every step of waste collection and management in a locality or anyplace is verified which will make the implementation more successful and cause involvement of people among the waste management. The stakeholders of our proposed system are as follows:

Table 1. List of Stakeholders.

S. No	Stakeholders	Roles
1	Municipal Corporation	It is responsible for the installation and management of the Trash Bin in the assigned area.
2	Garbage Collector	Person who is responsible for the collection of the garbage from the trash bins.
3	Trash Bin Users	Common people who put the garbage in the dustbin.

The components associated with our system are as follows:

Table 2. Components of System

S. No	Component	Roles
1	Public Block chain Server	It will host the blockchain associated with all the trash bins for a locality. It'll help to broadcast the blockchain every time it's updated. This server can be hosted by any person with sufficient computing resources.
2	Local Server	These are the microcontrollers which will make the chain of different type of nodes locally before it's pushed to Public Server. These local server will be installed at every trash bin and it will be responsible for all the operations associated with a trash bin like data collection, signature generation etc.
3	Client Interface / App	This app will allow the users to verify the work done by the municipal operator and help him to generate the proof of his/her work. Each app will have a unique identifier. In a device only one such app can be installed and it's identifier will depend on information about phone like Mac-Id and IMEI number, because these are unique to each device.

The components associated with our system are as follows:

Table 3. Types of Nodes In Blockchain

S. No	Node Type	Description
1	Node Type A [Data Entry Node]	This type of node stores the state of the trash bin at a particular time stamp. The state includes the

		humidity level, depth and other factors of trash bin. This type of node is created whenever trash bin is used. The block of these nodes will be pushed to the public servers.
2	Node Type B [Half Verification Node]	This type of node will be created when number of type A nodes cross a certain threshold value and it is validated by municipal worker. This node will store the details of the municipal worker who has verified the block of nodes (type A).
3	Node Type C [Full Verification Node]	This type of node is created when the municipal worker has cleaned the dustbin and the trash bin has been verified by the local user who is part of the network. This node stores the status of cleaning of trash bin.

Above proposed nodes will be created at certain verification level. Here we are considering that the verification will be needed once the readings of the sensors in trash bin reaches to a certain threshold level. Our system will have three verification state and the characteristics of those verification level are as follow:

Table 4. Types of Verifications State

S. No	States	Description
1	Block Filling Stage (Pre Verification Stage)	At this level trash bin will be in working state and its state will be recorded every time it's used. At this state no verification is needed.
2	Half Verification State	Block will attain this state once a municipal worker comes in proximity of dustbin and cleans it. Here municipal worker has to show proof of his work to the local server as well as public servers which will be done by solving a hashing problem.
3	Full Verification State	Block will attain this state once the any person of will come in close proximity and make sure that trash bin is clean. Here also to validate the working of municipal worker, person has to solve a hashing problem after that person can give the rating [0 or 1] which will be stored in node type C along with the identifier of the application through which it is validated.

The blockchain component is the backbone of our work. Though it has basic functionality same as presented in the original paper [10], but the way in which we have implemented is different. From the original paper [10] we are just using the jay in which hashes are created and chain is maintained. The way in which we are carrying out the whole process is as follows. During the time of installation or when trash bin is fully empty it is in Block filling state. When the user puts the garbage in the dustbin, the ultrasound sensor, humidity sensor as well as other sensors records the reading of the state of the dustbin. The reading which is taken at particular time stamp which is representing the state of the dustbin is stored as an object which we are calling a node of type A. When the dustbin is used second time another node is also created and appended to a list on the local server. In the list we can append only fixed number of nodes once we reached the max threshold or dustbin gets filled, the whole list is packed as a block which can't accept any other node of type A. Simultaneously a node of type B will be created which contains the id of all the nodes of type A which are now packed together as a block.

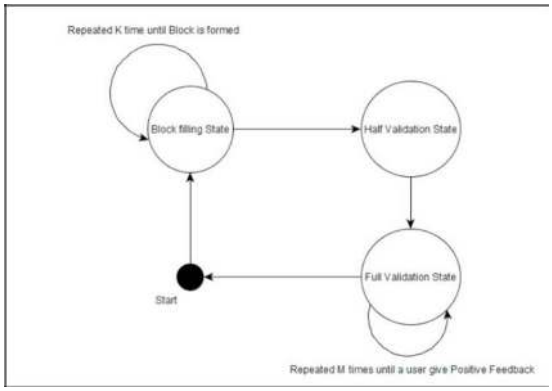

Fig. 1. State Transition Table.

On the formation of the block a text message will be sent to the local municipal corporation to go and clear the dustbin and this block will be sent to the public blockchain servers and the microcontroller will have a record of the id of the block which is pushed to the main server. When the person reaches on site to close proximity of the dustbin the android app which is a component of our system will get connected to the dustbin microcontroller through an access point which is hosted by the dustbin's microcontroller or we can say our local server. Once the connection is set up the microcontroller will share the id of the block with the app of the municipal worker. The application will send the request of connection to the public blockchain server. On connection, it will share the id of the block and app can fetch the block as well as a hash of the previous node of type C from the public server to validate. Now the municipal worker will create the hash from the hash of the previous node A and the nonce at run time to produce the hash which is smaller than a fixed threshold. We'll make sure that the challenge is complicated enough that it will be completed before the cleaning of the dustbin completes. But if a worker is enabled to solve the challenge but the dustbin gets cleaned or it reached to its initial state, the microcontroller will send that nonce which will help to create the suitable hash for which phone is working and we can say the block has completed half validation and the same time one node of type B is appended to the main blockchain in public servers. Alongside its id is also maintained by the local dustbin. It will clear the status of all the nodes in that block. Once any other person from the locality comes to use the dustbin and comes in the closer range to use the dustbin and validate the working of the municipal worker. To do so it also has to solve the hash problem for the node type B. Once it solves it node C will be added to the last added block of the blockchain and the block will achieve full validation and locally at the microcontroller another instance of the block will be instantiated.

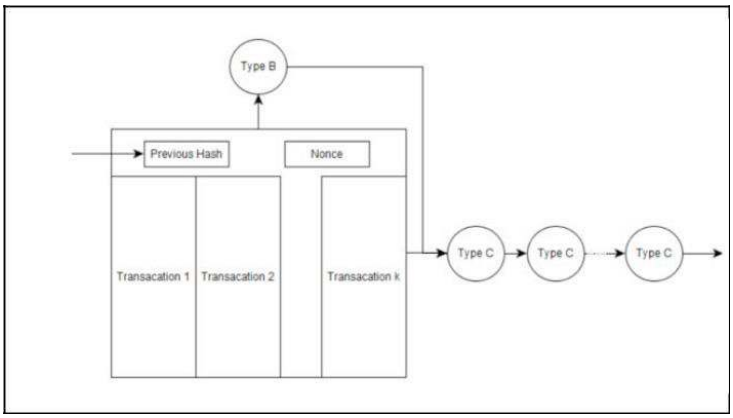

Fig. 2. Block after a Full Verification State

In case a municipal worker doesn't collect garbage, the local person whose role is to validate the working of the municipal worker can give him/her a lower rating. If the rating is zero means garbage is not collected in that case another type C node will be created with an identifier of the person received from the last type C node as well as the rating which is currently given by the user. In the blockchain, the type C node will be added repeatedly unless some give a positive review. So we can say the number of type C nodes between two blocks is correlated with the work quality of the municipal worker. Here one thing could happen that municipal worker can own two phones one for the municipal work and another application for one to validate his request. This can be prevented by ensuring that the pair of identifiers which are responsible for half validation and full validation should not be used for subsequent transaction only after certain no of transactions.

5. DISCUSSION

The proposed system involves the microcontroller operated blockchain-based cyber-physical system which is designed to introduce the additional level of verification in the usual microcontroller-based garbage collecting trash bins along with the involvement of more and more people to increase the reach of the idea of a clean and hygienic society. Every component which is a part of the designed system plays a crucial role in the loop of waste collection and management. A microcontroller and other components like the sensors and Wi-Fi module are added to the system, not just for the sake of automation, but to collect the relevant data from the system, verification of the duty of the municipal worker by solving a mathematical problem on the local system as well as to push the data to the public server and interact with the client interface. The Blockchain component is the backbone of the whole idea of hierarchical verification [11][10]. The system involves two-level verification; first which has to be done by a municipal worker after clearing the trash bins and verification involves the verification of the work of municipal worker by any local member of the locality or anyone who has the client interface of the mobile app. The blockchain is needed to enable this feature in the system. The working of the blockchain in the context of this system is discussed in detail in the previous section [Section IV] where the details of the system are discussed in nuance. There are several factors which lead us to incorporate the blockchain as it offers all the required amenities like handling of time series data, public-key encryption, and proof of work by both municipal workers as well as local people through solving a mathematical problem using their devices which will be managed by the client interface. The same features could have been achieved even without blockchain, but for that, several components needed to be incorporated like a database server, an encryption mechanism and some heuristic or a deterministic algorithm to verify the work. But blockchain encapsulates all these distinct things in a single entity in a secure way. The reason to go with blockchain because of its decentralized nature. The general-purpose databases are created with the purpose of centralized control, but this is neither the case nor the need in the problem for which we have proposed a solution.

6. RESULT & CONCLUSION

The proposed system and its components like public server, local server and client interface were developed and tested. During development, the cost was used as metric and power consumption was used as a metric to evaluate the economic feasibility of the system. The whole system was set up and deployed under the cost of 600INR. During the test, various possible corner cases were simulated to test the proper working of the system, verified by changing the state of the system in a similar fashion discussed above in Section IV. The designed system shows that the blockchain data structure can be used to add hierarchy to the authentication process. In the designed system, two level authentication is there which helps in regulating the work. The collected data which is stored in the public blockchain server can be processed and analyzed, to evaluate the better strategy for garbage collection by reducing the number of trips to the trash bins. The promising outcome of the system is the involvement of the local people in the cleanliness of the city or a locality, which will help to draw the better results from the government-enforced policies like Swacha Bharat Abhiyaan (Clean India Movement) [21].

7. FUTURE WORK

The system proposed in this paper is good for the solid waste management in the localities and in the common places. But there are other types of waste that are also generated in the localities at a regular basis. So, in future we would like to extend this idea so that it can be used to manage other type of waste also. For now we are considering involvement of only one government organization. In future we would like to involve more organizations and NGOs with this work so that the reach of the idea can be increased. The goal is to make it available in many public places for instance tourist spots, sports center any many other places with high popularity as well as high population density so that cleanliness and hygiene can be maintained. Also the data which is generated as the product of the process has to be utilized for the better monitoring of the area.

References

[1].Global Waste Management Outlook (2015) Retrieved from https://www.uncclearn.org/sites/default/files/inventory/unep23092015.pdf

[2].Richa Pinto, (December 2017) “43% of funds for waste management projects unused”. Retrieved from https://timesofindia.indiatimes.com/city/mumbai/43-of-funds-for-waste-management-projects-unused/articleshow/57949899.cms

[3]. Sunil Kumar, Stephen R. Smith, Geoff Fowler, Costas Velis, S. Jyoti Kumar, Shashi Arya, Rena, Rakesh Kumar & Christopher Cheeseman (March, 2017) “Challenges and opportunities associated with waste management in India” Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5383819/

[4].Christopher Greer, Martin Burns, David Wollman, Edward Griffor (March, 2019) “Cyber-Physical Systems and Internet of Things” Retrieved from https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1900-202.pdf

[5]. Plastic Bank [Online]. (n.d.) Retrieved from https://www.plasticbank.com/what-we-do/#.XZXWv1Uzapo

[6].Etienne Burdet, Data-tritus project: using blockchain technology to serve waste management. (June 5, 2017) Retrieved from http://www.arepgroup.com/news/126/data tritus_project_using_blockchain_technology_to_serve_waste_manage ment/.

[7]. Swachh Tokens [Online] (n.d.) Retrieved from https://icobench.com/ico/swachhcoin

[8].Solid Waste Rules (2016). Retrieved from http://pib.nic.in/newsite/PrintRelease.aspx?relid=138591

[9].R. Ganguly, "E-Waste Management in India--An Overview," International Journal of Earth Sciences and Engineering, vol. 9, no. 2, pp. 574-588, 2016. (April, 2016)

[10].Satoshi Nakamoto: Bitcoin: A Peer-to-Peer Electronic Cash System, (2008) Retrieved from https://bitcoin.org/bitcoin.pdf

[11].Sandip Chakraborty, Praveen Jayachandran. “Blockchain - Architecture, Design and Use cases”, NPTEL Course Lecture (2018) Retrieved from https://www.youtube.com/playlist?list=PLsAtoG7tyROMswghQtszHmNQ1Osi2XAHU

[12].Morgen E. Peck (September 28, 2017) “Blockchains: How They Work and Why They’ll Change the World” Retrieved from https://spectrum.ieee.org/computing/networks/blockchains-how-they-work-and-why-theyll-change-the-world

[13].Recereum Whitepaper [Online]. (n.d.) Retrieved from http://recereum.com/files/WhitePaper-Recereum.pdf

[14].Recereum Coins [Online]. (n.d.) Retrieved from https://icobench.com/ico/recereum

[15].Gupta, Neha & Bedi, Punam. (2018). E-waste Management Using Blockchain based Smart Contracts. 915-921. 10.1109/ICACCI.2018.8554912.)

[16].Salimitari, Mehrdad & Chatterjee, Mainak. (September 2018). A Survey on Consensus Protocols in Blockchain for IoT Networks. Retrieved from https://arxiv.org/pdf/1809.05613.pdf

[17].Siva Sankar, Lakshmi & Sindhu, M & Sethumadhavan, M. (2017). “Survey of consensus protocols on blockchain applications”. 1-5. 10.1109/ICACCS.2017.8014672.

[18].D. Zhaoyang, L. Fengji, and G. Liang, (July 2018) “Blockchain: a secure, decentralized, trusted cyber infrastructure solution for future energy systems,” Journal of Modern Power Systems and Clean Energy, vol. 6, no. 5, pp. 958–967, 2018.

[19].B. Notheisen, J. B. Cholewa, and A. P. Shanmugam, (2017) “Trading real-world assets on blockchain,” Business & Information Systems Engineering, vol. 59, no. 6, pp. 425–440.

[20].Annual Report of Telecom Regulatory Authority of India (TRAI) (Feb 21, 2019) Retrieved from https://main.trai.gov.in/sites/default/files/Annual_Report_21022019.pdf

[21].Swachh Bharat Abhiyan | Prime Minister of India (October, 2014) Retrieved from https://www.pmindia.gov.in/en/major_initiatives/swachh-bharat-abhiyan/