Blockchain-based Healthcare Ecosystem

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Abstract—The subject of research is the development of a blockchain-based healthcare ecosystem. The paper will analyze the concepts of blockchain technology with a focus on application in healthcare. The paper will present the business model of blockchain application in healthcare. A blockchain ecosystem for healthcare will be presented. The practical part of the work will cover the design and development of a smart contract for participants in the proposed healthcare ecosystem. The PyTeal programming language will be used for the development of smart contracts. The Algorand platform will be used to record transactions between participants in the healthcare ecosystem. An application will be developed that will allow patients to monitor medical reports.

Keywords - healthcare, blockchain, smart contract, PyTeal, Algorand

I. INTRODUCTION

The healthcare industry today faces a number of challenges, including data privacy, interoperability, and trust issues. In general, emerged, modern technologies have significantly improved services in healthcare, and in recent years, blockchain is frequently viewed as a method of solving a number of issues in the healthcare area [1].

Blockchain technology is a distributed ledger and simultaneously decentralized database that can be used to securely store and share patient health data, enabling patients to have greater control over their own health data while ensuring its privacy and security [2] [3].

In a healthcare field, enables secure transfer of patient data, eliminating the need for a central data administration [4], strengthens vulnerable data defenses, manages pharmaceutical supply chains [5] and make an advancement in genetic research and clinical research [6]. Blockchain is frequently viewed as the most necessary and optimal healthcare technology and its most popular application is to keep medical data safe and secure. This is achievable by decentralized nature of itself technology.

The health applications could use blockchain technology to create a tamper-proof, decentralized record of patient health data, with patients and healthcare providers holding their own private keys to access and update the data. These applications could also use smart contracts to automate and streamline the process of managing patient health data, such as sharing it with other healthcare providers or researchers. Furthermore, the applications could use blockchain technology to incentivize healthy behaviors through the use of cryptocurrency-based reward systems. Patients could earn cryptocurrency for meeting certain health goals or participating in clinical trials, which could be used to pay for healthcare services or to purchase health-related products [7] [8].

In this paper, we propose a blockchain-based healthcare ecosystem. The new business model for healthcare based on blockchain is shown. As part of the proposed ecosystem, an example of a smart contract between two stakeholders from the ecosystem is developed using the PyTeal programming language and the Algorand blockchain platform. Furthermore, an application for patients that allows them to quickly test for the COVID-19 virus based on a blood sample is developed.

II. BLOCKCHAIN IN HEALTHCARE

Healthcare is a complex system. It deals with versatile data that are sensitive and confidential information about patients' condition, prescriptions, etc. [4]. Patients' data is stored within EHR and usually are transferred to different stakeholders and central data stores. Today, with the growing digitization of medical care, medical industry is faced with the inability to safely and securely distribute sensitive patient data [9]. Centralized data stores and cloud-based systems are attractive targets for cyber attack and illegal modifications [10][11]. Besides that, standards which regulate interoperability among healthcare systems are not uniform or absent, which cause difficulty to exchange data between healthcare organizations and other participants in

healthcare set [12].

In general, emerged, modern technologies have significantly improved services in healthcare, and in recent years, blockchain is frequently viewed as a method of solving a number of issues in healthcare area [1]. Blockchain technology forms a part of the fourth industrial revolution and it is also big buzzword around the medical technology area [13].

Over the years, the number of patients, medical reports, analyses, results, connected medical devices has been increasing and it is increasingly difficult to handle such an infrastructure where the exchange of such data requires increased interoperability. Blockchain technology has the potential to keep address the interoperability concerns currently present in health IT systems [14] [15].

The paper [16] in details elaborate key layers of interoperability framework such as business model, platform, infrastructure. In addition, the importance of data standardization, legal framework and critical attitude towards commercialization is emphasized. Haddouti et al. [17] proposed solution called Fedidchain as innovative framework that relied on smart contracts. Experimental results show the efficiency of Fedidchain compare to previous existing centralized models of data transfer. In their paper, Reegu et al. [18], proposed blockchain-based interoperable framework based on two EHR frameworks HL7 and HIPAA enabling security and privacy for vulnerable health data.

Blockchain technology, based on principles of decentralization and cryptography, has potentials to solve data privacy, security and highly interoperable Electronic Health Record (hereinafter: EHR) [19]. At the patient side, EHR data can be easily accessible for them and whole system could become more patient-centric [20]. Healthcare patient data are securely transferred over P2P system and cloud-based solution to hospitals and healthcare providers, as in working prototype MedRec [21]. Also, solutions from US company CareCloud [22], Avaneer Health [23], and Coral Health [24] presents the use of blockchain to accelerate the care process, improve health outcomes and implementing smart contracts between patients and healthcare professionals.

Blockchain can have a global impact on clinical research and it can be used to point problems of false results. It is inevitable that blockchain will strengthen trust in clinical trials [1] [25]. The good example is Clinical Trials Intelligence founded by ClinTex [26], platform for data analytics, machine learning and smart contracts in clinical trials. Another example comes from Mayo clinic, implementing a blockchain-integrated platform for pulmonary arterial hypertension trial. The platform will provide secure, decentralized data capture, document management, study monitoring and electronic consent for the clinical trial [27].

Another field where blockchain is affecting healthcare is the pharmaceutical industry. Drug traceability and medical or drug supply chain management is provided by a distributed ledger which is shared among all the stakeholders within the supply chain [28]. Some examples come from Chronicled [29] and BlockPharma [30] which build blockchain networks that helps pharma companies ensure safety, privacy and efficiency of medical supply chains. Interesting is start-up and pilot project Modum.io AG [31] with pharmaceutical distributors where efficacy and safety of the product is paramount. The proposed system includes sensor devices that monitor the temperature during the shipment and the data is transferred to blockchain with smart contract where temperatures can be assesses automatically and notify sender and recipient.

Blockchain along with Internet of Things (hereinafter: IoT) sensors can be used for transportation, collection, and storage of vaccines, especially during Corona virus disease [32]. Vacchain System, which is proposed in the paper presents decentralized system for vaccine distribution and elimination of counterfeit vaccines.

Wearable devices and IoT have a significant role in monitoring the health of patients. These systems generate huge amounts of data that are analyzed through big data and forwarded to healthcare stakeholders. The infrastructure of the IoT systems can be realized through blockchain technology. An example of this is a system based on Cloud storage, smart contract and IoT devices is given in [32]. System provides advanced security using cryptographic techniques like ARX encryption scheme to the current IoT based remote patient monitoring system.

Despite blockchain presents numerous opportunities for health care [32] [4], it is still in the development stage and there is not yet awareness in this technology in the healthcare area.

In order to its successfully implementation, it is necessary to overcome certain challenges. These are primarily technical, organizational and legal aspects as data standardization [5] [33], laws, as well as social and cultural change [34].

III. BLOCKCHAIN ECOSYSTEM FOR HEALTHCARE

A. BMC – Business Model Canvas

In the following chapter, the Business Model Canvas applied in the healthcare industry will be described, as well as description of all its elements (Table 1). The business model is considered as the preliminary stage before entering into a business, as this should guide towards the path of achieving the successful business goal.

B. Key partners

Companies enter into partnerships with each other for

many reasons, and partnerships become the cornerstone of many business models. Companies enter into alliances to optimize their business models, reduce risk or acquire resources. Key partners for a healthcare application are primarily hospitals and patients. The main role of hospitals is to update the existing database containing illness track records. Then, the patient is the most important part because he is using the app for booking appointments and buying medicines with prescriptions. Pharmacies are important partners because they are the ones issuing prescribed medicine. Prescription is done by the app/doctor after the appointment. Government regulations are provided through the Ministry of Health.

C. Key activities

A successful healthcare application requires many key activities. These are just some of the activities that a company must undertake to operate successfully. Like obtaining patient information, that activity is important because the patient is the main role in this development act.

Customer service is important because it inspires patients' user-friendly experience and makes Medical staff's jobs easier. By providing great customer service, Medical facilities can offer trust and obtain more users. Medical software development is the technical part. The company is in charge of the successful development and maintenance of the app/website, using Blockchain technologies.

D. Value propositions

The value proposition is why patients decide to use our platform. Each value proposition consists of a selected set of services that meet the requirements of a specific patient segment. When a Medical facility is transparent about its values and processes, patients gain more trust in that institution and are more likely to book their appointment in that way. If an institution does not provide high protection of confidential information, it may later lead to the loss of

Table I. BMC for the application of the blockchain in the healthcare

<table>
<tr><td colspan="5">Business idea: Offering medical support, tracking patient data, and designing a business model for the application of Blockchain in the healthcare industry
Products and services: Medical favor, laboratory results</td></tr>
<tr><td rowspan="2">Partners
- Pharmacies
- Patients
- Ministry of Health
- Hospital
- Healthcare providers and workers
- Medical laboratories
-Health insurance investors
-Research institutes</td><td>Key activities
- Research & Development
- Quality Control & Quality Assurance
-Patient information & Medical data management
- Marketing & Advertising
- Medical treatment
- Customer support
- Medical software development
-Partnership development</td><td rowspan="2">Value propositions
For stakeholders:
- Transparency
- Tracking all transactions
- Regulate interactions
- Monitoring all interactions in each medical institution
- Minimal risk
- Protection of confidential information
- Managing a large amount of information
For customers:
- Issuing prescriptions
- Security and trust among consumers
- Protection of personal data
- Quick response
- Keeping track of illness history</td><td>Relationship with users
- Quick & friendly service for the patient segment
- Save patient time
- Allow the patient to have more control over their medical records
- Pharmacies sales & support
- Technical assistance</td><td rowspan="2">Customer segments
- It targets patient participants who prefer to adopt and test new technologies
- Medical facilities that invest in new inventions and technology development
- Medical insurance
- Research companies
-National government</td></tr>
<tr><td>Key resources
- Funds (govt schemes, investors)
- Skilled software developers & database administrators
- Professional staff
- Facilities
- Software & Analytics</td><td>Channels
- Doctor inputs directly
- Medical institutions
- Corporate offices
- App store</td></tr>
<tr><td colspan="3">Cost structure
- Website development and maintenance, marketing costs, equipment maintenance costs, web designer costs, legal formalities, pharmacies costs</td><td colspan="2">Revenue Streams
- Free basic application for doctors and patients
- Data analysis sold to Pharmacies\Insurance companies & Research Facilities
- Sponsorships</td></tr>
</table>

sensitive information. Therefore, developers must understand the law of trust, what it protects, and the obligations of doctors and third parties.

E. Relationship with users

The way you connect with patients impacts their experience. We aim to establish automated relationships to improve the application and make it user-friendly. Social media is an effective tool to reach a wider audience and engage new users who would benefit from the application. What is most attractive for the users themselves is the privacy of their data and, of course, greater control over it. Certainly, what completes the user experience itself is an application that is simple and practical yet provides great and essential functionality.

F. Customer segments

The identification of the range of customers is crucial for an organization as it helps define the groups of people they aim to serve. These groups of people are known as the customer segments. Factors such as age, gender, user behavior, location, interests, and other relevant aspects are considered while grouping the customers. In our business model, we aim to serve people who require medical help, use medical services, or need appointments in healthcare institutions.

G. Key resources

In addition to these main types of resources, other important resources for medical institutions may include:

1. Technological resources - the software and hardware required to run the medical system, electronic health records, communication devices, telemedicine, etc.
2. Supply chain resources - suppliers, distribution channels, transportation, warehouses, and inventory management.
3. Reputation resources - brand image, reputation, credibility, patient satisfaction, and relationships with key stakeholders such as physicians and insurers.
4. Regulatory resources - compliance with laws, regulations, and quality standards, risk management systems, and legal support.
5. Cultural resources - organizational culture, values, and norms that influence the behavior of employees and stakeholders and contribute to the success of the business model.

Identifying the key resources and managing them effectively is essential for the Medical institution's success. It requires careful planning, allocation of resources, and continuous evaluation and improvement of the resource allocation strategy. Proper management of resources can help medical institutions to deliver high-quality care, improve patient satisfaction, reduce costs, and achieve sustainable growth.

H. Channels

This part of the business model canvas is discussing the methods of distributing a software solution and promoting it through advertising. The "distribution channels" section of a company's strategy describes how they connect with customers, not just how they deliver the product. The purpose is to not only deliver value but also to spread awareness of the product's existence. Channels are how the organization communicates with its consumers or patients and serves as the interface between the medical institution and the public, which includes patients, the Ministry of Health, and pharmacies.

Medical institutions can be an effective channel for distributing healthcare applications, especially if your app is designed for healthcare professionals or patients with specific medical conditions. By partnering with medical institutions, you can tap into their existing patient and provider networks, increasing the reach and impact of your healthcare app.

Doctor inputs can be a valuable channel for distributing healthcare applications. By partnering with doctors and other healthcare providers, you can leverage their expertise and insights to improve the effectiveness and relevance of your healthcare app. To effectively use doctor inputs as a channel, it's important to establish strong relationships with healthcare providers and offer value to both providers and patients.

I. Cost structure

Regarding cash flows, this paragraph discusses the cost structure of a business, specifically concerning creating and distributing a value proposition, maintaining customer relationships, and generating revenue streams. For a healthcare app that uses blockchain technology, the cost structure will depend on factors such as app complexity, security level, and development resources. It's important to create a budget that accounts for all potential costs associated with app development and deployment. A company can either focus on minimizing costs or providing maximum value within a selected price range.

Cost-driven business models aim to minimize costs by maintaining a lean cost structure, using low-priced value propositions, extensive automation, and outsourcing. On the other hand, value-driven business models prioritize value creation over cost implications, characterized by premium value propositions and personalized service.

J. Revenue Streams

The revenue streams section of a business model is an important component that outlines the various sources of

income for a company. It identifies how a company generates revenue from its customers, including the pricing strategy, revenue models, and sales channels.

In the Business Model Canvas, the revenue streams section is directly linked to each previously defined customer segment. This means that the company's revenue streams are directly influenced by the needs and preferences of its customers. It is important for a company to carefully consider the revenue streams associated with each customer segment, as this will impact the overall financial performance of the business. It is also worth noting that revenue streams do not necessarily equate to profit earned.

While revenue is an important component of a company's financial success, it is important to also consider the costs associated with generating that revenue. For example, a company may have high revenue streams but also high costs, which can impact profitability. Therefore, it is important for a company to carefully manage both revenue and costs to maintain financial stability and achieve sustainable growth.

Sponsorships are a valuable revenue stream for healthcare apps. By offering sponsored content, research opportunities, in-app advertising, sponsorship of features or tools, or data analytics, you could generate revenue while also providing value to your users. However, it's important to ensure that any sponsorships align with your app's mission and values and that they do not compromise the integrity or security of your app or user data.

Offering a free basic version of your app for doctors and patients can be a good way to attract new users and build a user base. However, it's important to consider potential revenue streams to monetize your app, such as data monetization, affiliate marketing, or sponsored content.

Selling data analysis to pharmaceutical companies, insurance companies, and research facilities can be a viable revenue stream for this kind of app that collects and analyzes data. Keeping in mind it's important to consider the potential ethical and legal implications of data sharing and ensure that any data sharing agreements are transparent and protect user privacy.

IV. BLOCKCHAIN-BASED HEALTHCARE ECOSYSTEM

A blockchain ecosystem for healthcare is a decentralized platform that utilizes blockchain technology to manage, store, and share medical data securely and transparently. In such a system, all medical data related to a patient, such as medical history, lab results, and prescriptions, are stored in a distributed ledger, which can be accessed by authorized parties in a secure and tamper-proof way.

The benefits of a blockchain ecosystem for healthcare are numerous. Firstly, it enables patients to have full control over their medical data and who can access it. Secondly, it enhances interoperability among healthcare providers by providing a unified view of a patient's medical history. This can improve patient outcomes and reduce medical errors. Thirdly, it reduces administrative costs associated with managing healthcare data, such as paperwork and data entry.

Figure 1 shows the proposed Healthcare ecosystem based on blockchain.

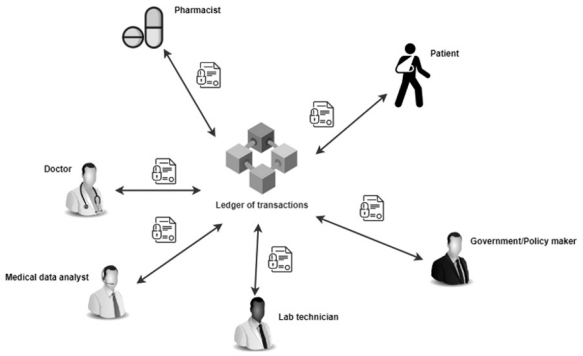

Fig. 1. Blockchain-based healthcare ecosystem

In this ecosystem, blockchain technology would be used to securely and transparently store and share medical data, allowing all parties to access the information they need to make informed decisions.

Patients would be able to control their medical data and grant access to healthcare providers as needed. This would give patients greater control over their healthcare and enable doctors to make more informed diagnoses and treatment decisions. Pharmacists could also benefit from this system by having access to a patient's medication history, allowing them to avoid potentially harmful drug interactions. Government officials and policymakers could use the data stored on the blockchain to analyze healthcare trends and make informed policy decisions. They could also ensure compliance with regulations and monitor the quality of care provided by healthcare providers. Lab technicians would be able to use the blockchain to securely store and share test results, which could be accessed by healthcare providers as needed. This would allow for faster and more accurate diagnoses, leading to improved patient outcomes.

Overall, a blockchain ecosystem that includes all the represented parties in the picture above has the potential to greatly improve the efficiency and effectiveness of the healthcare industry. By utilizing the transparency and security provided by blockchain technology, this ecosystem could lead to better patient outcomes, more informed decision-making, and a more efficient healthcare system.

V. DEVELOPMENT OF A SMART CONTRACT FOR HEALTHCARE

The following three algorithms present the smart contract created between two stakeholders in the healthcare

ecosystem, the Patient and Laboratory. Algorithms are used to present the connection and the conditions that must be met for all operations to be performed and for the smart contract to be successfully created. They also show what happens in a situation if some of the conditions are not met.

Algorithm 1: Patient starts COVID-19 testing in Laboratory

Input: Laboratory ID, Patient ID, Patient LBO, Labaratory
If *Caller == Patient*

then

Issue an announcement (Event) that the patient is asking for COVID-19 testing.

else
return error.

Fig. 2. Algorithm for the first operation – Patient starts COVID-19 testing in Laboratory

Figure 2 shows the first algorithm that represents the first operation performed by the patient, which is the request for testing for the Covid-19 virus. The request and the operation itself are quite simple, which is why the conditions are not complex either.

Algorithm 2: Laboratory accepts testing and clears previous results

Input: Laboratory ID, Patient ID, Patient LBO, Testing Fee, CRP, WBC, LYM
If *Caller == Laboratory and*
Testing Fee == 100000 and
CRP == " " and
WBC == " " and
LYM == " "

then

Issue an announcement (Event) that the testing fee is correct and Laboratory can test blood samples.

else
return error.

Fig. 3. Algorithm for the second operation – the Laboratory accepts testing and clears previous results

Figure 3 shows another algorithm that represents the next operation that is performed when communicating between these two stakeholders. This operation is performed by the Laboratory and the conditions are such that they check whether the blood parameters (crp for c-reactive protein, wbc for white blood cell, lym for lymphocytes) are empty so that the results can be written into them and the Patient can be tested for the virus. The laboratory also checks whether the Patient has paid for the testing as required.

Figure 4 shows the last algorithm representing the third operation. This operation is performed by the Patient. If the LBO (insurance number) exists in the Laboratory, the blood results are obtained and the Patient is informed whether the test is positive or negative for the virus. Otherwise, the personal number of the insured is not found in the Laboratory and the Patient does not receive his results.

Algorithm 3: Patient receives COVID-19 test results

Input: Laboratory ID, Patient ID, Patient LBO, CRP, Patient CRP, WBC, Patient WBC, LYM, Patient LYM
If *Caller == Patient and*
Patient LBO == Patient ID

then
Patient CRP = CRP and
Patient WBC = WBC and
Patient LYM = LYM

Issue an announcement (Event) that the patient is receiving COVID-19 test results, whether the results are positive or negative.

else
return Patient LBO Not confirmed.

Fig 4. Algorithm for the third operation – Patient receives COVID-19 test results

In the Figure 5 there is a representation of all transactions after finishing all steps of the smart contract. There are two accounts in question, a patient and a laboratory that does the blood testing for COVID-19. First transaction is actually the creation of our app. Next, second and third one are the OptIn transactions that both accounts should have in order to continue onto the next main transactions. After clicking the Request testing button and choosing the antigen test another transaction will show on our AlgoExplorer. When that is done the laboratory also makes another (fourth) transaction by clicking the Start COVID-19 button. Finally, the last transaction is created when the patient requests his blood results back, the laboratory provides them immediately after the funds for the blood testing expenses are moved from the patient account to the laboratory account (Figure 6).

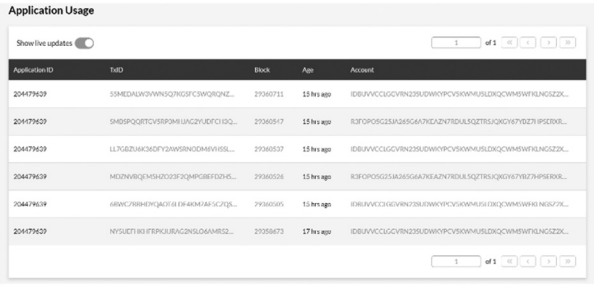

Fig. 5. Representation of all transactions after finishing all steps of the smart contract

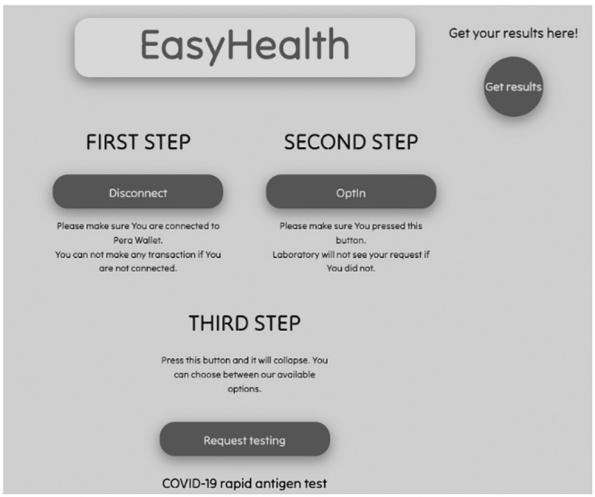

Fig. 6. EasyHealth application

An application was developed using the React framework, which should allow the Patient to request a quick test for the Covid-19 virus, after which the Laboratory, based on the blood sample, returns the test results. The front end of our EasyHealth application is shown in Figure 7.

VI. CONCLUSION

In this project we proposed:

- BMC for the application of the blockchain in the healthcare
- Blockchain-based healthcare ecosystem
- Implementation of the smart contract between the Patient and the Laboratory using PyTeal and Algorand
- User application

Future development will be related to development of the smart contracts for the all participants in the proposed ecosystem and development of the new features for the EasyHealth application. It would require a skilled team of developers, blockchain experts, and healthcare professionals to implement the proposed blockchain ecosystem, as well as ongoing maintenance and support.

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