MedBlock: Using Blockchain in Health Healthcare Application based on Blockchain and Smart Contracts

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Abstract: Nowadays, healthcare data is generated every day from both medical institutions and individuals. Store and share such large amounts of data is expensive, challenging as well as critical. This challenge leads to a scenario of a lack of interoperability between health institutions and consequently to a patient's health data scattered across numerous systems. Blockchain emerges as a solution to these problems. It consists of a distributed database where records are saved with cryptographic encryption, making them immutable, transparent and decentralized. There are multiple healthcare applications blockchain-based that are being actively developed in order to solve the problem of interoperability between different health providers. The main objective of this work is to analyse and survey the blockchain technology and to study the smart contracts development, for the purpose of healthcare applications. Since this research is developed in the context of MedClick – a web platform that has the goal to give patients the possibility to save their health data plus interact with all the medical institutions they choose to, in one single site – an additional goal of this paper is to set the architecture to MedBlock – the MedClick platform based on blockchain and smart contracts.

1 INTRODUCTION

In our society, healthcare is a domain where a large amount of data is generated, accessed, and disseminated on a regular basis. Storing and distributing this large amount of data is crucial, as well as significantly challenging, due to the sensitive nature of data.

Furthermore, the healthcare interoperability landscape is generally centered around business entities, like hospitals and clinics. Each entity, creates and maintains data with its own format and it is siloed within the information system that creates it. Because of this business centered scenario, a patient is also obligated to fully trust his or her Electronic Health Record (EHR), that contains highly sensitive and critical data, to certain institutions. Besides, when needed, the exchange of patients' data between different institutions can be technically challenging and requires significant collaboration between the entities involved (Gordon & Catalin, 2019).

The consequence of the lack of interoperability between entities is that an individual patient's health data may be scattered across numerous systems, and no institution may have a complete picture. This causes a lack of patient centricity and can lead to a compromised treatment (Medicalchain, 2018).

A technology that has been growing and expanding is the blockchain technology. Succinctly, this technology consists in a distributed database. Its records are saved in blocks which makes it an immutable, secure database. Being decentralized allows its transactions to be transparent. This emerging technology is being developed in many different sectors, including healthcare.

Using blockchain, the problem of the lack of interoperability between different health providers can be solved, lowering operations costs and coordination efforts. Besides, patients' health records integrity is ensured and allows them to own their private health records.

Considering the need to come up with a solution to develop healthcare applications capable of handling healthcare information at an increasing scale, capable of sharing patients health records between different institutions, increasing interoperability, the main goal of this work is to survey the state of the art of blockchain technology, its principles and applications and how smart contracts can complement it. Furthermore, this paper aims to survey the state of the art of healthcare applications based on blockchain. Since this study is done in the context of MedClick

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(a web platform that aims to give patients the possibility to schedule appointments, interact with all health providers and manage healthcare information in one single site), an additional goal of this work is to implement MedBlock – the MedClick platform based on blockchain and smart contracts.

The rest of this document is organized as follows. In Section 2, the related work is presented, including the background and state of the art of blockchain and smart contracts, its application in healthcare and an analysis of existing blockchain applications that focus on healthcare. In Section 3, the proposed solution is described, as well as its requirements and the work already implemented. In Section 4, the evaluation methodology to analyse the proposed solution is defined. Finally, Section 5 concludes this document.

2 RELATED WORK

This section first describes how blockchain works and its main components. Then, a few blockchain platforms are analyzed. Next, the benefits of blockchain in healthcare are explained. Lastly, existing works that refer to healthcare platforms based on blockchain are presented.

2.1 Blockchain Background

2.1.1 Distributed Ledger

A possible technology to solve the lack of interoperability among health institutions and to solve the lack of patient centricity is the distributed ledger.

A distributed ledger is an asset database that can be shared across a network of multiple sites or institutions. This network is composed by participating nodes or peers, where each peer is a computing device. All participants nodes can have their own identical copy of the ledger. Besides sharing assets, the participants nodes can have resources allocated, that when functioning together can make decisions on behalf of the network (Leeming, Cunningham, Ainsworth, 2019). This technology is highly efficient since changes made by any participant with the permission are immediately reflected in all copies of the ledger. (Gupta, 2018).

2.1.2 Blockchain Network

Blockchain is one form of a distributed ledger.

This specific shared ledger has records saved in blocks that are linked together creating a chain. This means the records saved have an order. In its turn, each block consists of a group of transactions and a hash that binds it to the preceding block (Li, Nelson, Malin, Chen, 2019).

This type of distributed ledger is defined as an immutable ledger for recording transactions, because no participant node can tamper a transaction after it has been recorded to the ledger. (Gupta, 2018).

Besides being a type of database, blockchain can also set rules about a transaction and tied them to the transaction itself. In contrast with conventional databases where the rules are set at the database level, not in the transaction (Walport, 2016).

An important aspect to mention is that, in practice, blockchain may not be a suitable technology to store large amounts of data due to the cost and speed of writing data. A solution to this problem is to store the actual data off-chain, in external data sources, and store on-chain the pointers to that data as hashes (Leeming, Cunningham, Ainsworth, 2019). This design continues to guarantee the integrity of data by comparing the hashes off and on-chain.

2.1.3 Smart Contract

Smart Contracts are computer programs written to form agreements or establish a set of rules between participants in a blockchain network. Using smart contracts it is possible to ensure that the clauses of a contract are accomplished and that breaching the contract is expensive (Rosado, 2018).

Smart contracts are stored in the blockchain network and are executed automatically as part of a transaction, without relying on a third party (Gupta, 2018). This means that when a participant node receives a transaction, the smart contract associated with that transaction is invoked to ensure the validity of the transaction and that the conditions stated in the contract are met (Rosado, 2018). The result of the transaction, if valid, is then recorded in the blockchain. They cryptographically assure business logic, provide controlled access to the blockchain and allow that a transaction over an asset is made in a transparent, conflict-free way while avoiding transaction costs and the interference of a third party (Swanson, 2015).

There is a variety of smart contract use cases that can be applied to different application domains. They can be used for banking transactions, for registering any kind of ownership, or managing access control to a specific asset. In each case, the smart contract includes all the terms and conditions agreed by each stakeholder available in the respective process.

The existence of smart contracts makes it possible to create decentralized applications based on blockchain technology. Putting it simple: if the blockchain is the database, then the smart contract is the application layer that accesses it.

2.1.4 Permissioned and Permissionless Blockchain

Blockchain networks can be permissioned or permissionless.

Permissioned networks are private. This means users need credentials – a unique identity – to connect to the network and have restricted levels of access. Within these networks there is a main identity provider that manages access control (Li, Nelson, Malin, Chen, 2019). These types of networks are more suitable for organizations that want the ability to constrain network participation. This leads to a lack of transparency which is a disadvantage, but it compensates assuring confidentiality.

On the other hand, permissionless networks are public. This means they are accessible to every Internet user and do not need credentials to add new blocks to the distributed ledger. Any machine can become a trusted node in the network, have an identical copy of it and participate in it (Li, Nelson, Malin, Chen, 2019). These types of networks typically involve a native cryptocurrency (Androulaki et al, 2018).

2.1.5 Consensus Mechanism

A consensus mechanism is the process in which a majority of network participants come to an agreement on the state of a ledger. It is a set of rules and procedures that allows to add blocks to the blockchain and maintain coherent a set of facts between multiple participating nodes (Rosado, 2018).

There are several mechanisms that vary from blockchain to blockchain. Table 1 presents a description of the most used.

Table 1: Table with the most used consensus mechanisms.

Consensus	Description
Proof of Work – PoW	Requires nodes to spend large amount of computational power to solve intensive hashing algorithms to add a new block. PoW gives economic incentives to participating nodes so they spend their computational power (Li, Nelson, Malin, Chen, 2019)
Proof of Stake – PoS	Has miners that stake their cryptocurrency tokens as a bet on which block they want to include in the ledger. This proof makes it so that any participant of the network has in its best interest to be honest. This mechanism is less wasteful than PoW (Costa, 2018)
Proof of Authority – PoA	The transactions are validated, aggregated into blocks and put into the blockchain by approved known nodes, which act like administrators. This is a more centralized kind of consensus (Li, Nelson, Malin, Chen, 2019)
Byzantine Fault Tolerance – BFT	There are numerous BFT algorithms and they require each node to know every other node in the network so that consensus is reached. They normally require a trusted central authority.

2.2 Blockchain Platforms

Blockchain emerged with the creation of the Bitcoin blockchain in 2009. Bitcoin was developed as a peer-to-peer electronic cash system and its goal was to develop electronic payment system based on cryptographic proof, allowing a transaction to happen without trusting a third party (Nakamoto, 2008).

After that, there has been an increase interest on the development of blockchain-based technologies and blockchain capabilities started to be considered to improve existing applications and to develop new ones. This happen not only in financial sectors, but also in governments, supply services, insurances, commercial services and healthcare.

Besides, blockchain platforms started to appear to allow developers to develop blockchain applications at ease. There are a variety of platforms for a diversity of business needs that allow more companies to implement their blockchain-based business.

At the moment, Ethereum and Hyperledger Fabric are the most relevant blockchain platforms due to their features (Kuo, Rojas, Ohno-Machado, 2019). Considering network permission, consensus protocol, smart contracts support and scripting language as main features, it is possible to compare the two platforms to choose the platform that can be used for the proposed solution of this work.

Ethereum can be a permissioned or permissionless blockchain, uses the Proof-of-Work consensus and allows the development of smart contracts in Solidity, a domain-specific language. It has a public cryptocurrency that is used to mining, that is, to add new blocks to the network. Hyperledger Fabric is a permissioned blockchain, its consensus algorithm is pluggable, depending on the domain it is being used, and supports smart contracts in Java, Go and Node.js. Also, Hyperledger Fabric does not have cryptocurrency (Kuo, Rojas, Ohno-Machado, 2019).

When comparing these platforms in terms of their technical features, Hyperledger Fabric is most suitable for the purpose of this work. This is because it supports smart contracts in popular languages that most developers know, it has a modular and pluggable architecture that makes it more versatile to implement and does not have a cryptocurrency that makes the consensus computationally expensive. These features meet the requirements for the solution that will be proposed below.

2.3 Blockchain in Healthcare

Healthcare is one sector where blockchain technology can make a difference and have an impact in patient's lives.

In this sector, all clinical data transactions have verification costs associated. There is the cost of securing data, along with the cost of maintaining a primary source of truth (Gordon & Catalini, 2018). Moreover, a result of the current healthcare being centered around business entities is the use of highly centralized information technology systems.

Blockchain is one possible technology that can mitigate this problem. It is economical and efficient and being a decentralized ledger, it eliminates duplication of effort and reduces the need for intermediaries (Gupta, 2018). Additionally, applying blockchain to medical platforms may lower operations costs and coordination efforts to reach interoperability at scale (Gordon & Catalini, 2018).

This secure interoperability between health providers is assisted by smart contracts, since once set, a smart contract is immutable and can be trusted to operate the same way, using trusted information shared equally between all entities, indefinitely (Kumar, Ahmad, Ramadi, Braeken, 2018).

By design, permissioned distributed ledger systems are more compatible with healthcare systems and therefore provide more utility to medical institutions (Underwood, 2016). This is due to the need of selective disclosure of private information that rely on zero knowledge cryptography to provide verification of transactions with a high degree of privacy over the data (Gordon & Catalini, 2018).

2.4 Blockchain Implementations in Healthcare

Regarding the development of blockchain in healthcare, there are currently several papers and implementations.

A relevant example is the Estonian Government that implemented a blockchain solution in 2012 where each person in Estonia has an online e-Health record that can be tracked. The KSI Blockchain technology is used. Because only a hash of data is stored on the blockchain, it can scale to provide im--mutability at high speed (Martinson, 2019).

Another example is the *Ledger of Me* platform where the access of medical data and digital interventions is combined. It is a system that allows apps to interact with patients and their data. This platform does not store EHR directly on the blockchain, instead it stores hashes in it that will work as pointers to the EHR stored off-chain (Leeming, Cunningham, Ainsworth, 2019).

Similarly, the *MediBchain* paper proposes a patient centric healthcare data management system by using blockchain as storage to guarantee privacy. Here the patient's data is also shared and managed by him (Omar, Rahman, Basu, Kiyomoto, 2017).

Likewise, *CareChain* is a consortium that establishes a blockchain to which everyone can connect but not be a computer node. It aims to create interoperable health data blockchains and to give individuals control over their own health information (Carechain).

Another example of a system that is blockchain based and will permit patients to easily and securely share their medical records with providers is the *Coral Health* platform. Its goal, using Ethereum, is to create efficiencies in small but multiple parts of the current health data landscape (Park et al, 2018).

Dovetail Lab is as well working on a healthcare system to share patient's data to improve the overall healthcare system and healthcare services. The system, based on Hyperledger Fabric, always informs patients about data sharing and never do this without the correct permissions (Dovetail, 2019).

MyMEDIS is also a blockchain-supported system that, using both Fabric and Ethereum, aspires to give control to patients over their existing medical records and health related data, while making them instantly available everywhere (Kovach & Ronai, 2018).

A blockchain infrastructure that implements its own blockchain platform, that is, it does not use blockchain platforms like Ethereum or Hyperledger is *Patientory.* Its goal is to empower patients, professionals, and healthcare providers to access, store and transfer information safely, thus improving care coordination while ensuring data security (McFarlane, Beer, Brown, Prendergast, 2017).

Another identical proposal is the *BlocHIE* paper. It suggests a blockchain-based platform for healthcare information exchange between medical institutions and individuals. It uses two loosely-coupled blockchains – Electronic Medical Records Chain that stores EMR for medical institutions and Personal Healthcare Data Chain that stores PHD for individuals (Jiang et al, 2018).

MedRec is also a proposal of a decentralized re-cord management system to handle EHR and its implementation is based on Ethereum. It has a modular design that integrates with providers' existing data storage solutions (Azaria, Ekblaw, Vieira, Lippman, 2016).

One more example is the *Medicalchain* platform, built on Hyperledger Fabric. This platform allows other digital health applications to develop on. It is currently developing two applications: a telemedicine to consult a doctor remotely and a marketplace of health record to use in research. It uses two blockchain structures – Hyperledger Fabric and Ethereum (Medicalchain, 2018).

The majority of the solutions presented focus on the benefit of blockchain to provide an audit of access to data to allow the patient to manage consent and to provide interoperability between several institutions. Thus, this work is based on existing works, that is, it is the combination of specific elements of each work in order to develop a use case of a healthcare application – MedBlock, the MedClick platform on blockchain and smart contracts.

Table 2: Table comparing related work mentioned above.

	Technology	Consensus	Cryptocurrency
Estonian Government	KSI Block-chain	Not specified	No
Ledger of Me	Available to use different technologies	Not specified	No
MediBchain	Own Technology	Own protocol	No
Carechain	Ethereum without mining	Not specified	Yes
Coral Health	Ethereum	PoW	Coral Health Tokens
Dovetail Lab	Fabric	Practical BFT	No
BlocHIE	EMR-Chain + PHD-Chain	PoW with FAIR-FIRST + TP&FAIR	No
MedRec	Ethereum	PoW	No
Medical-chain	Fabric + Ethereum	Practical BFT + PoW	MedTokens
MyMEDIS	Fabric + Ethereum	Practical BFT + PoW	MediCoin
Patientory	Ethereum	PoW	PTY/ DASH

3 PROPOSED SOLUTION

This section describes the proposed solution, its requirements and architecture.

3.1 Requirements

In order to develop MedBlock, the healthcare application proposed in this paper, it is necessary to consider the requirements of MedClick.

MedClick is a one-stop platform that allows to book an appointment across multiple medical service providers, in a fast and user-friendly way. By having a single platform for the patient to access multiple healthcare providers, booking a medical consultation becomes simpler and quicker. This allows the patient to avoid the tedious and complicated process of booking an appointment and always be dependent of the electronic system provided by each health provider. Figure 1 presents a UML Use Case diagram with the most relevant use cases of the MedClick platform that this work is expected to support.

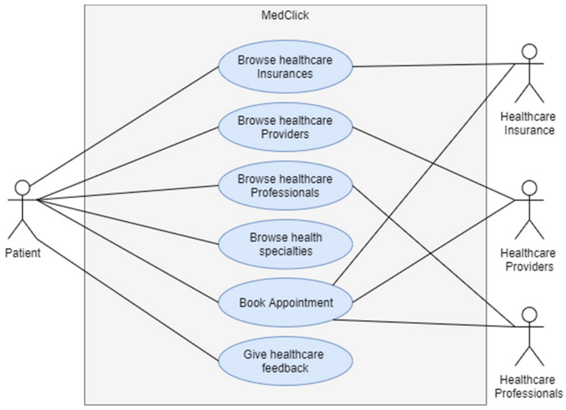

Figure 1: Use Case diagram of the MedClick platform.

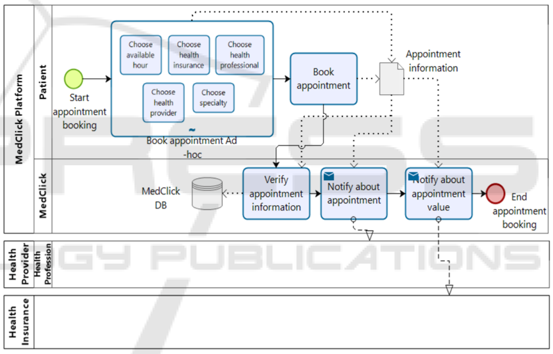

Figure 2: Business process for booking an appointment in the MedClick platform.

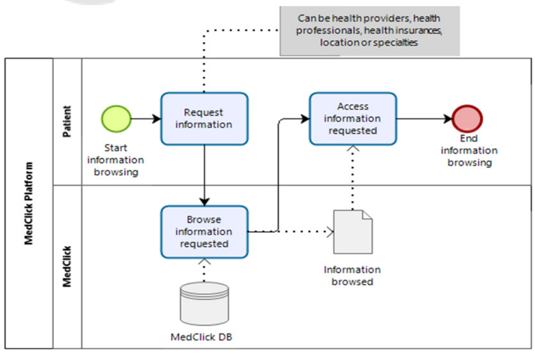

Figure 3: Business process for browsing information in the MedClick platform.

In Figure 2 and 3, it is represented the business processes, in BPMN, regarding the most relevant functionalities for the purpose of this work – book appointment and browse information.

3.2 Solution

Considering the distributed context of interaction with medical institutions, involving several healthcare providers, patients, and insurances, and the current architecture of the MedClick platform, a solution to help improve interoperability, security, shareability and accessibility of health data is to implement MedBlock – the MedClick platform based on blockchain and smart contracts.

The main goal of this solution is to save information in the blockchain regarding appointments, patients' most relevant information, health professionals, health providers and insurances.

Additionally, all transactions about this information are also stored in the blockchain so that these become immutable and visible to all authorized entities. In Figure 4, it is represented an Application Usage Viewpoint in Archimate of the main features of the MedBlock and the interaction of those authorized entities with the blockchain. The Other Ledgers mentioned can correspond to more Healthcare Providers.

Concerning the patient's health records, that differ from the patient relevant information in terms of size and quantity, they are saved outside the blockchain in a non-distributed way. Moreover, a hash of each health record, used as a pointer, is stored in the blockchain. This design avoids the expensive computational cost of storing large files in the blockchain, while assuring that the data is not changed without permission. This guarantee is made through the comparison of hashes off and on blockchain.

Considering the granular access control required for sensitive health data, the most suitable blockchain is a permissioned and private one. Here most of the blockchain control is given to MedClick, that has access to all data. This allows that each health provider has only access to data from their patients. This configuration ensures confidentiality of data.

In Figure 5, it is represented a UML sequence diagram of how a generic interaction between a patient and the MedBlock ClientApp is, using Hyperledger Fabric. Note that the MedBlock ClientApp includes the MedClick portal and the Node.js server. This server invokes the smart contract – chaincode – created for MedBlock, that in its turn communicates with the ledgers.

Regarding the requirements of MedClick mentioned above, this proposal supports the flow of

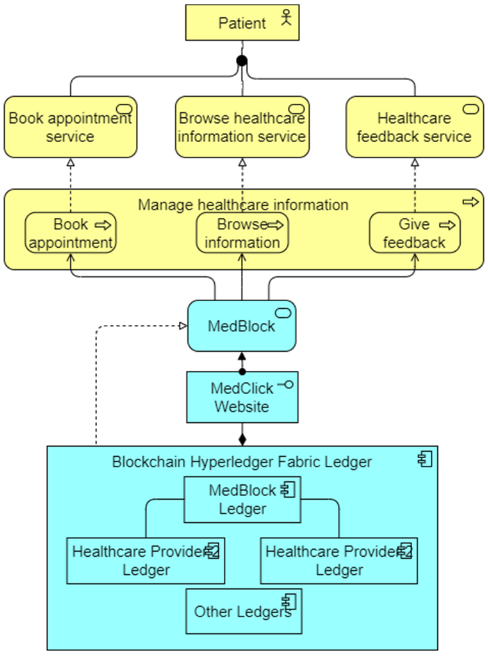

Figure 4: Archimate Application Usage Viewpoint of the proposed solution.

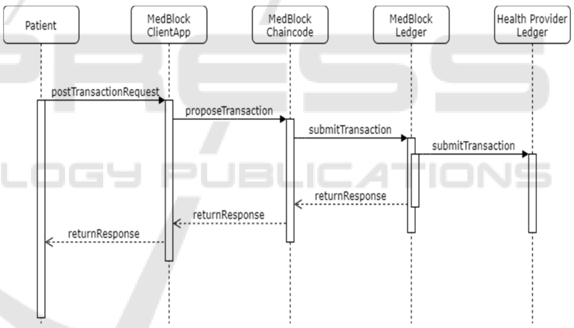

Figure 5: UML Sequence Diagram of a generic interaction with MedBlock.

booking an appointment and browsing information regarding health providers, health professionals, health insurances, locations or specialties. The smart contract, that in Figure 5 corresponds to *proposeTransaction*, includes one function for the book appointment and another for browsing information.

Taking in consideration the characteristics of the proposed solution, the supported flows and considering the reference of multiple existing works already presented, Hyperledger Fabric, with Practical Byzantine Fault-Tolerant consensus algorithm, is the most suitable blockchain platform to implement this solution. This choice is due to the fact that Fabric supports smart contracts in Node.js which is the language used in MedClick, it has a modular and pluggable architecture that makes it more versatile to implement and does not have a cryptocurrency that makes the consensus computationally expensive.

In figure 6, it is shown a Technology Usage Viewpoint in Archimate, which is an example of a set of nodes for the MedBlock Network and for a Healthcare Provider, using Hyperledger Fabric. The number and the type of the peers in each network can be specified. This is an example for only one Healthcare Provider, though the architecture for several Healthcare Providers is the same structure.

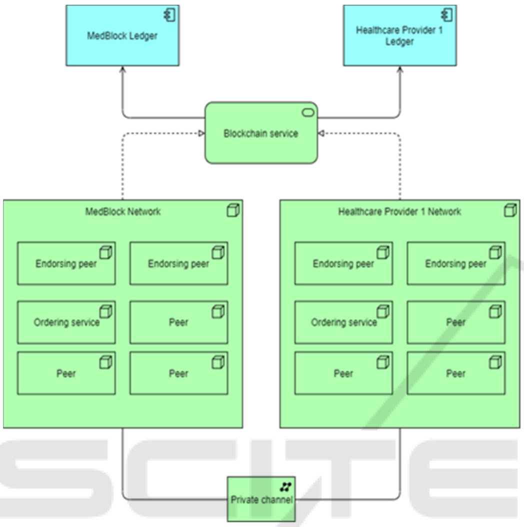

Figure 6: Archimate Technology Usage Viewpoint of the proposed solution.

3.3 Implementation

Using Hyperledger Fabric, the main steps to implement the proposed solution are:

- Create a blockchain network, including the peers. It must be specified where these peers are created – in MedBlock and in each healthcare provider;
- Create private channels between MedBlock and healthcare providers – this allows confidentiality;
- Create a Hyperledger Fabric ClientApp. This is the connection between the end user and the MedBlock blockchain network;
- Integrate the MedClick website that already exists with the ClientApp;
- Write smart contracts – chaincode – that are called from the ClientApp and submit transactions to the blockchain network.

At the time of writing this paper, a few steps of the implementation of the proposed solution have begun to be developed after installing the prerequisites and downloaded the necessary samples and images from Hyperledger Fabric. The first step was the creation of the MedBlock blockchain network, specifying the number and the type of the peers. Afterwards, an initial chaincode was written in Node.js, to initiate the MedBlock blockchain with a set of patients, health professionals, health providers and appointments, and to request simple queries – for example to get all health professionals or to get appointments by patient email. Then, a preliminary version of an Hyperledger Fabric ClientApp was developed as a Command Line Interface, where the input from the command line was parsed to invoke the chaincode previously created.

This initial implementation will be improved and will be used as a base to continue to develop the remaining steps of the planned solution.

4 WORK EVALUATION METHODOLOGY

Blockchain technology has its strengths as well as its weaknesses. To analyse the proposed solution in the context of the MedClick using Hyperledger Fabric and considering the trade-off between its performance and its limits, an evaluation methodology must be defined.

The performance of a blockchain platform can be affected by many variables such as transaction size, block size, ordering service, network size and topology of nodes in the network, the hardware on which nodes run, the number of nodes and channels, and the network dynamics (Hyperledger Working Group, 2018). To measure the performance of Fabric, the Hyperledger community is currently developing a draft set of measures along with a corresponding implementation of a benchmarking framework called Hyperledger Caliper (Hyperledger Fabric, 2019). It allows to measure the performance of Fabric given a set of use cases. This tool can produce reports containing various performance metrics such as execution time, latency, resource consumption, scalability and throughput (Pongnumkul, Thajchayapong, Siripanpornchana, 2017).

To measure the performance of MedBlock, the Hyperledger Caliper will be apply to the use cases in the context of MedClick regarding different types of patients, appointments, health providers and health professionals.

5 CONCLUSIONS

Nowadays, with the increasing number of medical services providers and consequently the number of appointments, with the lack of interoperability and the lack of patient centricity that is adjacent to it, comes the need to find a solution with a secure and viable way to store healthcare data and process transactions in this sector. This solution must be capable of mitigating these difficulties and improve usability for the patients as well for the professionals.

This is where blockchain comes in. Being a technology that ensures immutable and secure transactions, it becomes a possible resolution for the health sectors. Considering these two major factors, after analysing the state of the art of blockchain technology and of smart contracts, this work presents a healthcare application blockchain-based – MedBlock – as a solution to mitigate such problems.

To summarize, this research combines the blockchain features that are beneficial for healthcare with the smart contracts strengths, within the context of the MedClick. This result in a healthcare application based on blockchain and smart contracts that gives patients the possibility to save their health data plus interact with all the health providers and professionals they choose to, in one single platform. Besides, being implemented in Hyperledger Fabric, a blockchain platform that has a modular architecture, allows this work to take advantage of the blockchain strengths in a business development context.

Currently the authors are finishing the implementation of MedBlock and the evaluation of results is planned.

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