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Distributed logistics platform based on Blockchain and IoT

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Abstract

This paper presents an approach to integrating Blockchain and IoT technologies into modern supply chains. We propose the concept of a new logistics platform that is built as a distributed network of nodes and offers an alternative approach dealing with the complexity of modern supply chains by breaking them into smaller, functionally independent parts. The modular structure of the platform allows users to add their own nodes or extend the functionality of the existing ones. Nodes are communicating with the use of IoT technology, which serves as a bridge between the virtual and real worlds, making this platform truly digital. Blockchain technology is not only used for writing down agreements and for making transactions, but also as a trustworthy public listing of services and information. It connects the nodes into a public and secure system that provides reliable services of a supply chain. In this work, we describe the individual nodes and their implementation and present preliminary results of experiments using a laboratory model of a logistic chain.

Keywords: Internet of Things; Blockchain; logistics; supply chain management; distributed network

1. Introduction

Digitalization of the logistics and supply chain has created many opportunities for companies, however, it also presents them with new challenges. With the arrival of e-commerce, parcel industry is on a constant rise with the numbers of Stock Keeping Units (SKU) historically at their highest, with 85 million packages and documents delivered around the world every single day [1]. On the other side, customer demands are getting bigger and more divergent, creating new challenges for supply chain management. In order to control the whole supply chain, companies are investing a lot of their time and money in new technologies such as it is the Internet of Things (IoT). Smart devices implemented in every part of the chain are acquiring and working with enormous quantities of data. Regardless of all new technologies, ever-growing complexity of the supply chain still represents a major obstacle for supply chain companies. For example, placement of the RFID tags in parts of the supply chain alone does not fully realize its potential unless the company knows how to share the data and how to use it to solve the problems [2].

The growth of the larger companies, taking control over the supply chain as they increase their market share, has become a serious problem for SMEs. In order to become a part of the system, they have to compete with low prices and global reach of bigger companies. Distributed digital platforms are allowing small companies to have a global reach and to compete with the sector's established giants, becoming increasingly important in the logistics industry. In the future, a dominant global platform is going to transform the customer's experience of logistics and the companies which will be able to adapt and join the platform will be the winners in a truly digital logistics industry [1].

A further strategic issue that provides a challenge for logistics management is the continued trend towards globalization which adds its own piece to the complexity of supply chain management. A global company is more than a multinational company. In a global business, materials and

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components are sourced worldwide and products may be manufactured offshore and sold in many different countries, perhaps with local customization. Challenge for globalized supply chain companies is in the management of the complex web of relationships and flows that characterize their supply chains [3]. Globalization is providing a variety of opportunities for improving supply chain performance. However, the same advancements also increase global competition, increasing pressure on both established and emerging industries and firms to design and operate their supply chains as efficiently and cost-effectively as possible [4]. A result of globalization is the involvement of various independent parties (freight forwarders, 3rd party logistics service providers, multimodal transport operators, carriers, etc.). Accurate communication between these parties is the key to success and a platform is a common way where all parties share the necessary relevant information. The problem when adopting such approaches is that existing platforms are managed by the central authority. While having platform dominance often represents a good business opportunity for the company running the platform, other actors have to pay fees and follow the rules of the platform owner. Furthermore, having a single player to control the rules, poses a risk for diversity and fairness in the market. Multiple competing platform companies, on the other hand, create the risk of a splintered market resulting in non-optimal logistics decisions in separate silos [5].

The emerging technology of Blockchain has brought a lot of attention to the supply chain companies with its functionality, as they are putting a lot of their effort to integrate the technology into the supply chain [6]. Manufacturing part of the supply chain has already made some implementations of the new technologies, to open up and share manufacturing knowledge in order to increase production [7, 8, 9]. The main property of the technology being a cost-effective transmission of transactions in peer-to-peer networks with no central system and without the mediation of a third person, can simplify B2B integration and enables micro level IoT integration [10]. When in 2017, IBM and Maersk have announced collaboration to implement Blockchain technology in the supply chain, one of the biggest steps has been made to integrate Blockchain with IoT in order to transform a global supply chain [11]. Their goal for the year 2017 was to enable a shipment of 10 million out of 70 million containers they ship yearly, over the Blockchain network [12]. IBM is making even more effort to insert Blockchain into the supply chain with its cooperation with Walmart. In order to decrease the response time of product recalls they are using Blockchain technology to improve track capabilities of food supply chain [13]. So far an integration of Blockchain into the supply chain has been carried out with transactions on self-executing smart contracts which can serve as a public database for tracking of the products [14, 15].

The proposed concept is addressing the described issues of modern supply chain and logistics. The idea of a distributed network of nodes is to deal with the complexity of the systems on the local level. With Blockchain technology, the nodes are connected in a public and secure system that provides efficient and reliable service for procurement, storage and transport of products. The concept is the next step in the evolution of the digital platforms in logistics and its main purpose is to liberalize and open the way for all actors to equally take their part in the supply chain.

2. Concept

The proposed concept of the logistic platform is combining two technologies Internet of Things (IoT) and Blockchain in a new and innovative way. The structure of the platform is a distributed network of nodes which provide or consume different types of services. There is also a third group of nodes which are universal nodes which are ubiquitous on the platform, see Fig. 1. There is no central authority to supervise existing nodes and their actions, relying on the behaviour of the trustworthy actors supporting the platform because of their needs for it, therefore the platform will eventually reject bad actors and eliminate. Each node is fully autonomous and can communicate and cooperate with other nodes in pursuit of its goals. The main property of the platform is modularity which supports the inclusion of an unlimited number of different types of nodes at any given time. The main idea behind the platform is to define a set of elementary nodes of the platform and the most basic interactions between these nodes. As there is a possibility for other users to add their own modules to the system and extend already existing nodes, the platform will eventually converge to the optimal distributed system based on users demands and needs after some time.

As all parts of the supply chain are being equipped with small IoT devices and the future of the supply chain is moving towards fully automated processes, we are taking in account that service providers like transportation companies have digitalized their services in a way that they are able to connect on the Internet at any given time. IoT has an important role in closing the gap between physical and virtual worlds and automation of the supply chain has made a huge step through the involvement of this technology. Nowadays, one of the main problems of the supply chain management is the growing complexity of the systems which is resulting in difficulties to assess the performance of the system. Implemented technology of the IoT in the supply chain enables a stream of real time information about the current state of single components of the system from anywhere in the world. So far these streams of

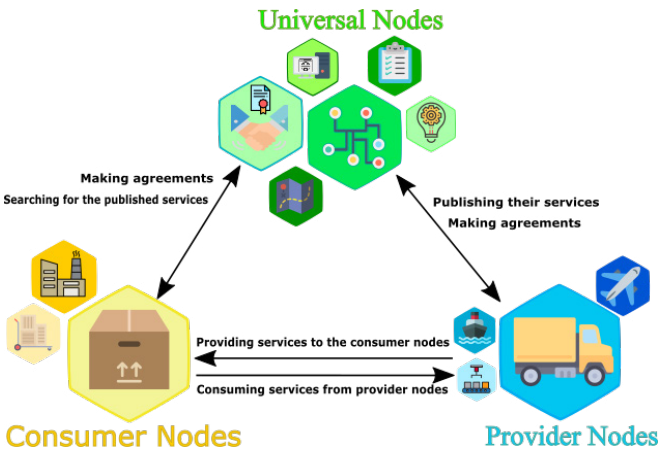

Fig. 1. Concept of the platform.

information were only stored in big data centres or clouds but the data was not used for analytics and system improvement. With Blockchain, supply chain managers are finding new ways to incorporate and optimize the supply chain. Many believe that Blockchain serves as a missing piece to the puzzle of IoT, as it enables agreements between two parties without the intermediate party. Therefore, two smart devices from opposing parties can make an agreement in the form of a smart contract which is not susceptible to corruption and scams [16]. Microtransactions between smart devices in an extremely safe manner are now possible and can be executed without human interference if devices are programmed to do so.

2.1. Platform nodes

On the proposed platform we can set different types of nodes but there are some core nodes which are necessary for the platform to become operational. In these next subsections, a few examples of the nodes that could be used in a modern supply chain are described. We are also proposing technologies and methods for implementation of these nodes that are currently concerned to be good practice but can be also implemented differently by the users when they find better solutions in future.

2.1.1. Genesis node

As the name explains, the Genesis node is the first node of the platform and it holds all the information about the platform. It serves as an entrance point for new users to join the platform. Its purpose is to inform new users of the platform how the system works and how to create new nodes. One of the functions of the node is also holding a list of all elementary nodes on the platform and a way to find them. The Genesis node is implemented as a smart contract written on Blockchain. As long as the Blockchain network is running, all the information from the Genesis node is available to all users.

2.1.2. Service node

The Service node represents actors that are providing services in the supply chain. In our concept, each of them is an individual node, which allows them to interact with other nodes of the system. The node serves as a bridge between physical and virtual worlds for providers of the service. The main component of these nodes is the API (Application Programming Interface) in any form they want as long as it enables the other nodes to use it as a mean of communication over the Internet. The goal here is that in future, the whole process of providing a service would be fully automated. Fig. 2 is representing an example of the Service node, which is providing transport service. The most obvious examples of service nodes are transporting companies and warehouses but there are also other possibilities like insurance companies. They can provide insurance in case of certain events during this

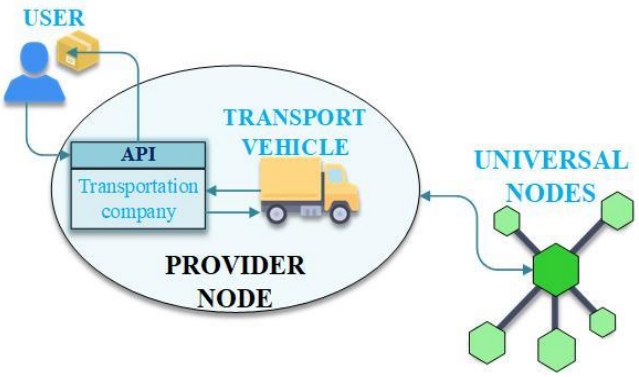

Fig. 2. Service node.

autonomous process, for instance, if transportation is late due to the unforeseen events on the way.

2.1.3. User node

User nodes represent each user accessing the platform in order to communicate or cooperate with other nodes of the platform. Usually, users are looking for services provided by the Services nodes. For example, the most common user would probably be some production company that is looking to store or to transport their products and goods. Of course, it can also be an individual that finds some use in the platform. Packages are getting smarter and smarter with every device pinned to them and the idea is that in the future they will be able to order a transport or storage by themselves. The proposed platform provides them with a way to do it, as they reach service providers through their API, they can order a means of transport to move them to another warehouse where they reserved a storage place. So technically the users of the platform would rather be smart packages than the companies who are shipping the product. Companies only task would be to program package's logic in a manner they would find the most necessary at that moment. For example, if they wanted for a package to get from production to the customer in the fastest way possible, the package would acquire offers from transport providers and chose the fastest possible.

User node is composed of two parts: the first one is a physical package and the second one is a virtual representation of the package in the form of a computer program. Physical package is equipped with an IoT device which integrates small microcomputer, powerful enough to enable communication with the virtual package and management of the auxiliary components for the monitoring of the package location and other sensor data that are important to the package owner like temperature, humidity, acceleration and others. The reason behind virtualization of the package is to ensure sustainability of the system. All management processes that require more computations are executed away from the package on some other computing resources such as personal computers, servers, clouds or Blockchains. This way smart packaging is carrying fewer electronics and it is easier to recycle or furthermore, we

can reuse packaging if we can transfer the ownership of the package on the virtual level.

2.1.4. Interface node

The main purpose of the Interface node is to provide easy access for users to certain nodes with their functions and information. To keep the idea of a distributed system the implementation of the Interface node is a decentralized web page based on peer-to-peer technology, but normal web pages can also be an example of the Interface node implementation. Example of an Interface node would be a decentralized web page which extends the Genesis node. New users are more likely to search on the Internet for the platform and for all the information about how one can be involved in the system.

2.1.5. Agreement node

When multiple nodes of the platform reach an agreement, the Agreement node takes care of writing it down in the form of a contract. With the use of Blockchain and smart contracts, the terms of an agreement can be implemented in a self-executing program. Writing down an agreement is done in four main phases as it is shown on Fig. 3. If the terms are being violated, consequences are forced immediately. All agreements are publicly written on Blockchain whereas the content of the agreement can be encrypted to enable privacy of all parties of the agreement. For example, when a user node accepts an offer for transportation of the package from certain transport provider, the Agreement node writes it down with the terms of an agreement in the smart contract. Signature is made with their own private keys; thus authenticity of the signature is ensured. A smart contract also locks-in some of the funds from both of the parties, as one of the parties is violating the terms of an agreement their locked funds are taken from the smart contract and are given to the opposed party according to the predefined measures. In case both parties fulfil their part of an agreement all locked funds are returned to the previous owner.

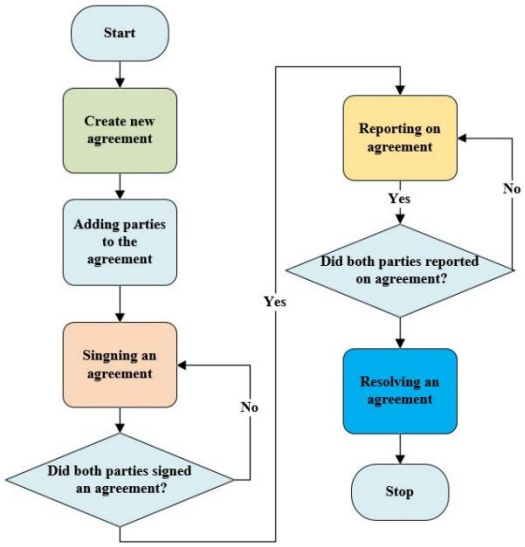

Fig. 3. Flow chart of writing an agreement to the Agreement node.

2.1.6. Mapping node

The Mapping node serves as a list of connections between information. It can connect only address of the node with the type of the node or it can hold much more complicated connections such as a discovery mechanism for the service nodes APIs. Implementation of the Mapping node is a smart contract on a Blockchain network. We are leveraging the Blockchain property as decentralized time immutable database to make our platform robust and decentralized.

2.1.6.1. Address Resolver Node

In order for the nodes to find each other and exchange messages, distributed networks have a service discovery mechanism. In the proposed concept of the platform, this mechanism is implemented via the Address Resolver Node (ARN) which maps certain nodes address with their IP addresses. ARN is extending a Mapping node and has all the properties of the Mapping node. ARN node is analogous to the DNS mechanism that map domain names with IP addresses. ARN contains address information of all service nodes so the user nodes are able to communicate with them and manage their supply chain.

ARN node structure basis on the smart contract platform like Ethereum or EOS. Smart contract platform defines how the smart contract is written and how to build a smart contract API for the other nodes to be able to communicate with it. ARN node enables public listings of service providing nodes to be used by service consuming nodes. For example, if a new transport provider node wants to start offering its services it registers with the ARN node and its services are publicly available for user nodes to use.

2.1.7. Rating node

The Rating node is serving the platform as a mean to calculate the rating for each user on the platform based on their actions. Platform functionality is to exclude bad actors from the system and the Rating node is one way of doing it. Objective calculations of the ratings are done from the trustworthy data of other nodes, especially from the Agreement node where is written when some actor broke terms of an Agreement. Ratings can be calculated also in other ways. Users with the best rating would be rewarded, financially or in other ways, in order to promote fair and objective use of the platform.

3. Case study

To represent how the proposed platform would work in real life a case of a manufacturing company producing a particular product will be presented.

Step 1 - Discovery: Together with other companies, they are facing challenges of managing their supply chain. They are in need of automated processes which can be controlled remotely by computers, so they can optimize their production and supply chain. They find the platform through the Interface node as the Genesis node is using it to present information about the platform.

Step 2 – Exploring the platform: The Genesis node provides a link to all other elementary nodes of the platform. Because the company is looking for a service of transport for the product, their attention is focused towards the Mapping node which maps transport providers with their API. The Address Resolver Node (ARN) is one of the mapping nodes which maps providers of service with their IP address of API. Besides a list of all service providers, this type of node also describes what kind of an API service providers are using and what functions are integrated into the API. The main area of operation of the company is in Europe, therefore they find an ARN that is listing only providers of transport in Europe.

Step 3 – Using the platform: As the company receives the list of all providers on the platform, they start sending their demand to the providers by using their API. Transport providers return their offers and the company can select the best option for their production. When they reach an agreement, everything is written on a smart contract of the Agreement node, where the company and transport providers sign the contract with their digital signatures. With the terms of the agreement, opposing parties also decide on the penalties in case of breaking the terms. Both of the parties lock a certain amount of funds on the smart contract. After the service is done, they report about the outcome, if they agree about the outcome the funds are distributed among both parties according to the written terms. To incent opposing parties of the contract to report correctly about the outcome, some funds locked in the contract are distributed also as a reward for the actors that confirm they broke the terms. In case that all parties of the contract can't reach an agreement, the funds are locked in the contract. The Rating node takes in account trustworthy of the users based on the amount of resolved conflicts on the Agreement node and users with the best rating would get a reward from the funds locked in the smart contract where there are still unresolved conflicts. Another provider of the service is also an insurance company which is another example of the Service node on the platform. The company decides that they would like to insure themselves in case of unresolved conflicts, the insurance company would pay for the agreement between the company and service providers. Insurance premiums for the users are based on their ratings written on the Rating node, which are calculated from the unresolved conflicts.

Step 4 – Modifying the platform: The company is pleased with the way platform works, so they decide to upgrade their shipments with smart packaging. Each package is running its own User node and can interact with other nodes on the platform. Package nodes are programmed so that they fulfil the

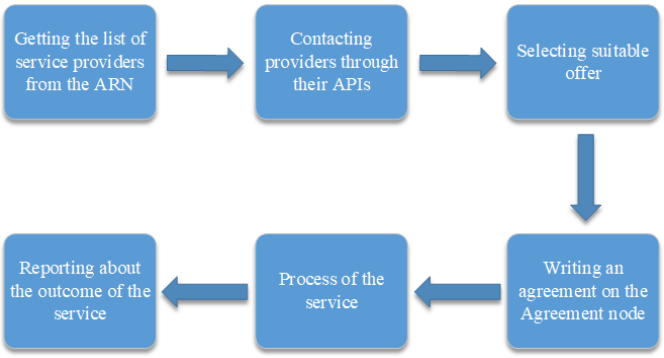

Fig. 4. The process of getting the service from the platform.

criteria set by the company. For example, if they want to transport package the cheapest way possible, the package will look for the cheapest offers from the service providers. While they are using the platform, they recognize the need for another feature of the Agreement node. In order to ensure the best quality of the product at the end point of the transport, the product must be shipped in the vehicle that ensures certain conditions. Therefore, the company can write a smart contract that extends the Agreement node. The new smart contract adds to the terms of the agreement a function which obliges transport company to provide a certificate from a selected institute, certifying that their vehicles can provide required conditions during the transport.

3.1. Validation

To validate the concept, we implemented a platform with the following nodes: Address resolver node, Package node, Transport node and a Storage node. The Address resolver node is a smart contract written on the Blockchain network. The smart contract was deployed on the test network Rinkeby. Package node is a consumer of the services listed on the Address resolver node. Transport and storage nodes are providers of the services and are written on the list. All of these nodes were implemented as IoT devices with microcomputer

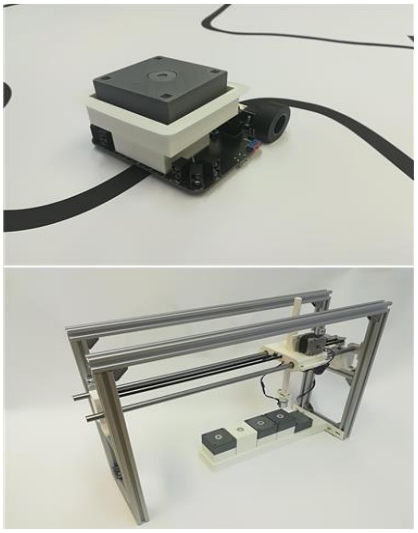

Fig. 5. Physical model.

Raspberry Pi and were running their own REST API. For the physical model, we used ten package nodes, two warehouse nodes and one transport node. On the physical model, we ran different tests to determine the feasibility of the concept. In the first test, the initial package distribution between warehouses varied to verify if the package distribution converges to the expected equilibrium (equal number of packages in the warehouses) over time. The price of storing a package depended on the number of packages currently stored in the warehouse. The results show that even though tests were run with different initial package distributions, in time, the packages ended up equally distributed among the warehouses.

A part of testing on the physical model was also a measurement of the overall system efficiency indicator which was determined by the difference between the measured real times of providing services and the agreed upon times. As a part of the experiment, we have measured the time delays of transport node during the service of transporting the package from storage to storage. At first, the transport node didn't use any kind of an algorithm to determine when it should start driving. It reacted on the agreed times and the measured time delay average was 9.96 s. In the second part of the experiment, we implemented a simple algorithm which predicts the time of transport in advance. The measured time delay average with an implemented algorithm was 0.77 s. The results are showing that in order to increase system efficiency, existing nodes will have to optimize their own algorithms first.

4. Conclusion

In this work, we are proposing a new concept of distributed logistic platform based on Blockchain technology. The proposed concept of the platform is solving modern supply chain problems with a distributed network of nodes. By breaking complex logistic system on smaller parts, individual users of the platform are taking care of fewer processes at any given moment. Since the platform is providing an option for a fully automated supply chain, new options for the optimization of all processes in the supply chain are possible. Using Blockchain technology as the basis for the platform is not only allowing the users to write down agreements in the self-executing smart contracts without an intermediate person, but it is also a way for trustworthy public announcements of services. Furthermore, new technology can publicly display untampered information on compliance with the agreements of individual platform users. This kind of trustworthy information can affect the position of every actor on the free market. We see the limitation of the proposed concept of the platform in the critical mass of users. In order for the platform to work the way it is meant to be, there has to be a certain number of users who are supporting the platform. Only when the users will create new nodes and change the platform according to the users' demands and needs, the platform will truly be functional. Considering that the platform is providing an alternative way for smaller supply chain companies to join the global market and is undermining monopolies of the bigger companies, it is expected a lack of interest for the platform from their side. But if they want to be a part of the digital supply chain, they will have to provide their own platform or join an existing one. Our work in future will be focused towards the implementation of all proposed nodes in the concept.

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