Blockchain-based E-waste Management in 5G Smart Communities

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***Abstract*—With our increasing reliance on technology, the amount of e-waste generated after their life cycle ends is increasing at an exponential rate. Going by this rate, we'll have an equivalent amount of carbon footprint as the transportation industry, only by the smartphone segment by 2035. We can imagine the total carbon footprint if we extend this to all the other numerous electronic gadgets we use. With the increasing volume of e-waste, the chances of these toxic non-biodegradable elements polluting the environment are astronomical. This problem is being addressed by various nations and laws to regulate the waste have been passed in recent years. The Indian Government has placed E-Waste (Management and Handling) Rules in 2011 which forms a part of the Environment Protection Act to ensure coherent disposal of e-waste. However, a rather large percentage of e-waste in India is still not regulated and it runs vastly by unorganized sectors. We provide a solution to the above problem by proposing an efficient e-waste management technique by using blockchain in the 5G scenario. Our solution keeps track of the e-waste generated and we provide an incentive-based system where users are encouraged to channelize their e-waste through government regulated agencies which efficiently dispose of them in an environment-friendly manner. We propose a public-private partnership (PPP) model for implementing this, which can generate thousands of jobs by organizing this unregulated sector with huge underlying potential.**

***Index Terms*—5G, blockchain, distributed ledger, e-waste, smart contract**

I. Introduction

People adapting to a more tech-heavy lifestyle, and the rapid growth of electronics market with improved and affordable products have led to the problem of e-waste management. Any discarded/non-functional household/business commodity, with electrical circuit components, driven by direct power or battery supplies, forms e-waste and the process of getting rid of e-waste products in a way that environment is not harmed is called e-waste management which is becoming more and more critical with each passing year [1]. Electronic products that usually get thrown in the bins could have been repaired or re-used as long as they are in working condition, thus increasing the amount of generated e-waste. As these electronic products continue to pile up, they start constituting a significant portion of the landfills [2]. They are more prone to leaking toxic chemicals or substances that cause various environmental hazards like the polluting of water supplies, the air and the ground itself. To get an idea of its impact we can take a look at a statistics which states: All the countries of the world together produced 44.7 Mt (Million metric tons) of electronic waste in the year 2016. Hence it is being predicted that by the year 2021 this figure will rise up to 52.2 Mt [3].

India is regarded as one of the rapidly growing industry of electronic products in the world. Hence it contributes a huge amount of produced e-waste towards the total e-waste generated by Asia. Also the fact that many developed countries in order to solve their own problem of e-waste illegally export them to developing countries, like India, aggravating the e-waste problem of this country. The untrained and uneducated workers engaged in separating and disassembling of the waste Electrical and Electronic Equipments (EEEs) [1] are lured by the probability of finding some precious metals in such electronic wastes and end up adversely affecting their health by following poor techniques during this improper recycling process [4], [5]. The E-waste management (EWM) should involve the following steps:-

1) Gathering of e-waste products from the consumers.
2) Classifying them into non-reusable and reusable items:
    a) The ones which are reusable can be kept for re-selling.
    b) The remaining ones which are non-reusable can be disassembled and its parts can be shredded and separated multiple times to be treated as
        - Reusable recycled products.
        - Discarded off in a safe manner only after adequate treatment of its harmful constituents.

The situation is hence quite alarming and it is high time to take some understandable and justifiable actions to solve this problem by enforcing management to follow the above mentioned EWM process strictly [2]. There has been much effort by well-meaning people and organizations to combat this growing and dangerous problem but various issues have sprung up in order to do that [6]. These systems lack in the following parameters:

- Transparency of collection and channelization of e-waste, preventing stakeholders in adopting illegal ways to justify their collection targets and prevent their operating license from getting revoked.
- Authenticity of the owner by providing proper documents of ownership.
- Accountability on the part of owners that they actually deposited the e-waste as they claim.

- Tamper-proof record keeping to properly indicate the amount of actual e-waste produced and what part of it reached the e-waste centre.
- Incentives, which leads to consumers giving away their electronic waste products to rag pickers for a small amount of money towards returning them back to the e-waste centres.
- Prevention of the leakage of e-waste into unorganized sectors, by asking the entities involved in the system to deposit e-waste only at e-waste centres which are authorized by the government.

Most viable solution to this problem is the introduction of blockchain into the e-waste management system.

A portion of information, called a block, gets a digital signature assigned to it which is unique to it. Each new piece of information that follows is another block, which has its own signature. These connected blocks form a chain of information called the blockchain.

To make it nearly impossible to corrupt, each new block stores the signature of the previous block [7]. This blockchain system is also decentralized, which makes the editing and auditing belong not only to one person or a controlling organization but it to the users in the network, similar to a peer-to-peer control system. [8] How blockchain solves the above mentioned problems?

1) Blockchain is capable of recording and securing every stage of e-waste management, from the point a manufacturer produces an electronic product to the point when it reaches to an e-waste centre. It thus eventually boils down to accountability-where everyone has to pitch in and be accountable as a whole.
2) No discrepancy of actual ownership of the product when it is brought to an e-waste centre. This is because all information about any electronic product is stored in the blockchain including all the transfers stating how the product travelled from the hands of the manufacturer to the current owner/customer via some supplier, retailer or another customer (second hand product purchase
3) Vital information such as the amount of electronic items produced, the amount of e-waste generated and part of it which got collected, and the stakeholders involved are all saved in blockchain which promotes accountability.
4) Bringing consumers, stakeholders and government agencies on the same blockchain platform will eventually lead to improvement in supervision and transparency in the entire e-waste management process due to the inherent immutable and decentralized nature of blockchain.
5) Penalizing the appropriate party whenever targets of e-waste collections are not met.
6) Providing incentives to stakeholders of the system when they properly channelize their e-waste to the formal sectors and penalizing them when they try to derail the system will eventually reduce the supremacy of the unorganized sector [3].

II. Literature Review

Supply Chain Management is perceived as one of the most important and beneficial use cases in Blockchain technology, as it is the epitome for firms and industries in which goods are taken through several stages, from producer/manufacturer to consumer. IBM and Walmart collaborated with each other to initiate BFSA(Blockchain Food Safety Alliance) in China. This project was undertaken to enhance food tracking and safety. China has proved to be an excellent place to execute any tests related to Blockchain technology since that is where the world's first blockchain commodity based on agriculture is housed. Several projects have made use of this powerful distributed ledger technology specifically in this particular domain, making use of it along with maritime logistics firms in order to enforce the concept of transparency into the inevitable bureaucracy present in International Trades. Being one of the largest Global shippers, Maersk first made use of blockchain. [9]

Specifically for the agricultural food domain, an idea has been presented by the authors of the article [9] which introduces inventory transparency using IoT devices. The aim was to discover the use of NFC and RFID based devices to attain real-time information about the products with complete transparency by setting up a centralized cloud database, directly in the area. However, the use of IoT and Blockchain technologies in the agricultural food domain is yet to be explored and it is worth exploring this field. The authors have also presented, a supply chain tracking system for safety of food, based on Hazard Analysis and Critical Control Points (HACCP in short). It included description about various phases of different crops like retailing and harvesting but did not show any in-depth analysis of the performance. Raw materials cannot be obtained, modified and delivered to the consumer or final user without Logistics. In Logistics Optimization and Management, Blockchain proves to be one of the most promising technologies available [3], [9].

The problems related to global waste management are numerous - Excessive generation of wastes, landfill issue, toxicity waste, increasing amount of plastic, waste mismanagement etc. [10]–[17]Managing resources in an efficient manner and minimizing wastage is not an easy task. The current recycling management system is prone to cheating.

Technologies which power cryptocurrencies like Bitcoin are slowly making its way into waste management. Swacchcoin is a special blockchain-driven trial at managing wastes from households and firms and efficiently transforming them into products of high economic value. The Decentralized Autonomous Organization(DAO) aims to create a completely sustainable, neat community evolution across the world and at the same time enhancing the economic conditions of all individuals associated formally with the firm in some capacity including the domestic households. The company employs various customized tools and technologies like SWATA(Big Data), SWIOT(Internet of Things), SWAPP(Decentralized App), Blockchain etc [18].

The Plastic Bank app is a fast and safe way to exchange plastic waste for currency. It's blockchain verified system eliminated the need for cash transactions and empowers the world's poor to support their families. People can interact with the app and find a shop near them. Digital coupons incentivize the collection of low-value plastics and provide rewards such as school tuition or products from the coupon sponsor. This project is still in process. The country also needs to tackle its domestic(generated within the country) and imported (dumped into the country) e-waste. There has not been much noticeable amount of work done in the area of e-waste management [4].

III. The Proposed Solution

In this paper we suggest an incentive based model by which proper tracking of the electronic product's disposal can be done using blockchain to reduce the carbon footprint produced by these e-wastes. Our model shown in fig. 1 comprises of five entities which form an integral part of the e-waste management system. We have taken into consideration the real life scenario for any electronic product life cycle.

A. System Model

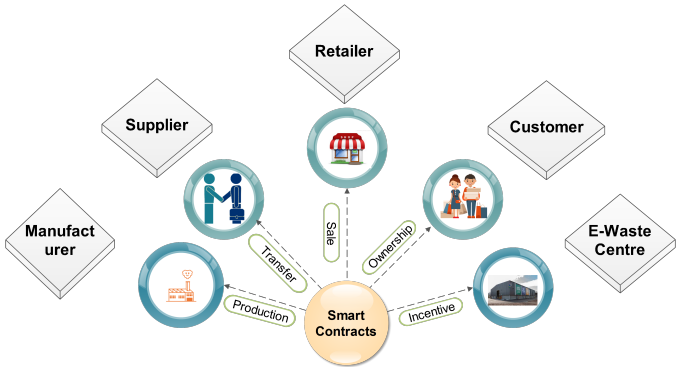

Fig. 1. Interaction among all entities and role of smart contract

The product is manufactured and the product details are added by the manufacturer into blockchain network. The supplier buys the products from the manufacturer and the transfer in ownership is also logged. From the suppliers various retailers carry forward the sales to the customers. The customers might also plan to resale the product in second hand market. All these are inserted into the blockchain network for efficient tracking. Now after usage of the products the customer disposes it to the e-waste centers. Smart contracts are deployed in the e-waste module where some incentive in the form of ether is transferred to the accounts of all those involved with that product in a predefined ratio. This marks the end of the product's life cycle.

Our objective is to make it exciting for all the customers, retailers and manufacturers to complete the cycle from creating the product to ensuring that it is disposed properly. We propose a cess or tax to be imposed by the government on the initial product which will be used for giving the incentive later on. Also at the time of transfer of ownership of the products the entities will have a small token amount locked through the smart contract. When the product reaches the e-waste center, the locked amount will be distributed along with a surplus incentive amount to all the stakeholders involvedwith that particular product. However, even if after the end of the life cycle of a product, it doesn't reach the e-waste center, the token money will be forfeited. So this gives the participating entities motivation to make sure the product reaches e-waste center after its usage.

From a commercial point of view, a public-private partnership can be forged to execute this plan of action. This will generate numerous jobs and unify this huge unorganized sector. The e-waste center efficiently recycles or disposes off the items in an environment friendly manner.

Entity	Description
Manufacturer	The electronic products are created here. Contains all information regarding the products. Products are connected to ethereum blockchain.
Supplier	Works as an intermediary between the manufacturer and retailers. Transfer from manufacturer to supplier is logged in blockchain.
Retailer	The units from where customer buys the electronic products. The transactions from these points of sales (POS) are added in blockchain.
Customer	Change in ownership of the product from retailer to customer or customer to customer in case of resale is added to blockchain.
E-waste center	Government Agency regulating the e-waste production. When customer disposes e-waste, incentive is calculated accordingly and given to the participating entities.

Fig. 2. Entities in our proposed E-waste Management System

B. Implementation

In order to implement this E-waste management system we have used the following technologies:

- Remix : It is a browser-based compiler and integrated development environment (IDE) that facilitates one to build Ethereum smart contracts with the help of Solidity programming language. It also allows debugging of transactions initiated by calling of the functions present in the smart contract after it's deployment.
- Ganache : It is used to create a personal/private Ethereum blockchain where the smart contracts can be deployed.
- VS Code (Visual Studio Code): is a code editor used to develop the front-end of the dApp (decentralized application) to interact with the deployed smart contract.
- MetaMask: is a browser extension that allows running dApps by connecting it to the private Ethereum blockchain network created using ganache. It manages the Ethereum wallet of the user, which contains ethers, and allows the transfer and acceptance of ethers through the dApp of interest.

Our decentralized application is built using VS Code and is linked to a smart contract written in remix IDE and

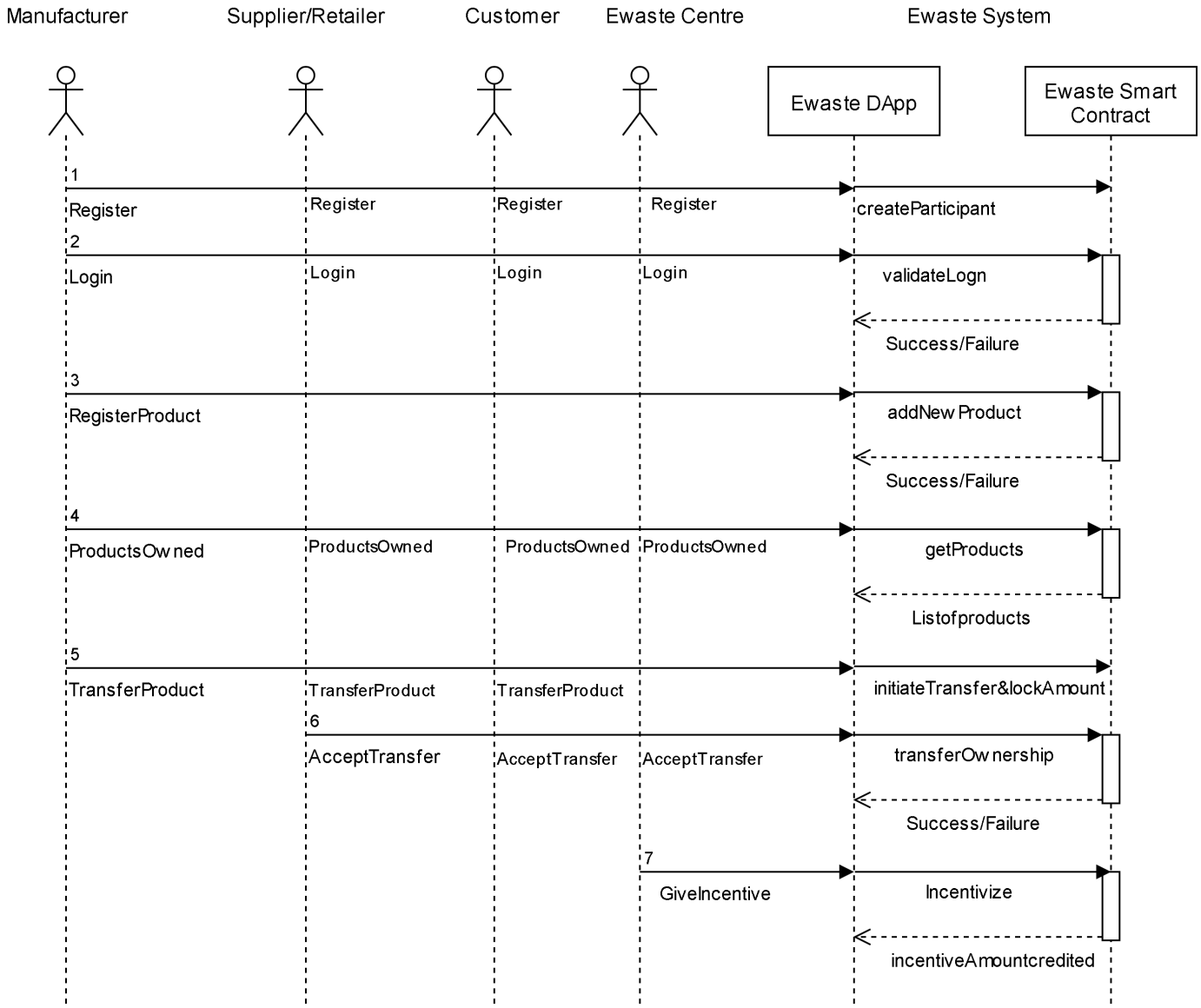

Fig. 3. Sequence diagram of our proposed system

deployed on a private blockchain created using Ganache. Users are created and assigned addresses linked with their metamask wallets. Next in this section, we will be presenting the implementation details of how the various participants of this e-waste management system (as discussed in the system model section) can interact. We are maintaining 3 prime data structure.

1) Participants: Contains the details like the user name, password, type of user (Manufacturer, Supplier, Retailer, Customer, e-waste Centre) of each participant of the system. This structure is indexed by the user's Ethereum wallet address.
2) Products: Contains the details about each product (name, price, specifications, type, manufacturing date, manufacturer name, expiry date) added by all the manufacturers indexed by a unique product id.
3) Track: Contains the details of each transfer taking place in this system. The details include previous owner name, new owner name, and type of transfer (Manufacturer to Supplier / Supplier to Retailer / Retailer to Customer / Customer to Customer / Customer to e-waste centre) and the time of transfer. This is indexed by a unique track id.

The different processes that a user can execute on the dApp of Ewaste management system are as follows:

- Registration : Each of the entities who wish to be a part of this system needs to register itself on this dapp website. This process internally involves calling of the createParticipant function of the e-waste smart contract with the required details (username, password, user type)

as filled by them on the registration form and also the user's metamask wallet address. On successful execution of which a new entry gets created into the participants data structure with these data.

- Login : After a successful registration when the user tries to login to this dapp website the validatelogin function of smart contract gets called which checks the authenticity of the user based on its wallet address from metamask and user name and password as supplied by them in the login form.
- Register Product : Only the entity with user type as Manufacturer has access to this feature by the help of which new products can be introduced in this system. It internally calls the addnewproduct function of smart contract with all the required details filled in the add new product form provided on the page. On successful execution, a new record gets created in the products data structure with the specified details.
- Products Owned : Each user after successfully logging in to the system can get a list of products currently owned by them.
- Transfer Product : The logged in user can initiate the transfer of a product currently owned by them to another user of the e-waste system. This is done by invoking the initiateTransfer and lockAmount function of contract with the user's wallet address, wallet address of the recipient and time of transfer and product id. In this a certain amount of ethers gets deducted from the initiator's wallet and gets deposited into the contract which comes back to the initiator's wallet only after the corresponding product reaches the e-waste centre at the end of product lifecycle. It also triggers an event to notify the recipient entity of this initiated transfer.
- Accept Transfer Request: When a user (having the recipient wallet address as mentioned by some other user in their initiate transfer function) logs in to the system gets a notification of transfers pending for him to accept. On accepting a request the transferOwnership function of smart contract gets called and on successful execution of which an entry into the track data structure gets created with the details of this transfer.
- Give Incentive: This is invoked by the e-waste centre only after a product arrives at their centre. It is used to give away incentives to the entire chain of entities involved in the process of transferring the product from the manufacturer to it. Internally an incentivize function of smart contract gets invoked which transfers the adequate amount of ether to the wallets linked to accounts of all those entities. It also returns the ethers of all the entities that had got locked in the contract when they had initiated a transfer of that corresponding product.

There is a special user called the admin who is the owner of the smart contract that is the person who deployed it. The admin can view all the current products present in the system and also track their transfers starting from the manufacturer to their current owners. He can also keep track of the products whose expiry dates are crossed but still have not reached the e-waste centre and can also notify it's the current owner about the product's status.

Figure 3 represents the sequence diagram of the various users of this e-waste management system and how they interact with the smart contract via the dapp linked to it. It also depicts the various functions each type of user can invoke and what form of responses they get in return.

IV. Evaluation and Discussion

We will discuss the critical aspects for our domain i.e. integrity, availability, immutability, economics, feasibility and security.

A. Security

In order to assess web security, web services security, and the security of DISV system's central server, OWASP a non-profit organization was employed whose task is to offer unbiased and realistic information on security of applications to the developers and security professionals. It mainly focuses on crucial vulnerabilities of the web applications. Their analysis of vulnerabilities detected ten most frequent attacks which are depicted in the figure[Fig 4] with the method to combat the attacks. These requirements are integrated into the proposed system. However attackers are finding new methods everyday to exploit the vulnerabilities of the web apps and hence preventing them entirely is not possible, but minimizing the potential damage or system hacking can be done. The technology and architecture of the Ethereum with regards to the smart contract have some vulnerabilities. Attacks on the Ethereum blockchain [19]–[21] are mainly related to the external calls but some other attacks are also present which targets particular functions to employ a loop in the smart contract. Our proposed solution is considered to be highly secure as it is using a private Blockchain.

V. Conclusion and Future Work

We have presented a robust, transparent and secure solution to manage the e-waste problem. Through the use of blockchain and smart contracts we automate the process of tracking a product till it reaches the e-waste center and then distribute the incentive among the entities participating in the chain. The novelty of this solution lies in the visualization of the big picture. By incorporating a public-private partnership model between the government and private players, we can have a whole new sector replacing the currently unorganized one comprising of unhygienic disposal methods by rag-pickers and kabbadiwalas(people who collect scrap materials). At the current rate of electronic goods production, this can turn out to be a multi-billion dollar industry in a few years. The incentive driven model will encourage more and more entities ranging from manufacturers to retailers and customers to participate in this system. As a result numerous jobs will be created. We can also segregate the e-waste further to select the items which can be reusable and we can have a resale market for

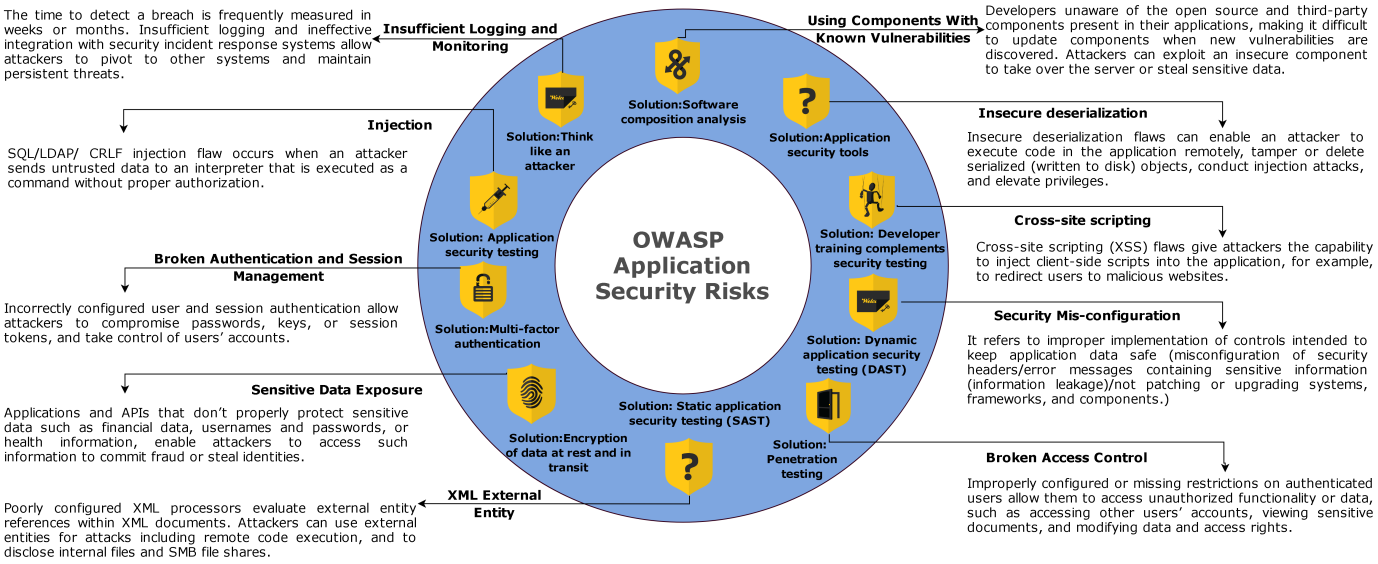

Fig. 4. Top ten OWASP Web Application Security Vulnerabilities

such reusable products. So, the environment will be saved from contamination by e-wastes, people will be earning incentives from this system, a resale market can be established and also numerous jobs will be rolled out creating a win-win scenario for every stakeholder involved.

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