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Electric Vehicles Battery Management Network Using IoT Blockchain

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Abstract

Electric Vehicles (EVs) have generated a lot of interest in recent years, due to the advances in battery life and low pollution. Similarly, the expansion of Internet of Things (IoT) allowed more devices to be interconnected. One major problem electric vehicles face today is the limited range of the battery and the limited number of charging or battery swapping stations. A solution is to not only build the necessary infrastructure, but also to be able to correctly estimate the remaining power, using an efficient battery management system (BMS). For some EVs, battery swapping can also be an option, either at registered stations, or even directly from other EV drivers. Thus, a network of EV information is required, so that a successful battery charge or swap can be made available for drivers. In this paper, a blockchain implementation for an EV BMS is presented, using the IOTA tangle as the network and data layer of the application.

Keywords: Blockchain, IOTA, Electric Vehicles, Energy Trading, Battery Management System

1. Introduction

Blockchain is a novel technology, which was first introduced in 2008 as the underlying network architecture for the cryp- tocurrency Bitcoin [1]. The technology created an environment for secure, anonymous transactions, using a decentralized network of devices [2]. The main goal of the architecture was to create trust between the participants without the regulation of central authority [1].

The Internet of Things (IoT) revolution has changed the way we use and interact with everyday items, from smartphones, tablets or smart homes and cities. One of the best use scenario for IoT devices is in the automotive field, where electrical ve- hicles (EVs) and, more recently, autonomous vehicles, became available on a large scale. With the recent advances in battery technology [3], [4], the autonomy of EVs has increased to well over 300km and it will probably continue to increase over the next few years. One problem that EV drivers face is the availability of charging stations. While the number of stations will increase over time, there is still the problem of charging time and battery life. Many pilot projects exist for implementing inductive charging on designated road sections, such as parking areas, traffic light stops or airport road segments for electric buses [5], [6]. Until the technology becomes mainstream, EV drivers will still depend on fixed charging points. One solution for this problem could be a decentralized network for battery charging or swapping, where users or charging stations can trade energy or batteries.

To implement a network of charging and swapping stations, which could allow even regular users to provide some of these services, some vital information is necessary, such as the type of batteries used in electric vehicles, the possibility of swapping these batteries, the state of the battery (charge cycles, health, remaining capacity, etc.) and the location of the stations and their availability of charging and swapping services. Battery swapping my not be available for all kinds of vehicles, such as cars or buses, but for smaller EVs, such as mopeds and scooters, it is already available in select models. For this system to function efficiently, a method of machine-to-machine (M2M) communication needs to exist. Using IoT, such a system can be implemented, by monitoring the battery parameters while driving and warn the user when a charge is necessary.

Blockchain is an ideal approach for building a network of interconnected EVs, where energy trading (battery charging or swapping) is the main goal, because it can be used as a method of ownership management, especially for the battery swapping scenario, as well as provide the payment methods for the services of the charging stations.

Blockchain technology has found many applications, out- side the financial world. For example, in [7], a review of existing and potential blockchain applications in the healthcare system is presented, while in [8], a decentralized electricity transaction model for microgrids is presented. The authors defined a continuous double auction mechanism directly be- tween the buyer and the seller, while continuously adjusting the energy price according to market changes.

In [9], a survey for the use of blockchain and IoT technolo- gies in the industrial sector is described, providing solutions for supply chain management, autonomous vehicles and man- ufacturing plant asset management. In [2], a blockchain data provider is presented, using IOTA to integrate IoT devices to create a decentralized data provider. To support blockchain integration for legacy IoT devices, a blockchain connected gateway for Bluetooth low energy devices is presented in [10].

This paper presents a blockchain application for electric vehicles (EVs) battery charging and swapping using the IOTApublic tangle. The performance of the system is analyzed and the advantages and disadvantages are highlighted. The application is tested using lithium-polymer (LiPo) batteries driving DC motors in an environment similar to that of an EV. The battery voltage and state of charge (SOC) is permanently monitored and the data is stored on the blockchain, together with the required functionalities, such as user and battery information and charge/swap requests.

2. Background

2.1. Blockchain and distributed ledgers

Since the introduction of blockchain in 2008, blockchain and cryptocurrencies have become mainstream terms. The technology proposes a network similar to that of a distributed ledger (DLT). Specifically, it implements a peer-to-peer (P2P)network of distributed data sets shared over multiple locations, where every change in the ledger is reflected in all copies on the network [11]. This means that, once a change is submitted by one of the participants, it must be validated and approved by the entire network before it is added to the ledger. To achieve this, a consensus mechanism is required, so that the information, once accepted, can't be altered by any user or group of users. Different implementations of the blockchain technology provide different methods of consensus, but, in most cases, consensus is achieved by means of cryptographic functions.

The first blockchain application was presented in [1], where the cryptocurrency Bitcoin was introduced, with the goal to replace the trust, provided by a 3rd party, with proof. The term *blockchain* suggests that the network consists of a series (or *chain*) of *blocks*, linked together by means of a cryptographic hash function (Figure 1).

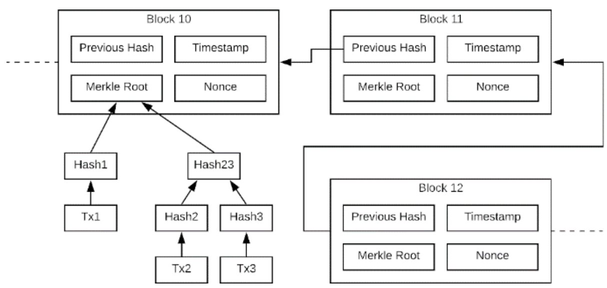


Figure.1. Typical blockchain structure [1], [2]

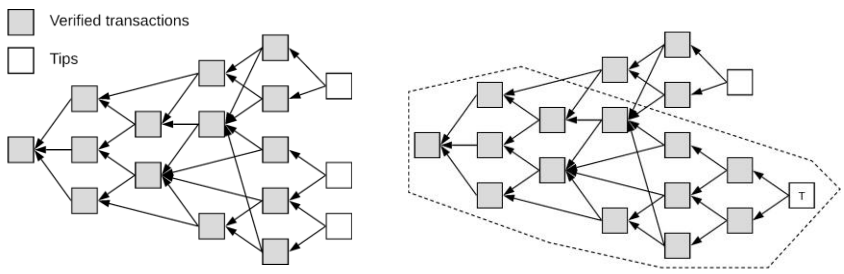
Each block can have multiple transactions (Tx1, Tx2, . . .). When a new block is created, the corresponding transactions are stored as a Merkle tree (or hash tree), where each leaf (data) node is labeled with its cryptographic hash and each non-leaf node is labeled with the hash of the labels of its children [12]. Each new block includes the reference to the previous block hash. The network participants (or miners) willgenerate the corresponding hash of the new block, with the restrictions imposed by the consensus algorithm (difficulty of the hash function). The miners can inject a nonce in order to find a resulting hash which respects the network specifications.Once this hash is created, the new block is added to the chain and the other users must validate and approve the block,by verifying the generated hash. Once the block has beenconfirmed by the network, it can no longer be changed, asany change on the block (or any of the previous blocks)will invalidate the computed hash and will be rejected by thenetwork. In this way, data immutability is achieved, which isone of the main advantages of blockchain technologies becauseit ensures that no single entity can have control over the data.On public blockchains, especially in the cryptocurrency applications, incentives are provided for network participantsas rewards for discovering new blocks (generating the block'shash function). The user (miner) which submits the valid blockis rewarded, using a token specific for each platform. Thesetokens can be used in further transactions on the blockchain oreven be exchanged for fiat currency. This method of submittingand verification of new blocks (consensus) is called Proof of Work (POW).

In 2014, the Ethereum platform was launched, introduc- ing *smart contracts* to the blockchain [13]. The term smart contract was first introduced in [14] as a set of promises, defined in digital form, including the protocols within which the parties will perform them. This novel concept allows blocks of code to be stored and executed on the blockchain. Once the contract is deployed, its code can't be altered, thus ensuring that the initial conditions will always be respectedfor any future executions. Just like real world contracts, a smart contract on the blockchain is created between two partiesand is executed once some triggering event is set, such asa deadline, or a specific target value is reached. In [15], the architecture and applications of blockchain smart contracts aredescribed.

2.2. IOTA Tangle

Since the blockchain consists of a series of blocks, linked together by means of their cryptographic hash, when the number of transactions increases, the difficulty of the hash function also increases, which means that the creation of new blocks will require longer times and greater processing power [16]. This is currently one of the main drawbacks of public blockchain networks. The so-called mining opera- tion is a required mechanism to achieve consensus between all participating nodes. To overcome the resource intensive protocols which are implemented by most platforms, various other consensus methods have been proposed. In [17], a comprehensive study of available and proposed consensus methods is presented. Regardless of the consensus mechanism employed, the scalability of the blockchain will still remain a problem, due to the linear fashion in which the data is stored. For data-driven systems, which require a large number of datapoints, such as IoT applications, this limitation may becomean issue. To overcome this, a novel approach was introduced by the IOTA foundation [18].

The IOTA network was specifically designed with IoT applications in mind, proposing a different method of organizing the transaction data, by using a directed acyclic graph (DAG) instead of a linear blockchain. The IOTA DAG is often referred to as the tangle (Figure 2a). Its main characteristic is that it allows zero-fee and zero-value transactions [18]. The mathematical model of the DAG is described in [18], [19].



(a) The tangle (b) Transaction validation path

Figure.2. IOTA structure [2], [18]

IOTA uses a balanced trinary representation of data, asopposed to the usual binary system. In balanced trinary, data can have the following states: 0, 1 or (trits). Similar to how 8 bits form a byte, in IOTA 27 3 trits for a trite IOTA uses special trinary hashing functions for data encoding and POW, which are described in [18].

In the usual blockchain implementation, the users have to perform the POW continuously, until a hash is successfully found. This is a power intensive operation which discourages new users from competing in the mining phase. In IOTA, each new transaction (tip) is attached to two previous transactions, which it must validate by performing the necessary POW. In this manner, POW is only necessary when a node wants to create a new transaction on the network, thus validating two previous transactions. This means that the node which actually initiates the transaction is the one which computes the POW hash. This allows the elimination of network fees, since it is in the interest of the initiating node for its transaction to be completed, so the network fee is replaced by the ”on-demand” POW computation. Since a new transaction validates two previous transactions, the scaling problem can be successfully solved, because more transactions on the network result in more validated transactions.

Once a new transaction is attached to the tangle, it also confirms all the previous transactions referenced by the two former tips to which it was attached. This creates a validation path (Figure 2b), which increases the trust for all the transactions inside this path. The IOTA network employs a Markov chain Monte Carlo (MCMC) method of choosing the tips to which the new transaction is attached [18].

3. Implementation

The proposed implementation uses the IOTA public network, since the platforms requires no transaction fees. This reduces the setup times and costs of the application. One big disadvantage is that IOTA does not (yet) support smart contracts, so the application logic has to handled by a master node, resulting in semi-decentralized system, where the master node has to perform extra operations to extract and filter the data from the tangle.

To implement the required functionality, the IOTA transaction structure is used (Table I), by routing the different types of transactions to their specific actions in the application. The flow of the application is described in figure 3.

To route the transaction to specific actions, the **tag** field isused, similar to a function call. Based on this, the applicationwill filter the data and assign it to the appropriate structures. For example, the newUser operation has the structuredescribed in Figure 4.

The tag field specifies the action of the transaction. Since theapplication is running on the public development network, anyuser can create a transaction with this tag. However, since all transactions are still handled by the master node as the sender,the application will only filter its own transactions from the tangle.
Since the IOTA implementation uses only raw transac- tions, their structure for the other operations are similar to the one presented in Figure 4. Each operation has a cor- responding tag field: IOTABMSNEWUSER for the new user transactions, IOTABMSNEWBATTERY for

the new battery operation, IOTABMSNEWDATA for battery data information and IOTABMSNEWREQUEST and IOT ABMS ACCEPT REQUEST for the request operations. Because the IOTA implementation uses the public devnet tangle, these tags can be used to examine the transaction details at https://devnet.thetangle.org. For this implementation, a battery test bed was developed, using a Raspberry Pi as the processing unit. The same functionality could be achieved directly by the on-board computer of the EV, or as an add-on for existing vehicles. The test bed monitors the voltage and SOC of the batteries, at the rate of 30 samples/minute. The data is stored directly on the tangle, using the Raspberry Pi which will handle the creation of the transactions, using the Proposed Transaction class from the PyOTA Python library:

```
tx = ProposedTransaction (
    address=Address ( IOTAAddress ) ,value=0 ,
    tag=Tag ( b 'IOTABMSDATA' ) ,
    message=
      TryteString . from  string ( IOTAJSONData )
)
```

where IOTAAddress is the address of the master node and IOTAJSONData is a JSON object containing the mea- surement information, similar to the Decoded message field inFigure 4. The ProposedTransaction object is a transac- tion which was created locally and hasn't yet been submitted to the network. To actually broadcast the transaction, the send_transferfunction is used:

```
IOTAApi . send  transfer (depth =3 ,
    transfers =[ tx ] ,
    min  weight  magnitude =  14 ,inputs=BatteryAddress
)
```

where Battery Address is the address of the registered battery (acting as the sender of the message), depth is the

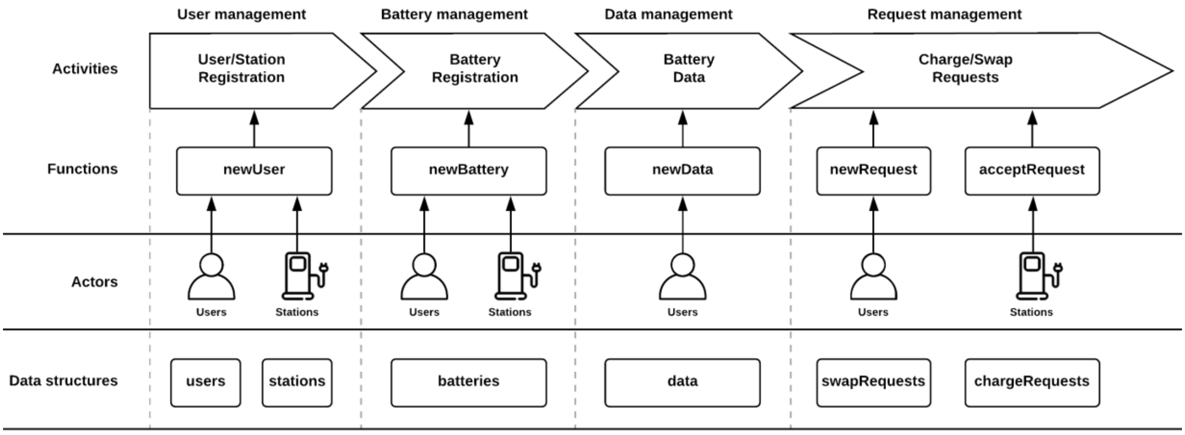


Figure.3. Application structure

Table.1. IOTA transaction anatomy [18]

Field	Description	Length (trytes)
address	Sender's or recipient's address, depending if the transaction withdraws or receives tokens	81
Signature Message Fragment	A signature if the transaction withdraws tokens or a tryte-encoded message otherwise. This can be split across multiple transactions	2187
value	The amount of tokens transferred	27
tag	User-defined tag	27
timestamp	Unix timestamp (seconds since Jan. 01 1970) of when the transaction was issued. In IOTA, the timestamp is not currently enforced and can be arbitrary	9
bundle	The hash of the bundle of the transaction	81
Current Index	Index of the current transaction in the bundle	9
Last Index	Index of the last transaction in the bundle	9
Trunk Transaction	Hash of a parent transaction	81
Branch Transaction	Hash of a parent transaction	81
Attachment Timestamp	Unix timestamp of when the POW was completed	9
nonce	The POW field of the transaction	27

maximum depth in the tangle for the tip selection mechanism and min_weight_magnitude is an optional parameter used to specify the POW difficulty. Note that the transfers parameter contains a list of transactions (in this case onlyone) since there is no value transferred between the two addresses. When transferring IOTA tokens (value), at leasttwo transactions are required, one which adds tokens to the recipient and one which subtracts the same amount from the sender.

Ideally, the POW should be performed locally, but the Raspberry Pi does not have the necessary resources to computethe POW, so the transaction is handled by the master nodeof the system, which computes the validation hashes for two selected tips. If the master node is not reachable, thetransaction data is stored locally and resubmitted when the connection can be established.

The biggest challenge and limitation of this implementationis the battery swapping operation. Since the swap requestis not sent to a particular station, the station which acceptsthe request has to do so by creating a new transaction. This new transaction has to somehow reference the swap request submitted by the user. Two solutions can be outlined for this problem: either reference the swap request transaction hash in the message field of the transaction, together with the rest of the information, or override IOTA's tip selection mechanism and attach the accept Request transaction directly to the related request transaction using the trunk Transaction or branch Transaction fields (Table I). For this implementation, the first method was preferred.

4. Results

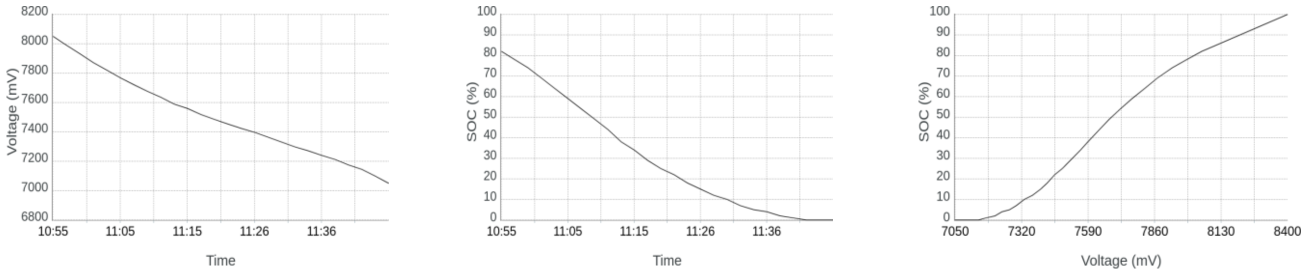
Figures 5 and 6 show the voltage and state of charge plots for a 2-cell and 3-cell LiPo battery, respectively. The same method can be applied for any type of EV battery.

The transaction times were also measured for a set of 500 transactions submitting new battery data (Figure 7). It can be seen that the transaction times range between 3.78 and 104.14 seconds, with an average of 17.86 seconds. In the proposed implementation, the IOTA POW is not done locally, due to the limited resources of the Raspberry Pi board. Instead, the required operations are performed by a public node outside the application infrastructure (in this case, the IOTA devnet node). Depending on the load of the node and the network congestion, the expected transaction recording time can vary, but the benefit is an easier setup and fewer resources necessary for the master and station nodes of the battery management application.

Transaction hash	AMCSQBBEUNDBITQMW9ZYDXA9H9YBMO9QQZMAQARQGFF WUZX9HOUYHFIENRBAUTQ9IZZ9ZSWBMULFZ9999
From	UHLEMW9QSZBRM9QVQGICTIMKWQNWDPQLYPHCMMHR9JDDYJ XHGAOVLJR LEWACCLJTXFOJLJAAJLXVRUDIW
To	SMVIZBPLNBFOALXONUIREQZZWN9HTLVJQVEDUDVNGMLYP9SQ DOLMMWC 9WXRKXFJZMLQZU9TMRSWJCDZKD
Bundle	STODQIOYCBKLUQWWHARYLQUEKLFDZNNSVASDQSHCHEXW ZEG9ZKCH9LJKV9YTHJZDTUJDGSESUHUQYYDA9
Index in bundle	0/0
Trunk transaction	Y9YHCOTRWEMFREDJ9HWRWSKONSUGADUCSXZDDMJLVD9IJ YDWSNCG9PNPWTCEWWTOXHKKBWYVDUIOXM999
Branch transaction	Y9YHCOTRWEMFREDJ9HWRWSKONSUGADUCSXZDDMJLVD9IJ YDWSNCG9PNPWTCEWWTOXHKKBWYVDUIOXM999
Tag	**IOTABMSNEWUSER**9999999999999
Message	ODGAPCSCSCFDTCGDGDGADBGABCWBECSBICLBZBVBXBLBPBY BKBVBGCY BXBDCSBACOB9CICICFCXBCBRBCCVBECTB9CECOBNBDCNBE CXBQBWBVBH CZBCBBC9CNBYBVBWBWBFCMBCBFCGCACUBGCPBTBICWBV B9CICDCCBCC WBACBCFCTBMBNBICUBNBGAQAGAHDMDDDTCGADBGAUA GAQAGAQCP C9DPCBDRCTCGADBZAUAQAGAHDXCADTCGDHDPCADDDGA DBGAVAZAZ ABBYAYAWAXAWACBVAYAWAGAQD

Decoded message	{
	"address": "SMVIZBPLNB. . . MRSWJCDZKD",
	"type": "0",
	"balance": 50,
	"timestamp": "1558442329142"
	}

Figure.4. New user transaction



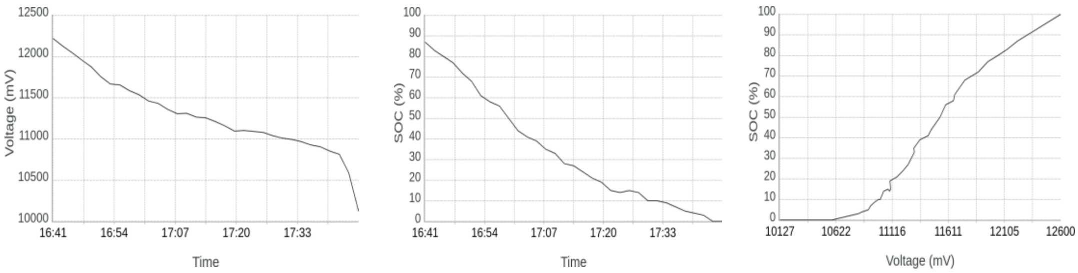
(a) Voltage vs. Time (b) SOC vs. Time (c) SOC vs. Voltage

Figure.5. Results for 2-cell battery

In this paper, a complete battery management system for electric vehicles is presented, using blockchain technologyto create a semi-decentralized network of electric vehiclesand charging stations, which are able to share data (battery information), based on continuous monitoring.

Blockchain is a relatively young technology, which has seenmajor growth and adoption in the last 10 years, with the development of cryptocurrencies. The underlying architecture makes it a strong candidate for data-driven applications, such as electric and autonomous vehicles.

IOTA was considered for this implementation because of itszero-fee transaction model and its scalability, which allows theapplication to run on the main tangle with minimal additional setup. The lack of smart contracts is the main disadvantage of this approach, because the application logic has to be main- tained by one or more central nodes, and it is more susceptible to failures, while possible changes of the application mayaffect its overall functionality on the network. These problems could be resolved when smart contracts become available in IOTA (which were already announced as of 2019), butthe implementation may provide additional difficulties which cannot yet be estimated.



(a) Voltage vs. Time (b) SOC vs. Time (c) SOC vs. Voltage

Figure.6. Results for 3-cell battery

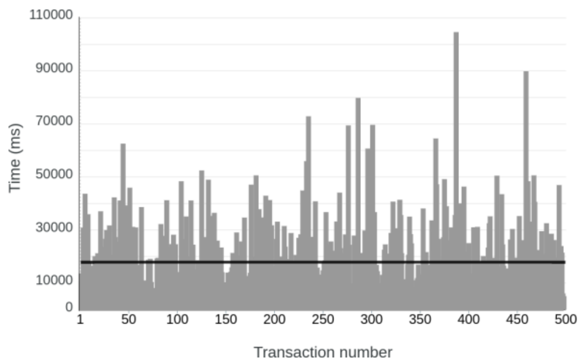


Figure.7. Transaction times

Using a blockchain system, the ownership of the batteries can be verified, while at the same time providing anonymity, each user being identified only by their address. Having the battery information on the blockchain can help users findcompatible charging stations or batteries.

The results show that the IOTA platform can be used for developing blockchain IoT applications, having acceptable transaction confirmation times for the purpose of the proposed battery monitoring system, which does not require real-time confirmations. In future works, other blockchain solutions, such as Ethereum and Hyperledger Fabric, will be analyzed and implemented, and the scope of the application will be extended to other uses of the blockchain network.

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