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# A Prototype of Supply Chain Traceability using Solana as blockchain and IoT

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## Abstract

The main objective of this article is to present a prototype that integrates blockchain and Internet-of-Things (IoT) devices to digitize information across a generic Supply Chain (SC). Blockchain bring many benefits to the operation of improving provenance and reliability, such as, digitizing the interaction among SC actors to allow implementation of smart contracts to support a secure and authenticated chain. In technical terms, blockchain is a decentralized database where information recording is secure and blockchain-based traceability in the SC can address shortcomings that exist in centralized solutions. Provenance could be achieved by implementing SC business logic within smart contracts using blockchains. This article presents an architecture of software that combines blockchain with IoT devices that allows traceability of a generic product from source to destination, through multi-echelon suppliers, logistics, manufacturers to the end-customer. The presented software architecture uses the Solana blockchain for the implementation of SC processes and business logic. This blockchain was selected from a review, reported in this article, of several widely used blockchain networks. It was selected mainly due to its speed and cost of transactions. Within the blockchain we store SC related data and events communicated over the internet and mobile application channels, in a Solana blockchain using Solana's native blockchain libraries. The IoT devices used are Sigfox cloud gateway, and Sensit that uses LPWAN (Low power wide area network) wireless telecommunication for data transfer. In our IoT device, the blockchain stores temperature, humidity, light, location, tilting, door opening, vibration, and magnetic field. The goal is to use existing technologies to develop a software architecture for a medium term objective of an implementable generic blockchain for SCs.

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**Keywords:** Blockchain; Supply Chain; Traceability; IoT; Solana; Sigfox ,LPWAN

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## 1. Introduction

Blockchain is a distributed ledger technology that uses decentralization storage with peer-to-peer transactions. In other words, no solo authority has control over a complete system. Satoshi Nakamoto was the first person to bring forward the idea of digital currency as an application of blockchain [1]. Blockchain, through various improvements, has potential to bring secure, traceability and transparency in many areas. The way blockchain works is that every transaction is turned into a hash; the hash is dependent not only on current transaction but also on previous hashes [2]. Once a transaction has been verified by miners, it is added to the blockchain chronological order. Each block is linked to the previous one and together they make a blockchain. Data within a blockchain is stored on multiple computers called nodes. What makes blockchain secure is that the data is stored on multiple computers, therefore, a major security breach would require data corruption on a multitude of computers [3]. Since all hashes are linked and inspected by nodes, a hacker would have to change all those hashes for an invalid data entry to be made in the blockchain [4].

Blockchains can be public where anyone can send a transaction or private where permission is needed for adding transactions. Open vs. Closed Blockchain exists in which open allows full public access to retrieve transactions. A closed blockchain allows participants with permission to retrieve transactions. [5]. Supply chain participants consist of manufacturers, suppliers, storers, logistics providers, processors, etc., each of them has terms and conditions among participants. Using blockchain smart contracts we can implement supply chain rules [6]. A smart supply chain by using smart contracts can facilitate multiple parties by requiring their digital signatures for agreement or shipment to be sent after manufacturer receives an order from supplier, or regulatory authority needs to provide compliance for components of product [7].

A smart contract is just another software program that constitutes a set of conditions and is executed automatically once those conditions are met. (Such as transferring funds or ownership and executing terms of contract etc.). Smart contracts can be written using blockchain code, such as, Solidity, Rust, Yul, Vyper, or DAML (Defense against money laundering) [8]. Another benefit of smart contracts is decreasing risk, and cost, removing intermediaries on one side, and increasing accuracy, speed, and real-time updates in business process on the other side. They are self-executing, self-enforcing, and governed by business logic among parties [9].

In our paper, section 2 provides context by briefly describing the history of blockchain. Section 3 describes how blockchain can be used in smart contracts and how they can make centralized and legacy supply chain a smart one and IoT devices. Section 4 explains the fundamental requirements for blockchain network selection like transactional fee, data transfer rate, data security, availability to write smart contracts, and software development kits provided by different blockchain networks with emphasis on the Solana blockchain. Section 5 describes the prototype blockchain software architecture for traceability in SC that uses the Sigfox platform for IoT that allows interaction between the IoT device, cloud and blockchain. Section 6 presents the prototype software developed, detailing the implementation of the web application, dashboards for different actors, technical design, libraries used to integrate with the Solana blockchain. Section 7 describes other industries that the prototype software could provide benefit from this blockchain implementation, for example, pharmaceutical industry that lacks traceability of the product and data and commercial airlines who need auditable and trackable parts.

## 2. Evolution of Blockchain

Blockchain has noticed rapid progression in the previous decade. With the advent of Blockchain 2.0 and Blockchain 3.0, the former associated with smart properties and smart contracts specifically for use in crypto currencies such as Ethereum, NEO and QTUM, and the latter introduced for use in non-financial sectors [10]. Today blockchain applications exist in a variety of fields: from healthcare to agriculture to food. It is not surprising, considering the nature of blockchain that it has found much popularity in the SC sector and many other industries, where with increasing globalization and trade, more and more parties are now involved within a transaction. Blockchain integration with smart contracts, cloud, and IoT devices can make smart automated interfaces removing the need for intermediaries or any other forms of third parties. Smart contracts, which use contractual clauses to perform certain actions depending on the fulfillment of those clauses, vastly expand the applications that blockchain can perform. The SC industry in specific could see a major shift due to this type of technology because of the automation,

communication, transparency, and accountability it is able to provide, all key components on making sure a SC process is resilient, efficient and in compliance with customers' requirements along with being auditable.

To this end, Everledger, a digital transparency company, has employed blockchain to give to clients and customers the entire history of the high-end luxury goods they order to ensure authenticity [11]. While it holds great potential to disrupt traditional business models, like all developing technologies blockchain is subjected to its fair share of drawbacks and is still far from being the convention. Scalability, high cost, integration and maintenance difficulties, and security concerns are some of the limitations of this technology. Furthermore, while it has noticed a boom in attention these past few years, there is still limited amount of research and understanding of this technology. This holds especially true in terms of real-life applications and applications within different industries where the true potential of blockchain has yet to be established.

### 3. Smart Supply Chain

The definition of a smart environment is “A physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in everyday objects of our lives, and connected through a continuous network” [12]. In the context of a smart SC, this refers to a SC where each member of the process such as the retailer, producer, and distribution centers can interact and communicate with all in-store and in-transit products to form a complete self-sustaining holistic system. An SC becomes “smart” when all parts of the process can exchange data with one another and make decisions based on it. A smart contract consists of value, address, functions, and state. A transaction is taken as input, the relevant comparisons are made and accordingly the code is executed to produce a certain output. Blockchain compliment smart contracts in a SC industry is where blockchain nodes complete the task of verifying and validating the conditions as well as allowing for this to take place in a secure open environment [13].

Modern SCs have become much more complicated than they previously were; this is because of the increase in the number of parties involved due to the advent of globalization, cross-border trade, outsourcing, etc. Complexities such as legal challenges, regulatory issues, quotas, etc., have increased the difficulty of SC management causing inefficient decision making, multiple third parties, erroneous communication, and lack of trust. A smart SC using blockchain and IoT devices can severely mitigate if not completely resolve many of the issues that modern SC faces. A blockchain network provides a central trustless medium of communication that is immutable and thus can be kept safe from any sort of illicit tampering or manipulation. In conjunction with IoT devices such as asset tracking sensors, RFID tags, etc., it can track and manage an innumerable number of connected devices in a safe, secure, encrypted manner. By creating a decentralized system that ensures easy access to up-to-date information, a smart SC promotes informed efficient decision making, can lower transport times, interconnectedness, real-time tracking, and provide overall lower costs [14]. This is not only for the benefit of the involved parties but also to the benefit of end consumers. Customers can track a product's origins and with advanced IoT devices even the conditions they were stored in. Smart infrastructure with real-time collaboration can reduce order delays, handle re-order or cancel order requests, and perform more accurate, faster stock control that ensures that goods that deteriorate over time reach their destinations in better quality [2].

Though this does entail considerable investment, such a system opens a plethora of new avenues. From eliminating third parties such as banks by using blockchain for payment processes to the use of different decentralized applications, smart supply chains have already begun being used and are assuredly a need of the future.

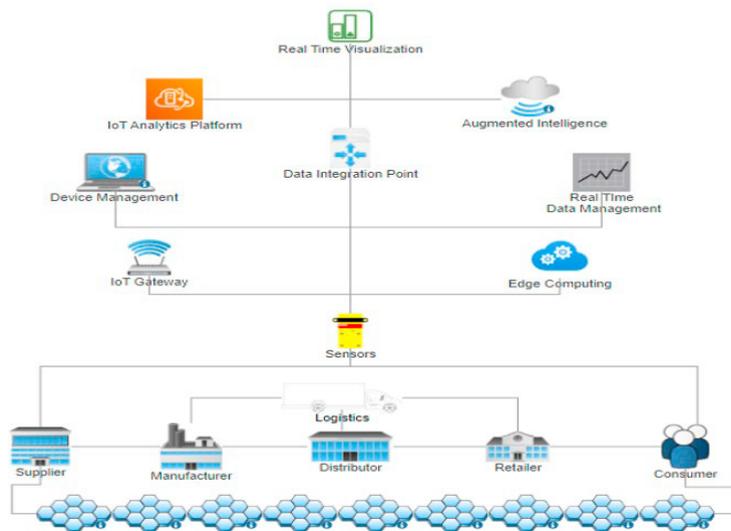


Fig. 1. High level design for smart supply chain [30]

Fig 1 illustrates in general terms the use of a smart SC. IoT sensors are sending information from a device to an IoT gateway and then to the cloud. This information/signal is two ways and can be used to move logistic vehicles. In this way we can add intelligence within a SC of products, e.g., if our package is carrying a box of cell phones and all data about that package is being shared in real time then we could re-route the logistics vehicle carrying the box of cell phones if it has not been sold to a particular retailer. We could also increase and decrease production of cell phones based on its demand. As we are persisting data to a ledger, we could provide this information to insurance companies and regulatory agencies in case that data is required. In this way insurance premiums could be reduced because less counterfeit claims are being sent to insure and more visibility and traceability is available to insurance providers. Sharing this information with government agencies will help in getting faster regulatory documents to logistics providers, therefore, easing the SC of goods movement across borders. Fig 1 further explains the advantages of blockchain integration within a SC. It provides authenticity of ownership because of no modifiable behavior of transactions or data stored within a ledger. It also provides non-mutable asset tracking since we have saved every movement, temperature, location etc. of a package from IoT sensors into a ledger, therefore, enhanced, real time and unified information making it accessible to all participants within the chain. We are also able to track authenticated and verifiable origin of products since all information in it's inception has been stored and has been left unaltered. As all participants are sending and receiving information from shared storage in this case to a blockchain, therefore, integration of financial transactions is easier. Suppliers will get paid faster as well as manufacturers and the rest of the participants within the chain.

Below are some benefits of using blockchain within SCs:

- SC audit and compliance which allows history of items through the entire supply chain journey.
- SC within import and export of goods.
- SC provenance and traceability.

- Integrated financial transactions among participants



Fig. 2. Benefits of Blockchain in Supply Chain

These benefits which are also listed in Fig 2 are further analysed within the context provided by the proposed product traceability application describe in this article.

#### 4. Requirements for selection of Blockchain Network

In this part of the paper, we go through multiple blockchain networks and their specific features. This will allow us to decide which blockchain could best fit our prototype for traceability. Mainly we are looking to select a blockchain network that holds the below characteristics:

- Transactional fees depend on transaction size or data saved onto the blockchain, speed with which we want a transaction to be processed. should be cost-effective in terms of gas (unit that measures how much computational power your transaction needs to register on a blockchain network) used to save data on to blockchain [15]. We could reduce transaction fee by sending smaller transactions at lower processing priority.
- Data extraction from blockchain network is faster (high transactions per second). In case we want to provide real-time data sent to the SC web application.
- Permissioned public blockchain where access to the network data and transactions is allowed by the SC.
- A blockchain that provides the ability to write smart contracts for the implementation of automation in transactions based on events.
- Provides security of data being sent from IoT devices to blockchain network as this data contains sensitive information, therefore security is required.
- A blockchain network that provides Development SDK or API to be used by the proposed prototype application .

Table 1 shows some of the common features of different blockchain networks. The implementation of blockchain within business are growing, and Forrester predicts that 30% of software projects globally will include blockchain in 2021 [16]. Below table has been generated based on my reading from several papers. From this brief description of a review of blockchains the Solana blockchain was chosen.

##### 4.1. Solana

Solana blockchain was founded in 2017 by Intel, Qualcomm and Dropbox engineers. It has theoretical speed of nearly 65,000 transactions per second which is 10,000 times faster than bitcoin, 4000 times faster than Ethereum, and 2.5 times faster than the Visa network [17]. It has transactions or events which are evaluated and will be given a unique hash and a count that can be publicly verified. This has proof of history (PoH) consensus with timestamp proving an event occurred at specific time which is an optimized version of Practical Byzantine Fault Tolerance [18]. Solana has a transaction processing unit for validation optimization. Pipelining is a process where a stream of input data assigns to different hardware components responsible for it. Solana is both a crypto currency and a DApps platform [19].

This mechanism allows transaction information to be quickly validated and replicated across all nodes in the network. Solana uses Delegated Proof of Stake (DPoS) in which a ‘validator’ is selected based on who owns large stake randomly every time after 4 blocks is created. This validator will be rewarded with a SOL (Solana crypto currency). On the other hand, the validators’ tokens could also be “slashed” or removed due to poor performance such as malicious voting. All events and transactions in Solana are hashed with SHA256. This combination of delegated

Table 1. Features of Blockchain networks

	Application	Smart Contract Execution	Smart Contract Language	Data Model	Consensus	Main Improvement Over Bitcoin	Network Permission	Special Hardware Requirement
<b>Hyperledger</b>	Smart contract	Docker	Golang, Java	Account-based	PBFT	Business Blockchain Network	Permissioned	No
<b>Ethereum</b>	Smart contract,	EVM	Solidity, Serpent, LLL	Account-based	Ethash (POW)	Automatic Digital Asset Management	Permission-less or Permissioned	No
<b>IoTeX</b>	Smart contract	EVM	Solidity	Account-based	Ten dermint BF	Roll-DPoS consensus	Permission-less	Yes
<b>Helium</b>	Cryptocurrency	-	Solidity	UTXO-based	HoneyBadgerBFT	Low-Latency Transaction	Permission-less	No
<b>Solana</b>	Cryptocurrency	EVM	Rust, C, C++ solana-web3.js	Account-based	Proof of Stack based on Tower Consensus	High Transaction speed	Permission-less	No
<b>Avalanche</b>	Smart contract	Haskell Execution	Pact/Solidity	Account-based	Scalable BFT	Heterogeneous interoperable network	Permission-less or Permissioned	No
<b>Stellar</b>	Smart contract	Dockers	-	Account-based	Stellar Consensus Protocol	Low transaction fees	Permissionless	No
<b>EOS</b>	Smart contract	EVM	Solidity, Serpent, LLL	Account-based	Blockchain Nervous System	Processing efficiency	Permissioned	No
<b>Multichain</b>	NFT is out of box	-	-	-	PoW/Mining Diversity	Private/Permissioned Blockchain Network	Private Permissioned	No
<b>Quorum</b>	Smart contract	EVM	Solidity, Serpent,	Account-based	Proof of Authority	Privacy/Security	Permissioned	-
<b>Tezos</b>	Smart contract, Cryptocurrency	Dockers	Tezos Contract Script	Account-based	Proof of Stake	On-Chain Governance	Permissioned	No
<b>Tron</b>	Smart contract, Cryptocurrency	JVM	Solidity	Account-based	Delegated Proof of Stake	High Transaction speed	Permissioned	-
<b>Corda</b>	Smart contract	JVM	Kotlin, Java	UTXO based	The transaction is accepted by contracts by signature	Privacy/Security	Permissioned	No

<b>Bitcoin</b>	Cryptocurrency	-	Bitcoin Script –	UTXO based	Proof of Work	Addition of Transaction Privacy - Taproot	Public	Yes
<b>VeChain</b>	Smart Contract and Cryptocurrency	JVM	Solidity	UTXO based	Proof of Authority	Contracts/Onchain governance/ multilanguage	Public	No
<b>Sawtooth</b>	Smart contract	TEE	Python	UTXO based	Proof of Elapsed, Time	Multilanguage support	Permissionless or Permissioned	Yes

leader validation and Proof of History provides faster transactions ~59k Transactions per Second whereas EOS (another blockchain network) is 3900 Transaction Per Second and Ethereum is ~17 Transactions Per Second. Discussing about the volume of Transactions per day is ~66Million for Solana which is far beyond 2.4M for EOS and 1.2M for Ethereum [20]. The Solana blockchain was used in the 145K project as compared to Ethereum which was used for 24K only [21]. This uses Cloud-break, a horizontally scaled database which allows concurrent read and writes. It archives for data storage. Data on Solana offloads from validators to a network of nodes known as Archivers. These blockchain nodes can be lightweight (e.g., laptops) and they will be subject to a check, every so often, to ensure they are storing the correct data [16].

### 5. Solution for Package Traceability using Blockchain and IoT

This section provides details of blockchain based solution for traceability of packages containing a parcel/produce/package etc. The solution will use an IoT sensor attached to the package which will send signals to Sigfox Gateway. This data is being sent using UNB (ultra-narrow band) having bandwidth of 100 bps (Bits Per Second) and 600 bps [22]. Our web application will send and receive data to the Sigfox cloud gateway using JSON API.

Fig 3 provides a high-level architecture of the proposed prototype software for package traceability from source to end user. It explains how many different components are used in our solution and communication of data. Our web server will have libraries for communication to local SQL database, and communication to Gateway API. The application also uses Sensit libraries to communicate with the Solana blockchain. We are also using a Web hook to get live status of Sensit and save that data in our database. We then are able to perform analytics on our device data which help keep track of packages while in transit. Our device is called Sensit which sends signal using Radio protocol and uses Ultra Narrow Band. LPWAN is t popular low-cost, long-range radio communications with long battery life, which it was found is a suitable IoT data communications interface [23].

Fig 4 below provides technical details on a Sigfox message from a device named Sens’it V3 which uses 12 bytes uplink and 8 bytes downlink. Byte 0 is mainly about the battery level of the IoT device, Byte 1 provides the mode which has been selected (0: Standby, 1: Temperature & Humidity, 2: Light, 3: Door, 4: Vibration, 5: Magnet) and most significant bits of Temperature, Byte 2 provides less significant bits of Temperature. Byte 3 provides humidity as shown below.

### 6. Web Application

Web application shown in Fig. 5 will pull data from Sigfox Gateway using Restful API (Application Programming Interface) over HTTP (Hyper Text Transfer Protocol) and extract relevant information about a package. Web application then displays configured data to its dashboard used by manufacturer, supplier, logistics provider, and retailer. We provide a dashboard with permissioned access control for each participant within the SC, e.g. supplier can only see information about logistics provider not retailer. At this stage web application will save a subset of data

(received from sensor and participants of supply chain) onto the Solana blockchain using Solnet SDK and Web3.js. Only data that can be used for traceability of the package are saved on the blockchain from a sensor.

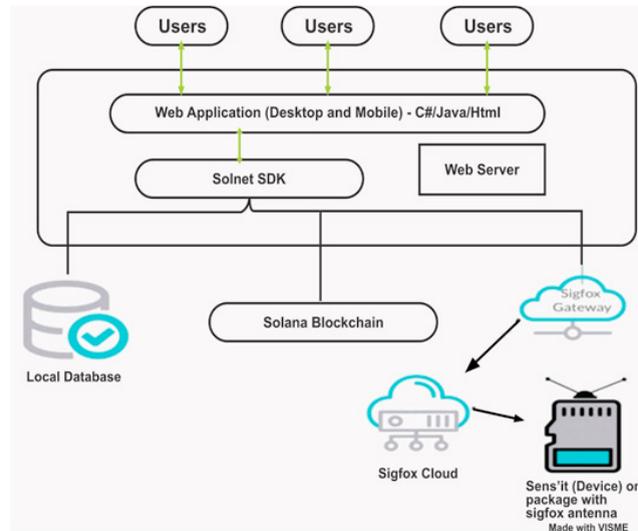


Fig. 3. High level system overview

	b7	b6	b5	b4	b3	b2	b1	b0
	0 = Standby Mode						Spare (0b00)	
	1 = Temperature Mode						Temperature MSB	
	2 = Light Mode						Spare (0b00)	
	3 = Door Mode						Button Alert Flag	Door Status
	4 = Vibration Mode							Vibration Status
	5 = Magnet Mode							Magnet Status

Fig. 4. Data structure of messages from Sigfox sensor [23]

Fig 6 below describes the high level architecture for a prototype solution with multiple software tiers starting from user interface which could be mobile or web based. We used Solnet SDK which provides a native programming interface for the Solana blockchain. We have created a wallet using Bip39 library within Solent for generating mnemonics codes for a wallet (which in turn creates mnemonic sentence) [1].

We then create all accounts for each entity e.g., supplier etc. within same wallet. The same wallet is used for one end to end traceability session of a SC from origin to destination. A transaction builder within Solent SDK is used to publish data on to Solana with programs to implement smart contract logic also used. Solnet RPC is being used to maintain a connection pipeline to the Solana blockchain. We are also using Solent serum to hold and maintain orders with most required features. In our Web Application we connect using the RESTful service to the Sigfox gateway to gather IoT data. Using an ID generation service, an artifact tracking services is used with many of the core services provided by Solana.

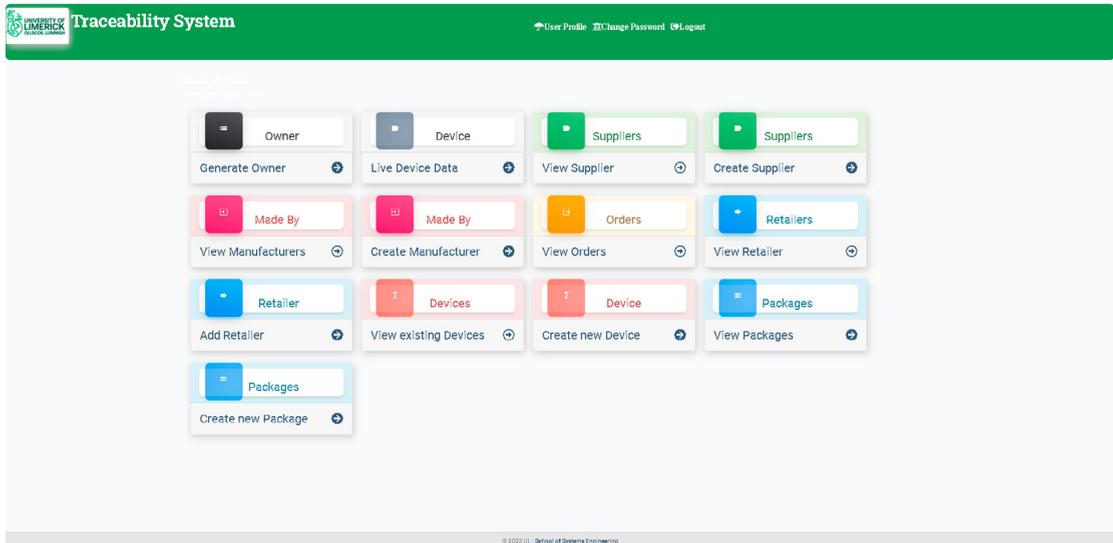


Fig. 5. Main Dashboard of Web Application

A multi-channel web application which is also accessible from mobile browsers developed in C#.NET Core will communicate with the Sigfox Gateway to fetch sensor data and send a subset of data using transactions on to the Solana blockchain using Solnet SDK which uses Web3 Libraries. In Fig 6 below a Serum module is used which is a protocol used for Distributed Finance [24]. This is helpful for making automated payments to each entity of within a SC. Another library we have used is Mango markets which provide a marketplace [25].

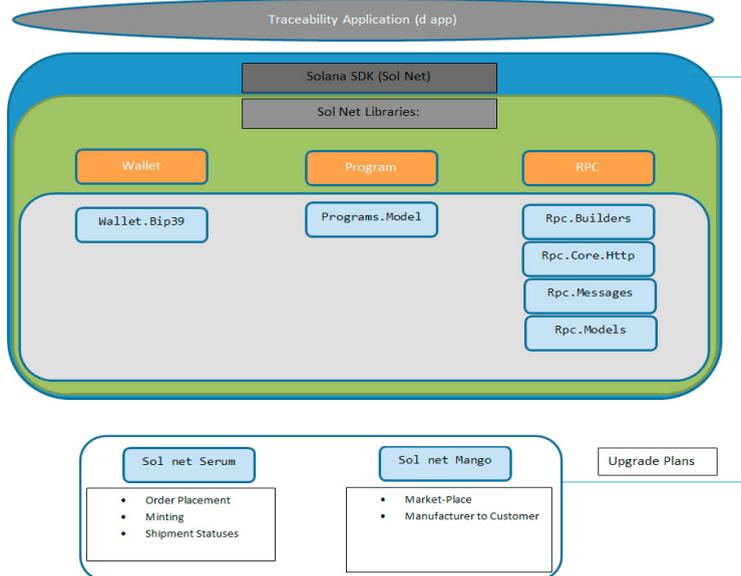


Fig. 6. Application architecture of Solana with Web Application

### 7. Non supply chain Industries using blockchain

In this part of the paper, we discuss how several industries would benefit from use of blockchain and what problems could be solved within each industry. Currently, the pharmaceutical industry suffers with problems of counterfeited drugs, lack of standardized quality and distribution of drugs without permission and authorization of drug manufacturers. A traceability application implemented with blockchain could be used to implement provenance.

Swiss based start-up Modem developed a blockchain based system for monitoring the temperature of drugs using QR sensors and smart contracts and saved data of drugs shipment from sources to consumers using an Ethereum blockchain. The manufacturer initiates temperature measurement using an Android phone and details of the package journey is saved on to Ethereum ledger which could be seen by scanning a QR code [6]. Manufacturing of parts for automobile supply chain named Part Chain was developed to ensure traceability of vehicle parts from different parts of world. This traceability is achieved by using permissioned Hyper ledger fabric blockchain and user interface is provided on a mobile app. This information is used by Federal Motor Authority of Germany to view end to end traceability of parts manufactured to reduce recalls. This mobile application has multiple steps which are: i) create order, ii) create delivery, iii) pick up delivery, iv) accept order and v) scan part for location [8].

Commercial airlines need auditable, quality assured, traceable and regulated spare parts for the maintenance of jets. Spare parts which are fitted within planes during maintenance and upgrades could be counterfeit, non-traceable to its original vendor which causes a higher threat to the performance of a plane. It also becomes hard for airlines to claim insurance for damage of reputation because of poor maintenance and to compensate non operative costs. Blockchain based solutions for track and trace of airline parts could provide reliable traceability, originality, auditable, quality assured, and compliance of spare parts used to service airplanes. Such a solution has been implemented by SITA technology company and Honeywell a reseller of spare parts [26]. Another solution was implemented by LG CNG IT services provider and Jeju Air, a Korean based budgeted airline aiming to provide traceability of parts fitted during maintenance of its planes along with maintenance of history for audit and compliance purposes [27]. US air force and Navy partnered with SIMBA chain for providing traceability of parts using blockchain [4]. Anomus is decentralized new protocol which provides blockchain based protocol for fair reporting, publishing and preserving legitimate news. It also provided intellectual property rights and digital ownership for publishers [9]. This provides an ANOM token to publishers, auditors of news authenticity and readers with engagement for publication [28]. It uses parmaweb which is collection of webpages and stays permanently on web .

Blockchain could be used within environmental and renewables industry which could help regulatory authorities to implement environmental laws. The European Community Directive Waste Electrical and Electronic Equipment (WEEE) directive consists of closed-loop supply chains, and reverse logistics implications along with product stewardship and return policies for electronics and providing history of products along with its source and components used within it. Blockchain would be a solution which could provide traceability, audit and quality assured components which would be traceable for regulatory authorities e.g., European Community Directive Waste Electrical and Electronic Equipment (WEEE) and stockholders [29].

## 8. Conclusion

In conclusion, while blockchain is evolving at a nearly exponential rate, it is a long way from when blockchain within SCs would be an industry standard. In this era of increasing globalization and communication, with many of the monetary and otherwise transactions being held online, blockchain technology is more relevant than ever. Its ability to integrate and work with other technologies especially within the SC sector where it can provide a multitude of benefits such as transparency, provenance, etc., allows for a great extent of versatility and adaptability. As a result, many leading companies involved in multi-national work in which it is important to determine the authenticity of goods have begun adopting it in their systems. The emergence of existing decentralized applications such as Origintrail and Devoluem as well as a few different systems of blockchain and IoT in SC are a testament to the increase of popularity; however, lack of research papers geared towards practical applications and architectures restrain it from reaching its true potential. This paper discusses extensively the characteristics of different blockchain networks as well as the features of the latest asset tracking technologies for use in traceability in SC. A wide range of options are available with focus on different speeds, ranges, and accuracy, without profound research, a blockchain network to fulfil any specific use cases' requirements could be implemented in blockchain can be found. This paper provides architecture for a traceability software system that provides real time information about packages such as the temperature, light, humidity etc., using a Sigfox sensor, a LPWAN network, using the Solana blockchain. A prototype was developed to demonstrate traceability using blockchain along with usage of available SDKs (software development kit) to communicate with blockchain network. Industries such as airline, environment, manufacturing, renewable, and the pharmaceutical, could benefit from adoption of a “smart” supply chain. Our prototype has only been integrated with Solana blockchain, however there are SC systems which may need to integrate with other

blockchain networks e.g., Ethereum, Stellar, Ripple, VeChain etc. We also have limitation of our system for connectivity with IoT is with Sigfox only where as other IoT networks LoRaWAN which provide a higher data rate. In future we are looking to enhance features of this prototype by providing a generic library which will allow integration with other blockchain networks and on IoT connectivity with LoRaWAN will be beneficial.

## 9. Acknowledgements

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