A Decentralized Application for Logistics: Using Blockchain in Real-World Applications

Panayiotis Christodoulou,[1] **Klitos Christodoulou,**[2] **Andreas Andreou**[3]

Abstract

A prototypical smart contract (wrapped as a decentralized application) is presented for investigating the potential benefits for applying Blockchain for Logistics. The decentralized application proposed exposes the various design challenges that programmers are likely to face when realizing the implementation of the application. The proposed methodology utilises the implementation of a dedicated smart contract that was developed based on a special-purpose structure for satisfying the requirements of the use-case. The evaluation was based on the execution of each of the functions measuring the gas costs and execution time. The prototype design was deployed and evaluated on a real-world Blockchain framework and can be considered as a first solution to how the Blockchain technology can be utilized within Logistics to overcome any barriers that may exist between professionals. In this paper we present a real implementation of a smart contract for the Logistics industry. The proposed dApp provides a live example of how Blockchain can be utilized within Logistics as it enables users to send and track products.

Keywords: decentralized applications, blockchain, smart contracts, decentralized logistics

Introduction

A transformation shift is inevitable, considering Cyprus' vision to invest in the digital era. In reality, the technological advances and digitalisation facilities are now an internal part of our daily activities and processes, becoming a part of our society gradually, and constantly influencing the economy, industry, education, and science. Considering the fast growing international competition fostered by the complexity of the manufacturing industry, increasing market volatility, and more efficient product life cycles, Industry 4.0 (namely the Fourth Industrial Revolution) is transforming and digitising the future of many business processes.[4] Under the Industry 4.0 vision,

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1 Panayiotis Christodoulou is a Postdoctoral Researcher at the Software Engineering and Intelligent Information Systems Research Lab, Cyprus University of Technology.

2 Klitos Christodoulou is a Faculty member at the Institute For the Future and the Department of Management and MIS - Digital Currency, University of Nicosia.

3 Andreas S. Andreou is a Professor at the Department of Electrical Engineering, Computer Engineering and Informatics of the Cyprus University of Technology..

4 D. Spath, O. Ganschar, S. Gerlach, M. Hämmerle, T. Krause, and S. Schlund, *Produktionsarbeit der*

emerging and disruptive technologies, such as IoT (Internet of Things), Distributed Ledger Technologies (including blockchains), and cyber-physical systems (CPS) opened up a range of potentials and opportunities. Taking into account the increase in the presence of shipping and logistics companies in Cyprus,[5] the emerging blockchain technology can be used to leverage Cyprus' position to become an exemplar to the supply-chain and logistics industry in the region of digital technologies and other related services.

Transparency is one of the major characteristics of blockchains, where actors are given access to a single point of truth, assessing the same data publicly, without the need for any intermediaries. In supply chain and logistics, transparency is a major challenge due to the various networks of actors involved, often in several key locations with concealed products. This poses a challenge to monitoring the transportation and provenance processes at various levels.[6] The lack of transparency often raises questions on matters such as the lack of provenance information, environmental footprint, and trust, while the information is stored in private silos and cannot be obtained. Blockhains can provide an alternative solution while at the same time removing intermediaries and providing self-verifiable data for shipment tracking. For example, a blockchain-enabled system can be used to record data (e.g., location, timestamp) from IoT devices that are attached to various products as they move through a supply chain or even as they move from production to a consumer. Such data are exposed publicly and can be used for self-verification and as proof-of-delivery, especially for shipment containers. As a result, shipment delays are expected to be minimized since it would be easier to predict what times products would be delivered.[7]

Firstly introduced in 2008, blockchain is considered to be one of the top technological advances of the 21st century.[8] Blockchain is a distributed and immutable public ledger, which enables people to perform transactions in a secure but transparent way over a peer-to-peer (p2p) network.[9] As the network grows, more transactions are recorded on the ledger, forming a chain of blocks, namely blockchain. Each block consists of a series of transactions and each new block generated is linked with the

Zukunft-Industrie 4.0 (Stuttgart: Fraunhofer Verlag, 2013).

5 Cyprus Profile, 'Steering into Growth', *Cyprusprofile.com* (2018, September), available at https://www.cyprusprofile.com/en/sectors/maritime-and-shipping/.

6 J. Baker and J. Steiner, 'Provenance blockchain: the solution for transparency in product', *Provenance.org* (2015, November 21), availabe at https://www.provenance.org/whitepaper..

7 D. Miller, 'Blockchain and the internet of things in the industrial sector'. *IT Professional,* Vol. 20, No. 3 (2018).

8 M. Swan, *Blockchain: Blueprint for a new economy*, (Sebastopol, CA: O'Reilly Media, 2015).

9 A. Brandstadt, V. B. Le and J. Spinrad, *Graph Classes: A Survey* (Philadelphia: Society for Industrial and Applied Mathematics, 1999).

previous block so that every transaction executed can be traced.

Bitcoin, the world's first cryptocurrency, is considered to be the first blockchain application ever made. There were many attempts in the past to develop a digital currency, but all of them failed as they could not solve the double spending problem without the requirement of a trusted third party.[10] Bitcoin was the first application that managed to deal with this problem using a p2p network: once a transaction is confirmed it is impossible to double spend it. Nowadays, there are hundreds of blockchain frameworks that used and evolved the Bitcoin concept. One of them is the Ethereum blockchain, which was introduced in 2015.[11] Ethereum was the first blockchain framework that allowed users to deploy smart contracts, enabling the execution of programmable code on the blockchain. On Ethereum, every transaction that changes the state of a smart contract costs a small fee, known as the *gas*. In brief, gas represents the unit of measurement for the computational tasks that are required on a specific smart contract, and it is the unit that sustains the Ethereum ecosystem, since this fee is rewarded to the nodes that support the network (aka the *miners*). This new dimension provided the opportunity for developers to design and implement the so-called decentralized applications (dApps) for any purpose.[12]

This article presents a dApp for the logistics industry implemented on the Ethereum network. According to Badzar,[13] the reduction of transaction costs, the easier execution of transactions, the exclusion of a central authority, the open access to information regarding the company's activities, and the ability to evaluate the product or supplier before deciding are just some of the factors that illustrate the potential benefits of blockchain as an advance within logistics. The proposed dApp provides a live example of how blockchain can be utilized within logistics as it allows users to send products and track them until they reach a delivery location. A unique element of the proposal is that any item can be traced during its whole life cycle; once a product is no longer in use and it is disposed, it can still be traced until it is recycled or it decomposes. All transactions are recorded on the blockchain and are publicly

10 S. Nakamoto, 'Bitcoin: A peer-to-peer electronic cash system', *Bitcoin.org.* (2008), available at http://bitcoin.org/bitcoin.pdf.

11 V. Buterin, 'A next-generation smart contract and decentralized application platform'. white paper *Ethereum.org* (2014), available at https://www.weusecoins.com/assets/pdf/library/Ethereum_white_paper-a_next_generation_smart_contract_and_decentralized_application_platform-vitalik-buterin.pdf.

12 G. Suryanarayana and R. N. Taylor, 'A survey of trust management and resource discovery technologies in peer-to-peer applications' (Technical report, UC Irvine, 2004).

13 A. Badzar, 'Blockchain for securing sustainable transport contracts and supply chain transparency-an explorative study of blockchain technology in logistics', Master's thesis, Lund University, Department of Service Management and Service Studies (2016), available at http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=8880383&fileOId=8880390.

available for ensuring transparency.

The remainder of this paper is structured as follows. Section 2 provides an overview of the related work with blockchain ecosystems and logistics, while Section 3 outlines important blockchain technological terms needed for our work. Section 4 summarizes the proposed methodology, and Section 5 presents experimental results. Finally, Section 6 concludes the paper.

Blockchain in Logistics

Even though there are various studies that propose designs of a blockchain application for logistics, very few of them are actually implemented, deployed, and tested on the actual blockchain network. Most of the studies present the vision/concept on how blockchain can actually help the logistics industry and its operations, but they lack providing any experimental results or design consideration based on the gas consumption.

Tian[14] first studied the use of radio-frequency identification (RFID) and blockchain technology, and then analyzed the advantages and disadvantages of the proposed approach in building an agrifood supply chain system. The study demonstrates the development process of the proposed system and concludes that any traceable trusted information in the agrifood supply chain would effectively guarantee food safety.

Hacklius and Petersen[15] conducted a web survey in which they asked logistics professionals for their opinion on case studies, obstacles, catalysts, and other general projections of blockchain in logistics and supply chain management. The outcomes of this survey demonstrated that most of the participants are fairly positive about blockchain and are aware of the benefits it can offer. However, factors such as cryptocurrencies and other bad blockchain experiences have a negative impact on the participants' overall evaluation and acceptance. The authors argue that more cases must be further investigated before logistics become more enthusiastic about blockchain.

Badzar's study,[16] which was conducted on a real-world use case, explored the potential application of blockchain in the field of logistics in regard to transparency and transport contract fulfillment. The study aimed to empower consumers, suppliers and manufacturers regarding any information about the product and the activities associated with the supply chain. Findings demonstrate that the deployment of

14 F. Tian, 'An agri-food supply chain traceability system for China based on RFID & blockchain technology', in *13th International Conference on Service Systems and Service Management (ICSSSM)* (2016).

15 N. Hacklius and M. Petersen, 'Blockchain in logistics and supply chain: trick or treat?', in *Proceedings of the Hamburg International Conference of Logistics (HICL)/Digitalization in Supply Chain Management and Logistics Smart and Digital Solutions for an Industry 4.0 Environment,* eds W. Kersten, T. Blecker and C. M. Ringle (Berlin: epubli, 2017).

16 Badzar, 'Blockchain for securing sustainable transport contracts'.

blockchain in logistics can generate more awareness about the supply chain and can contribute in improving service management within companies.

Finally, Francisco and Swanson introduced the Unified Theory of Acceptance and Use of Technology to increase end-users' acceptance of blockchain applications.[17] This theory presents behavioral theory as a means to understand users' adoption of blockchain in the supply chain, and, as a result, they derived conceptual model, which is supported by various scenarios and balanced with supply chain management implications and future suggestions.

According to our findings, blockchain can actually act as an innovation within logistics. The proposed approach, which was deployed and evaluated on a real-world blockchain framework, can provide a template solution for how blockchain can be utilized within logistics to overcome any barriers that may exist among professionals.

Technological Background

Smart Contracts

Smart contracts were introduced by Nick Szabo as self-executing programs that consist of rules which include the terms of agreement between part A and part B.[18] Smart contracts are essentially lines of executable code accompanied by conditions; the latter are checked automatically and, if certain conditions are met, the code is executed and recorded on the blockchain; therein, they exist across a distributed, decentralized blockchain network. But how does a smart contract actually work? The answer is quite simple: each smart contract has its own blockchain address, so any user can call a function on the smart contract by initiating a transaction and passing the function hash code into the contract. Smart contracts allow trusted transactions to take place among various parties without the need for a central authority or a middleman. Smart contracts inherit all capabilities of blockchain, and therefore, all transactions are transparent, secure and traceable.

Decentralized Applications

Decentralized applications run on a peer-to-peer network of computers instead of a single computer, and they are designed to exist on the Internet without being controlled by any single authority. Some classic examples of dApps that are not operating on a

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17 K. Francisco and D. Swanson, 'The supply chain has no clothes: technology adoption of blockchain for supply chain transparency', *Logistics*, Vol. 2, No. 1 (2018), 2, available at DOI.org/10.3390/logistics2010002.

18 N. Szabo, 'Formalizing and securing relationships on public networks'. *First Monday*, Vol. 2, No. 9 (1997, September 1), available at DOI.org/10.5210/fm.v2i9.548.

blockchain framework are BitTorrent,[19] Kazaa,[20] and Tor.[21] Blockchain provided the ability for users to trust decentralized applications and at the same time it tackled some of applications' limitations, such as the missing nodes and the virus affected software. Decentralized applications that exist on the blockchain require the deployment of a smart contract in order to function properly.

Methodology

The proposed methodology utilises blockchain technology through the functionality of a dedicated type of smart contract that was developed based on a special-purpose structure. The latter provides encryption, and hence, secured transmission of data. All transactions recorded and verified on the blockchain cannot be reversed, hacked or deleted. The main purpose of the proposed dApp is to allow users to securely send and track items on the blockchain and then share them with others. For the design of the dApp, we first used the Solidity language for the implementation and deployment of the smart contract on the Ethereum ledger, and then we utilized the Web3.js library, which is a collection of modules that contain unique functionalities for the Ethereum framework, to develop a user-friendly interface that allow users to easily interact with the smart contract. The proposed methodology was first tested on the Ropsten Test Network taking into consideration various validation scenarios and then it was executed on the Ethereum Mainnet.[22]

Smart Contract: Implementation

The proposed smart contract comprises of a series of writable and readable functions (i.e., getter /setters) that are called using their unique function hash. More specifically, each smart contract once deployed has its own blockchain address, so a user can call

19 D. Qiu and R. Srikant, 'Modeling and performance analysis of bittorrent- like peer-to-peer networks'. In *Proceedings of the ACM SIGCOMM 2004 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communication, August 30 - September 3, 2004*, Portland, Oregon, USA, (New York, NY: ACM, 2004).

20 N. S. Good and A. Krekelberg, 'Usability and privacy: a study of kazaa p2p file-sharing', in *Proceedings of the SIGCHI conference on Human factors in computing systems.* (New York, NY: ACM Digital Library, 2003).

21 D. McCoy, K. S. Bauer, D. Grunwald, T. Kohno, and D. C. Sicker, 'Shining light in dark places: Understanding the Tor network', in *Privacy Enhancing Technologies, 8th International Symposium, PETS 2008, Leuven, Belgium, July 23-25, 2008, Proceedings*, eds N. Borisov and I. Goldberg (Berlin-Heidelberg: Springer, 2008).

22 Y. Hu, T. Lee, D. Chatzopoulos and P. Hui, 'Hierarchical interactions between ethereum smart contracts across testnets'. In *Proceedings of the 1st Workshop on Cryptocurrencies and Blockchains for Distributed Systems, CRYBLOCK@MobiSys 2018, Munich, Germany, June 15, 2018* (New York, NY: ACM, 2018).

a function on the smart contract by initiating a transaction and passing the function Hash code into the contract.

```
sendProduct (string date, string details, string location,
    string final destination, address senderAddress,
    address receiverAddress)
```

Listing 1: *sendProduct*() function

Writable Functions The purpose of the *sendProduct*() function (as in Listing 1) is to pass information on the blockchain regarding the item that will be shipped from part A to part B. This transaction provides information about the item, the sender and the recipient.

```
\textbf{\textrm{sign}}(uint256 index, string location)
```

Listing 2: *sign*() function.

The *sign* function (as in Listing 2) is called to verify that the item was received at a checkpoint until its reaches its final destination.

```
\textbf{\textrm{maintenance}}(uint256 index, string details)
```

Listing 3: *maintenance*() function

The *maintenance*() function (as in Listing 3) is optional and can be used to add additional details on an item such as 'second-hand product' or 'fixes', or to track the item's history.

```
\textbf {\textrm {changeReceiver}}(uint256 index,
    address receiverAddress)
```

Listing 4: *changeReceiver*() function.

The *changeReceiver*() function (as in Listing 4) is used to change the recipient address at a checkpoint until the product reaches its final destination. This function can only be triggered if the receiver first signed that he/she had received the product.

Readable Functions The proposed implementation consists of various readable functions, including but not restricted to: (i) view the details of a sent item; (ii) track the location of an item; and (iii) track the maintenance history of an item. More functionality could be added to the core implementation based on the requirements and design logic.

Function Hashes Based on the proposed smart contract we outline below the function Hash of each function. The function Hash is used on a transaction in order to call a specific function.

```
{
"34461067": "records(uint256)",
"ed1d4870": "changeReceiver (uint256 , address)",
"5b61646c": "getAllMaintenanceItems ()",
"1f696924": "getAllRoutes ()",
"447fe289": "getParties(uint256)",
"6813b53b": "getProductDetails(uint256)",
"5786fd40": "getProductsCount()",
"b9e0db35": "locations(uint256)",
"a2c7f450": "maintenance(uint256 , string)",
"6533b77b": "maintenancemap (uint256)",
"8da5cb5b": "owner()",
"529f78a5": "send Product(string , string , string ,
    string , address , address)",
"a855418f": "sign(uint256 , string )",
"f2fde38b": "transferOwnership (address)"
}
```

Listing 5: Function Hashes of the deployed contract.

A Use-Case Example

The following use-case provides an overview of how our dApp works. John, an individual from Cyprus, is interested in sending an item to Alice, another individual living in the Netherlands. John visits a logistics company, which initiates, on his behalf, a transaction on the blockchain. As shown in Figure 1, the transaction is initiated by the logistics company in Cyprus, but as there is no direct link between Cyprus and the Netherlands the item must first travel to Italy before reaching its final destination. When a product reaches a destination, the end-user signs that she/he received the product and chooses one of the two options below:

- If the product did not yet reach the final destination (intermediary), the end-user assigns a new receiver and the procedure is repeated.
- If the product has reached the final destination, then the final recipient is called and it is required that she/he signs.

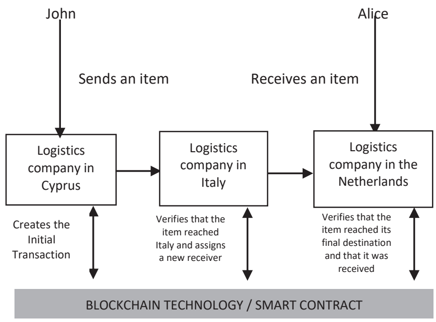

Figure 1: Abstract description of a real-world scenario

Experimental Evaluation

As already outlined in the previous section, the proposed implementation was first tested on the Ropsten Test Network, and then it was executed and evaluated on the Ethereum Mainnet. The address of the proposed smart contract is the following: `0x1E24e91148e6AfEbCD7Ac3E1DC54DC535a84B188`.

All transactions executed using the proposed smart contract are recorded on the aforementioned address and are publicly available on Etherscan.[23] Etherscan allows anyone to investigate the Ethereum blockchain for transactions, addresses and other activities that are taking place.

Besides the contract address, in order to interact with a deployed smart contract, the application binary interface (ABI) is required.[24] A user can call any function of the deployed contract only when she/he has the contract address and the ABI. A dApp can be called either on the application's Website or through MyEtherWallet (MEW),[25] which is a free, open-source, client-side interface for interacting with the Ethereum blockchain.

Tables 1 and 2 present the gas limit and gas price needed for the deployment of the smart contract, along with the execution of each writable function. In the Ethereum network, gas is a unit of cost for a specific function that needs to be executed, gas limit is the maximum amount of gas a user is willing to spend on a transaction and gas cost is the Gwei price per unit of gas. For each deployment, or function call, Ethereum proposes a certain amount of gas limit that is needed for the transaction, which value depends on the smart contract requirements, and it can be adjusted. If a lower gas limit is used, the contract deployment,

23 Etherscan: https://etherscan.io/address/0x1e24e91148e6afebcd7ac3e1dc54dc535a84b188.
24 Ethereums.com: https://ethereums.com/wp-content/uploads/2018/09/ABI.pdf.
25 Myetherwallet.com: https://www.myetherwallet.com.

or the function call, will be dropped, so it is advised to use the default limits or even increase them. The gas price value is also adjustable. This value affects the execution time: the higher the gas price, the quicker the deployment/function call will be verified on the blockchain. As already mentioned, Table 1 presents the gas values used for the contract deployment and Table 2 outlines the gas values used for calling each function.

Table 1: Gas used for contract deployment

	gas limit	*gas* price (Gwei)
Smart Contract Deployment	2262196	2.3

Table 2: Estimated execution gas per function

Function	*gas* limit	*gas* price (Gwei)
sendProduct()	292435	3
sign()	792936	41
maintenance()	112607	41
changeReceiver()	35573	41

For each function of the proposed smart contract we have used various gas values in order to highlight the main executional differences. In the Ethereum network if you multiply the gas limit with the gas price, you can calculate the maximum transaction fee needed for each function to be verified. Those values are presented in Table 4. The transaction fee is the amount that you will have to pay for the transaction to be verified on the blockchain; the higher the cost, the less time needed to verify the transaction on the blockchain.

Nowadays, execution time is not really an issue in the Ethereum network as this can be adjusted by the Gas values. According to Table 4 the Maintenance function has the higher cost; therefore, using Table 3 we notice that this function needs just 3 seconds to be verified on the Blockchain. The rest of the functions used the values either proposed by the Ethereum network or adjusted by us and they also need a few seconds to be verified.

Table 3: Execution time per function

function	execution time (sec)
contract deployment	<20
sendProduct()	< 20
sign()	< 10
maintenance()	< 3
changeReceiver()	< 15

As it can be observed from Table 4, the cost for deploying the proposed smart contract on the Ethereum Mainnet and being able to add and manage millions of records is significantly low at just $1.48 (Ethereum price (ETH) on the day experiments where conducted was $285 per Ethereum).

Table 4: Execution costs per function

function	max fee (in ETH)	max fee (in USD)
contract deployment	0.005203	$1.48
sendProduct()	0.000877	$0.25
sign()	0.003810	$0.98
maintenance()	0.004616	$1.19
changeReceiver()	0.001458	$0.38

Finally, the cost for calling a function of the proposed dApp ranges from $0.25 to $1.19, depending on how quickly the transaction is to be executed and verified on the blockchain. Taking into consideration the average costs, we conclude that one can run the whole process and send and track an item through blockchain for less than $2, and in less than one minute. With the gas values adjusted this cost may become lower or higher.

Conclusions

The emerging blockchain technology can be used to leverage Cyprus' position to become an exemplar in the supply-chain and logistics industry in the region of digital technologies and other related services. This paper presents a prototype implementation of a logistics decentralized application to minimize the gaps between professionals and blockchain in order to help them realize its benefits. The proposed dApp was executed and evaluated on the Ethereum Mainnet and the results were presented in this work. Based on our findings, we may argue that any professional can utilize blockchain in order to develop a secure and transparent application. A logistics dApp was just one of our implementations. In the near future we plan to investigate how to develop and evaluate real-world dApps of other business domains and to verify the suitability of blockchain in different market disciplines.

Acknowledgments

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