HERIOT-WATT UNIVERSITY

BS COMPUTER SYSTEMS (HONOURS)

FINAL YEAR DISSERTATION

Electronic Health Records in a Blockchain

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Declaration

I ,**Jason Shawn D'Souza**, confirm that this work submitted for assessment is my own and is expressed in my own words. Any uses made within it of the works of other authors in any form (e.g., ideas, equations, figures, text, tables, programs) are properly acknowledged at any point of their use. A list of the references employed is included.

Abstract

Blockchain is a rising technology that permanently records transactions which cannot be erased/tampered with and data gets appended to, thus keeping a never ending historical trail. These features have resulted in its implementation not only as a cryptocurrency but also in various other fields including the healthcare industry. This project looks into implementing blockchain in remote patient monitoring for easier management/sharing of electronic health records(EHR) between the user and neccessary healthcare officials/authorities. The purpose of this project is to use blockchain technology to allow users to share their EHRs with different personnel of the healthcare sector and remove unnecessary intermediaries thus creating an ecosystem where data is being shared among the all these actors and the data being shared is secure. The popular applications of health currently include Bowhead Health and Health care Data Gateways(HDG). Bowhead health has its beta tester unit out wheres HDG was a proposed mobile application using blockchain that hasnt been publicly released. The project will also aim to build an application depicting the blockchain network.

Acknowledgement

I would like to thank:

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- My family and friends for their support and prayers

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Abbreviations

Abbreviation	Full Form
EHR	Electronic Health Record
HDG	Healthcare Data Gateway
HCL	Hindustan Computers Limited
P2P	Peer to Peer
EMR	Electronic Medical Records

Chapter 1

Introduction

This chapter discusses the motivation behind the project, the aims and objectives of the project, the problems solved by the project and discuesses the relevant Professional,Legal, Ethical and Social issues faced by the project. The other chapters contained in this document are discused in the Document Overview section.

1.1 Motivation

Blockchain can be defined as a digital, decentralized ledger of all transactions in a given system[1]. The Blockchain technology initially was initially developed for the cryptocurrency. Bitcoin (an application of blockchain) has taken the tech world by storm. Researchers and enthusiasts alike are evaluating the use of blockchain in various other fields. The EHR(Electronic Health Records) used in the healthcare industry(for example, hospitals,clinics etc.) are currently decentralized, so sharing and managing data is time consuming and labour intensive in most cases. Blockchains are never ending historical trails of transactions which cannot be erased/tampered with.

1.2 Aims

- To understand and evaluate the potential of blockchains in the healthcare industry
- Studying and evaluating the effectiveness of usage of Blockchain in the healthcare industry by using them to store Electronic Health Records(EHRs)
- Developing an application to enable remote patient monitoring but with the use of blockchains as the data storage of choice

1.3 Objectives

Objectives of this project are :-

- Reviewing literature concerning blockchains and in particular blockhains in the healthcare industry and its usage in remote patient monitoring
- To study and create a structured blockchain model that closely resembles an EHR.
- Develop a smart contract backend for the proposed model.
- Creating a mobile/web application where users, and necessary personnel in the healthcare industry can share and manage data using blockchain technology

1.4 Problems Solved

The project answers the question of why a decentralized ledger (Blockchain) can be useful in the healthcare industry. In particular,it focusses on storing Electronic Health Records(EHRs) in a permissioned Hyperledger blockchain (patients can only see their OWN records and no one elses). Since Hyperledger blockchain (Hyperledger composer included) is an emerging technology many features are yet to be included which include the ability to enable ”participant” logins (logins by patients/doctors using the angular frontend generated by composer) although these will be implemented in the future. All work is done using the frontend provided by Hyperledger Composer.

1.5 Professional, Legal, Ethical and Social Issues

This section discusses the relevant professional, legal, ethical and social issues.

1.5.1 Professional issues

The project is my own work but is built on the Hyperledger Composer developed by Hyperledger and IBM. It is my responsibility as a professional to delete all data gathered for the project upon its completion

1.5.2 Legal issues

Since healthcare data is confidential and should not fall into the wrong hands,it is a moral obligation to not let this data fall into the wrong hands. A private blockchain network will be built. This is done because private blockchain operators can control who is allowed to operate a node, as well as how those nodes are connected. A node that restricts the transmission of information, or transmits incorrect information, must be identifiable and circumventable to maintain the integrity of the system [2].

1.5.3 Ethical issues

To tackle these ethical issues, while testing the system, it will be communicated with the participants that only with their consent will their data be monitored (anonymized data) and they can back out AT ANY GIVEN TIME

1.5.4 Social issues

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1.6 Document Overview

The chapters of the document are organized as follows :

- Chapter 2 gives an outline of the research conducted in the areas of blockchains, remote patient monitoring, blockchains in the healthcare industry and the possible impact of blockchain in remote patient monitoring.
- Chapter 3 puts forward the systems functional and non-functional requirements and research questions
- Chapter 4 showcases the project plan and the methodology used during the project

- Chapter 5 discusses the evaluation plan
- Chapter 6 takes a look at the risk analysis of the project.
- Chapter 7 discusses the Professional,Legal, Ethical, and Social issues of the project.

Chapter 2

Background

2.1 What is a blockchain?

Blockchain -It is a technology that is talked about everyday. This is because of its potential to revolutionize not only cryptocurrency but the other industries also. Blockchain was developed by Satoshi Nakamoto for the cryptocurrency known as Bitcoin. Blockchains can be considered as a collection of digital wallets

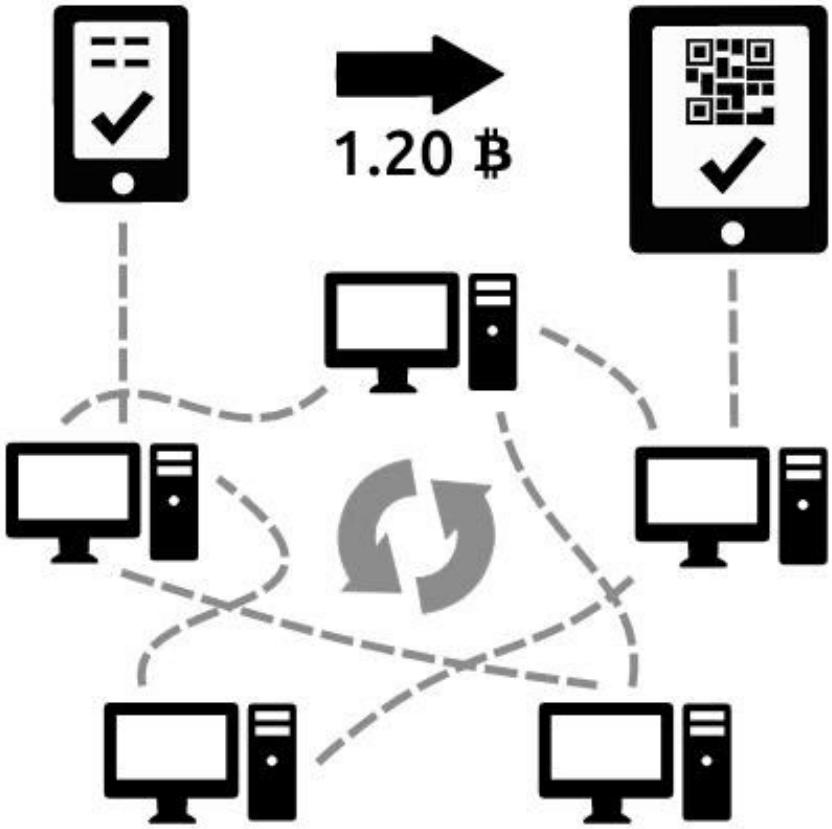


Figure 2.1: How a bitcoin transaction works[3]

On the off chance that a Bitcoin exchange takes place (Taking Figure 2.1 as an example) is produced using wallet A to wallet B(the mobile phone and tablet denote the wallets in this case), this data is at the same time imparted to every single other wallet in the basic Bitcoin Blockchain(all the connected pcs de-

note servers part of the blockchain). The data on a Bitcoin exchange (e.g. money transferred,ownership etc.)are combined in a block with a timestamp and is added as a new block to the existing blockchain(the transaction is simultaneously checked, verified and confirmed(or rejected) in case of false transaction) by all involved wallets . Due to this continuous sequence of blocks of information,the information(regarding transactions) made in the past and at any given time are visible and are tamper proof [4]. The commonly used blockchain technologies are Ethereum and Hyperledger. Ethereum is mostly used in applications to be used by the masses and is not as flexible as the Hyperledger technology. Hyperledger technology is more modular. For example, it is not possible to have a transaction visible to a person but to not have them visible to anyone else which is possible in hyperledger and NOT in ethereum [5](useful for private transactions). This is a negative about ethereum but it does not outweigh its positives which include that it has built in blockchains/cryptocurrency and can be useful for applications that utilize these. An interesting application of blockchain is the use of smart contracts. A smart contract is an agreement between parties that is deployed on a blockchain. Smart contracts allow for exchanging data/currency without a third party being involved or having knowing of the transfer and, it being set up on a blockchain is good as it lowers the trust required between parties which should effectively result in the fulfillment of the contract [6].

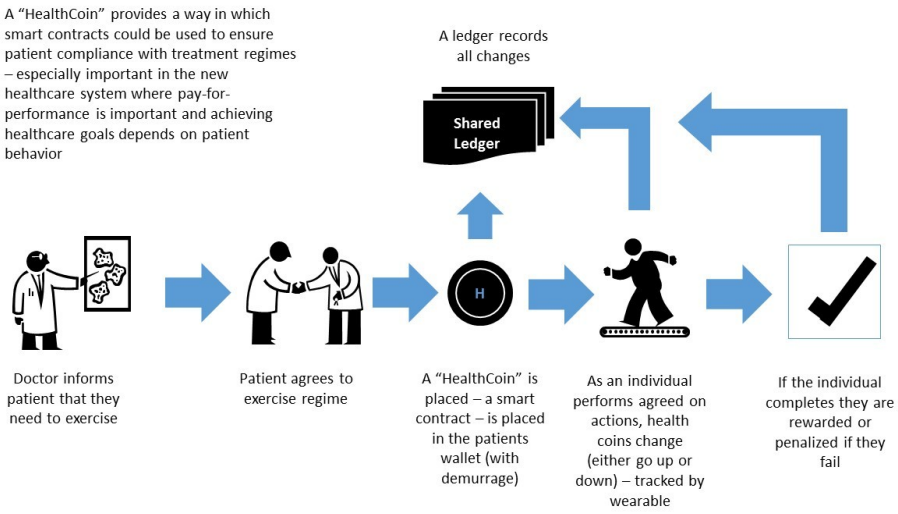
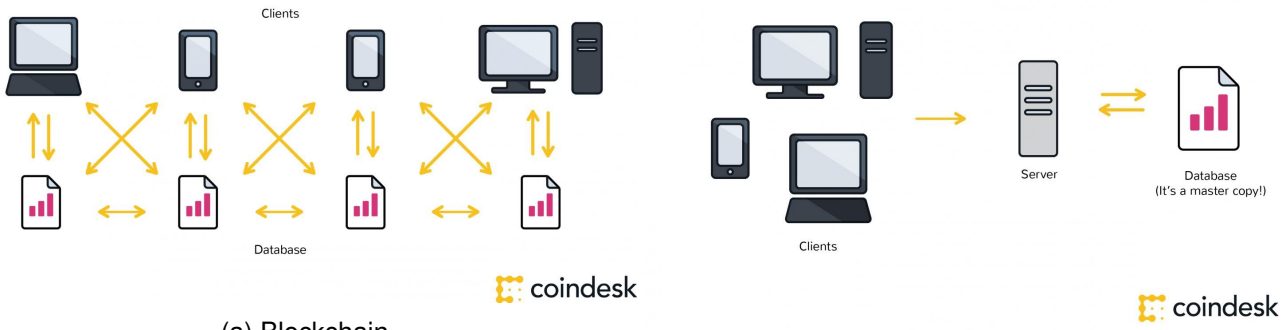


Figure 2.2: How a smartcontract in the health industry could work [6]

Figure 2.2 shows an example of how a smart contract would work in the healthcare industry with the contract being labeled "HealthCoin". This is different from the Porland based company healthcoin [7] that uses blockchain for diabetes prevention, heart disease and also obesity. The figure basically taks an example of a man being given a diagnosis of exercise and a smart contract being placed in the patients wallet. He either does the exercises as discussed with the doctor and gets rewarded or doesnt and gets penalised. All this is updated to the shared ledger/blockchain while the data is tracked using wearables

2.2 Comparison between Blockchains and Databases



(a) Blockchain

(b) Centralized Database

Figure 2.3: Comparison between centralized databases and blockchains[8]

Figure 2.3 shows the comparison between blockchains(Figure 2.3a and centralized databases(Figure 2.3b). Clients (PCs or mobile devices) connect to a main/centralized server where a database is located in the case of a **Centralized database**. The case of **Blockchains** is different as a client is not only its database but also the database of other clients (the other clients database is also connected to the same client **BUT THE CLIENTS ARE NOT CONNECTED TO EACH OTHER**) as can be seen in Figure 2.3a.

Gideon Greenspan [9], in his blog at multichain.com uses four metrics to compare databases and blockchains :

1. Disintermediation : This has the same meaning as Interoperability ,i.e, sharing of data directly across boundaries of trust. As will be discussed later on in this chapter, blockchain has the advantage over centralized databases in this regard

2. Confidentiality : Since blockchain consists of many nodes that contain the never ending historical trail of transactions, for many applications it is a negative point. This is where centralized databases winout. Since blockchain is append only, it is write-controlled whereas centralized databases are both read and write controlled.

3. Robustness: Blockchains are more robust than centralized databases as nodes of a blockchain are connected to each other in a p2p manner and this means that even if one node/ many nodes fails, the blockchain does not fail. Later on, if the nodes that failed are fixed, information that wasnt updated to them will automatically be synced to them [9]

4. Performance: Centralized Database Systems obviously win out in this regard due to the fact that blockchains have to carry out three additional tasks :

    - Signature verification : Each transaction must be verified
    - Consensus mechanism : All nodes in the node must reach a consensus about the transaction
    - Redundancy : Each node processes a transaction independently

A key point in the above comparison is that blockchains are significantly better than centralized databases in regards with disintermediation/interoperabillity. This is the main motivation behind this project using blockchains and NOT a centralized database.

2.3 What is an Electronic Health Record(EHR)?

An electronic medical record (EMR) is a single practice's digital version of a patient's chart which means that an EMR contains an history of diagnosis and treatments of a patient with only a particular doctor [10]. Since the whole point of the project is for easier sharing of data between patients and different doctors (or doctors forwarding their patients to other doctors) an EHR(Electronic Health Record) is more useful. An EHR contains not only the information that an EMR does but also involves a snapshot of the patients medical history.

2.4 Disadvantages of Blockchain in Healthcare

Tal Rapke MD [11], talks about both the positives and negatives about blockchains use in the healthcare industry. The negatives being:

- Integrity,privacy and security of data stored
  Blockchains are considered to be secure as data can only be appended and this stored data can be hard to tamper with. Although the data is secure, hacking attempts will still be possible so it is suggested that the Government of the country in question take an active role in making sure that everything is up to the security standards. [11]

- Transparency of the data
  Another issue raised about the issues of blockchains in the healthcare industry is that of too much transparency (each node can view the contents of a particular block). A challenge is achieving transparency,privacy as well as access to the required data concurrently. [11]

- Speed and Scalabilty
  Since blockchain technology is relatively new, adequate testing with healthcare data must be done so as to understand whether its use in the healthcare industry is reliable or not [11]

- Quality of Data
  Since data in a blockchain is appended, if any data in a block is corrupted it will and should be hard to erase. Solutions to tackle this possible issue needs to be made availible in case such issues arise[11]

Tal Rapke's criticism in regards with transparency and also regarding quality of data are well founded.

2.5 Advantages of Blockchain in Healthcare

In its current state there is a lack of interoperability in the healthcare sector(transferring healthcare records are an hassle). This is where the use of blockchain can make a huge difference. GEM, a startup in the US launched such a technology based on the Ethereum Blockchain technology. A Research Whitepaper by GEM [12] talks about how the blockchain technology can be used to enhance electronic health record(EHR) operability. They believe in this as blockchain will bring about File Integrity(Immutability),Cybersecurity as well as Interoperability. Gem has already developed its own blockchain "operating system" called the GemOS. The paper goes in depth on most topics but the most interesting is that blockchain guarantees file integrity. This is done through hashing. Users can check if the contents of a block/record have been modified/tampered if the hash is different than what was initially recorded. Since additions/revisions in blockchain are "append only" a new hash is recorded only for the new addition/revision. This can be understood from Figure 2.4

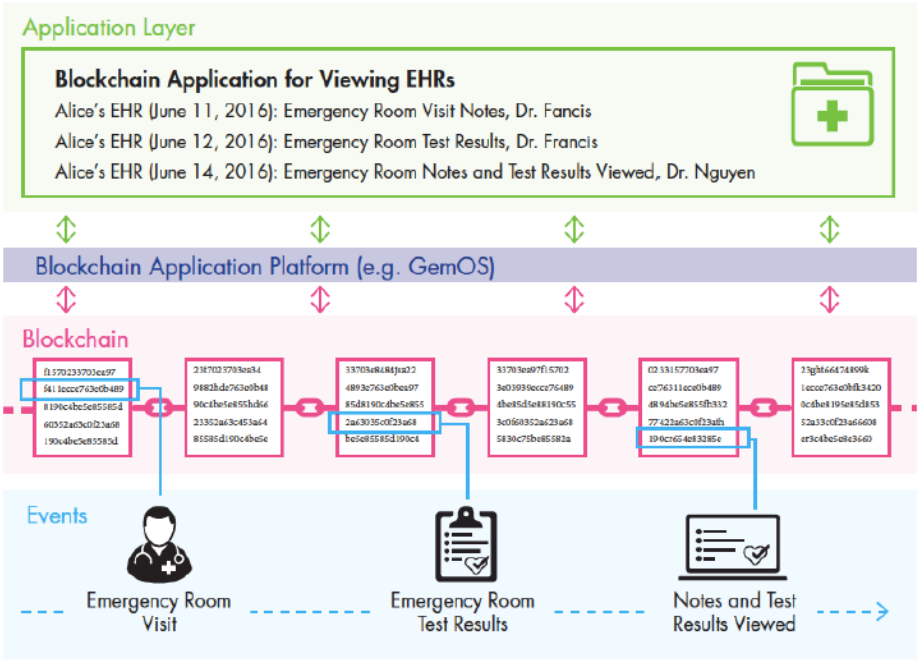


Figure 2.4: File immutability/integrity [12]

Another interesting topic was that of interoperability as shown in Figure 2.5. The figure depicts a scenario where a patient Alice is admitted to new doctor Dr. Francis who doesnt have her medical files. Her primary doctor Dr. Nguyen has her files and transferring them to Dr. Francis will take some time which wouldnt be needed if healthcare data was stored in blocks in a blockchain.

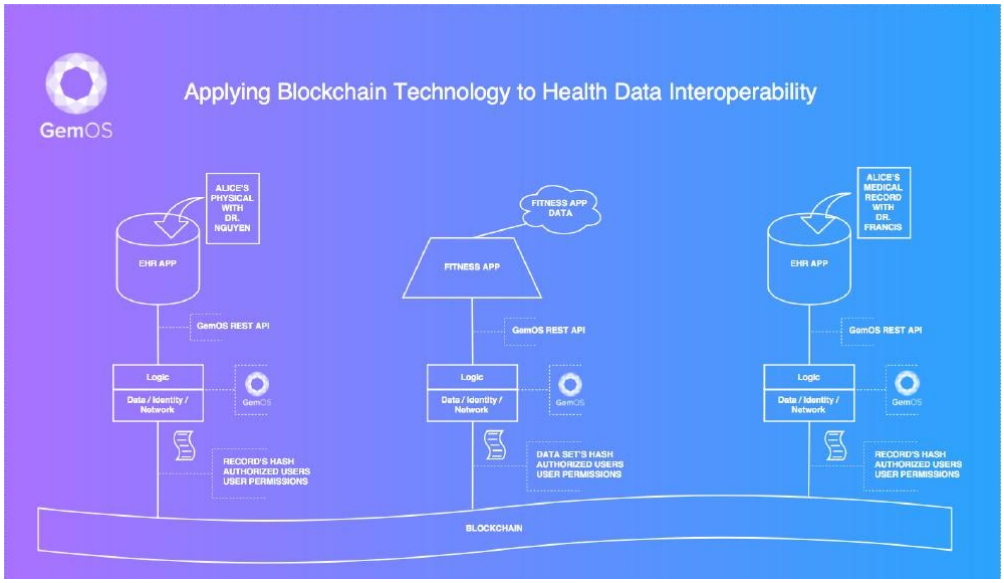


Figure 2.5: Interoperability[12]

Cases/Examples like these further increase the need of a better system for storing files and blockchain is one such alternative. An article by Gurmeet Chahal[13] considers blockchain as a technology that can redefine healthcare for the following reasons:

- Blockchain technology can enable more accurate diagnosis and enable better overall patient care while reducing economical costs.

- Current EHR systems make it hard to share healthcare data (lack of interoperability) and hampers data collaboration which is not true in the case of blockchains.

So the paper written by GEM [12] and the article written by Gurmeet Chahal of HCL [13] both confirm there is a lack of interoperability with the current EHR systems and both look towards blockchains as the solution to this problem

2.6 Remote Patient Monitoring

Remote patient monitoring(RPM) is only one of the many ways technology has improved the industry. Using RPM means patients need not be in an hospital to be under the supervision of doctors. The doctors can track their patients vitals from anywhere and this is beneficial to the patients that do not want to remain admitted to an hospital. There can also be cases where a doctor wants to monitor a patient from a remote place when he/she is not present at the hospital and RPMS can be of great use to them.

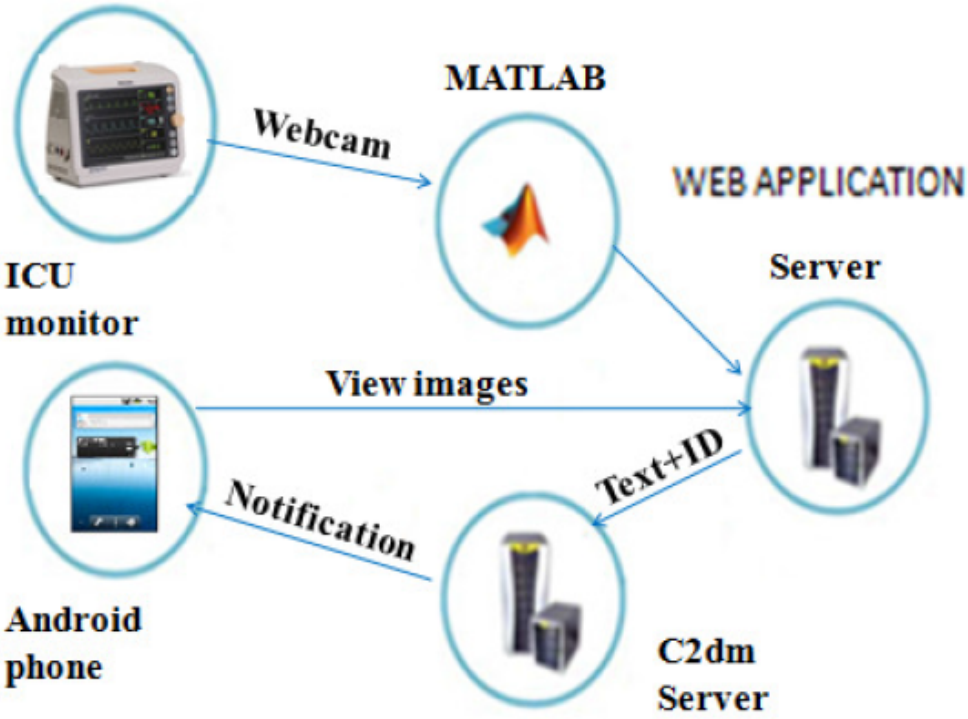


Figure 2.6: shows the working of an RPMS[14]

Figure 2.6 shows an example of an RPMS where the readings of an heart rate monitor are analyzed edited and sent to a server. From this server the Text and ID (heartate and other relevant data is passed to another server and notified to an end device/devices. This is an example of an RPMS in 2012 and with the emerging trends of fitbits [15] and other wearable data (most smartphones also), recording of heartrate has become easier and these can be used to make remote patient monitoring easier than in the given example.

2.7 Blockchain in Remote Patient Monitoring

The following sections take a closer look at the applications of blockchain in remote patient monitoring

2.7.1 Bowhead Health

Bowhead Health released a whitepaper on July 13th 2017 stating that they have a beta working prototype of the worlds first blockchain powered medical instrument.This instrument paired with their companion app will make remote patient monitoring easy. Their test device is equipped with test cartridges that support both blood and saliva samples and then sends these samples to a lab for testing. The instrument currently can perform the following:

- Can read and understand certain colors displayed by the test cartridge
- Can Refill,count and dispense spherical gel capsules.
- Can pair with iOS and Android devices.
- Can indicate percentage remaining of spherical gel capsules/nutritional supplement.

The feature of refilling and dispensing capsules can be particularly useful for the elder demographic with the companion app giving the user a reminder to take their supplements.

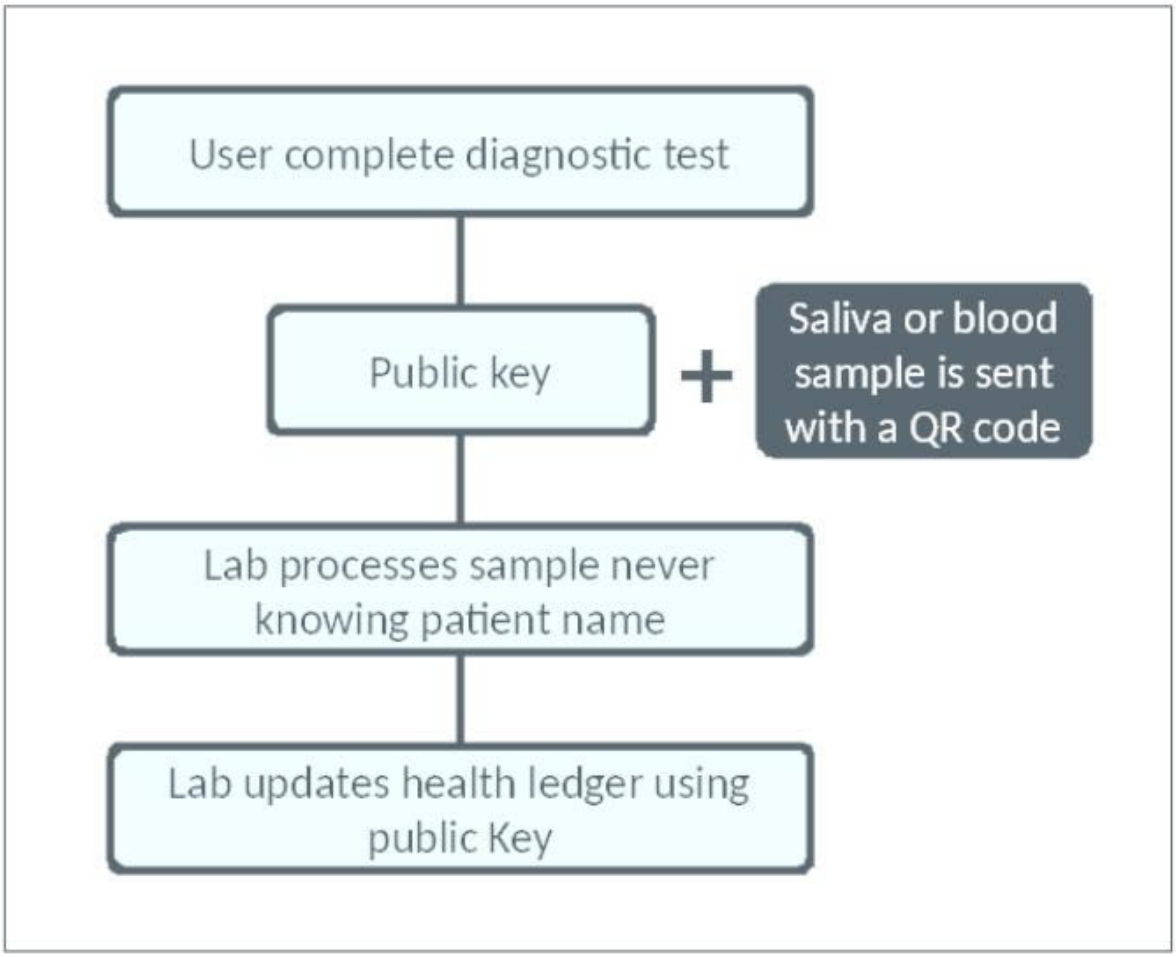


Figure 2.7: How tests are carried out with bowhead health[16]

Figure 2.7 shows that lab tests from bowhead healths device are run anonymously and are updated in the users ledger via a public key. The device is currently in beta currently has its public release in the summer of 2018.

2.7.2 Healthcare Data Gateways

Healthcare Data Gateways (HDG) is an app proposed by Xiao Yue et al. in their paper. They suggest the use of blockchains to enable the patient to manage and share his/her healthcare data with ease. The reason of developing the application for smartphones is down to their(smartphones):

- Popularity
- Computing power
- Ease of downloading and installing applications
- Network Quality [17]

These factors are hard to argue against and make it easier for users to store.
However, Xiao Yue et. al. [17] use EMRs in their app which is okay to use for one phycian as they do. Using EHRs would be better if they wanted to expand this project to allow for the patient to easily share his healthcare history with another medical expert.

2.8 Blockchain alternative in regards with healthcare industry

Deepmind Health a subsidiary of Google, works closely with NHS and has its own kidney monitoring app Streams currently only in use at Royal Free NHS Trust,London. The main reason for the use of Streams at this hospital is to help the doctors/medical practitioners identify and treat AKI (Acute Kidney Injury)[18].

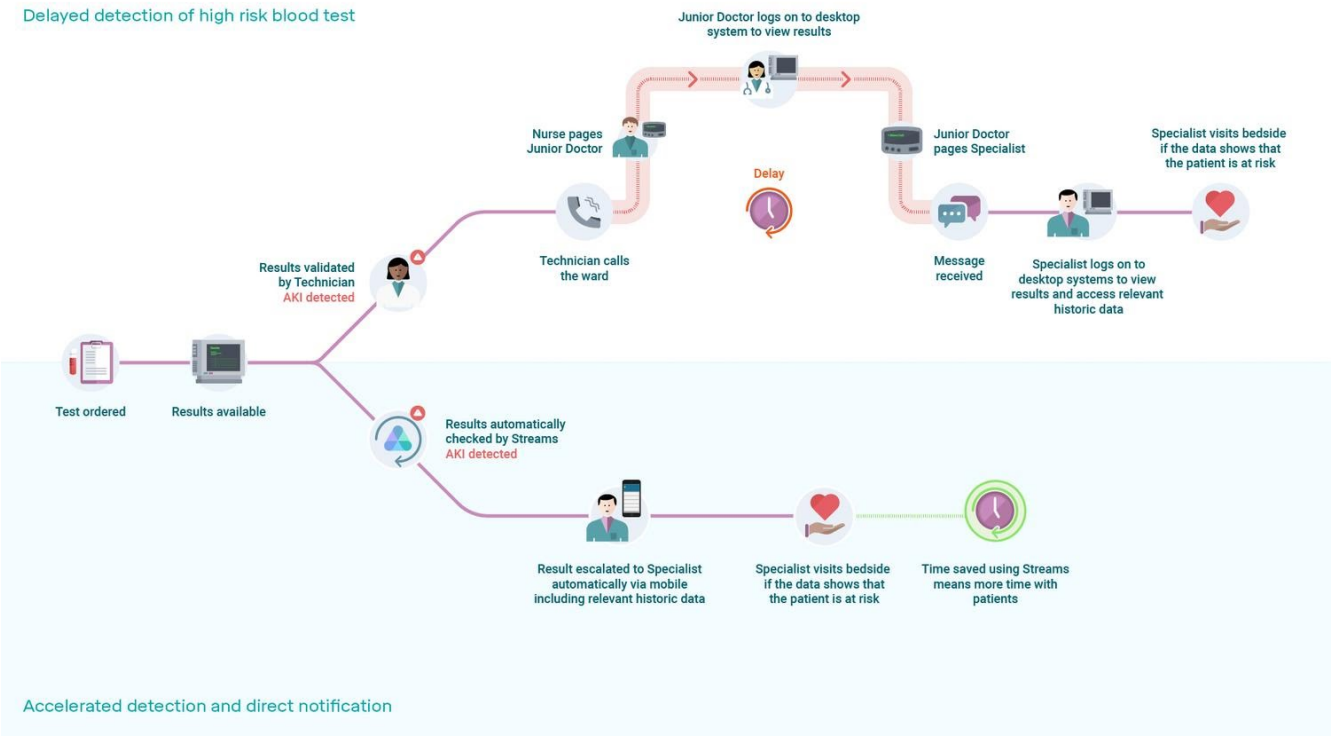


Figure 2.8: Comparison of normal blood tests versus streams[18]

Figure 2.8 depicts the comparison of how blood tests are conducted in hospitals(upper half) versus how it is conducted with streams(lower half). Streams uses a Verifiable Data Audit(Merkle/Hash trees

used instead of blockchains) which has special interactions with data,i.e, any entry in the record will also have the reason why the piece of data was used. The Verifiable Data Audit is just like blockchain in the sense that the data entered is ”append only” and just like in the case of blockchains, third parties can check whether data in these audits have been tampered with or not. The main reason that Deepmind doesnt use blockchain is that the participants of a blockchain need to carry out some complex calculations which involve high energy costs(estimates suggesting energy used are similar to the power consumption of the country of Cyprus)[19]. Another reason is that since deepmind should be used in accordance with trusted institutes like the NHS,hospitals etc. and they can be trusted to verify the integrity of the Verifiable Data Audits. The high energy costs of blockchains is a negative as pointed out by Deepmind. Verifiable Data Audits are a good alternative to save energy costs but only if the authorities using the data can be trusted.

Chapter 3

Implementation

This chapter investigates the implementation of the project.

3.1 How the system works

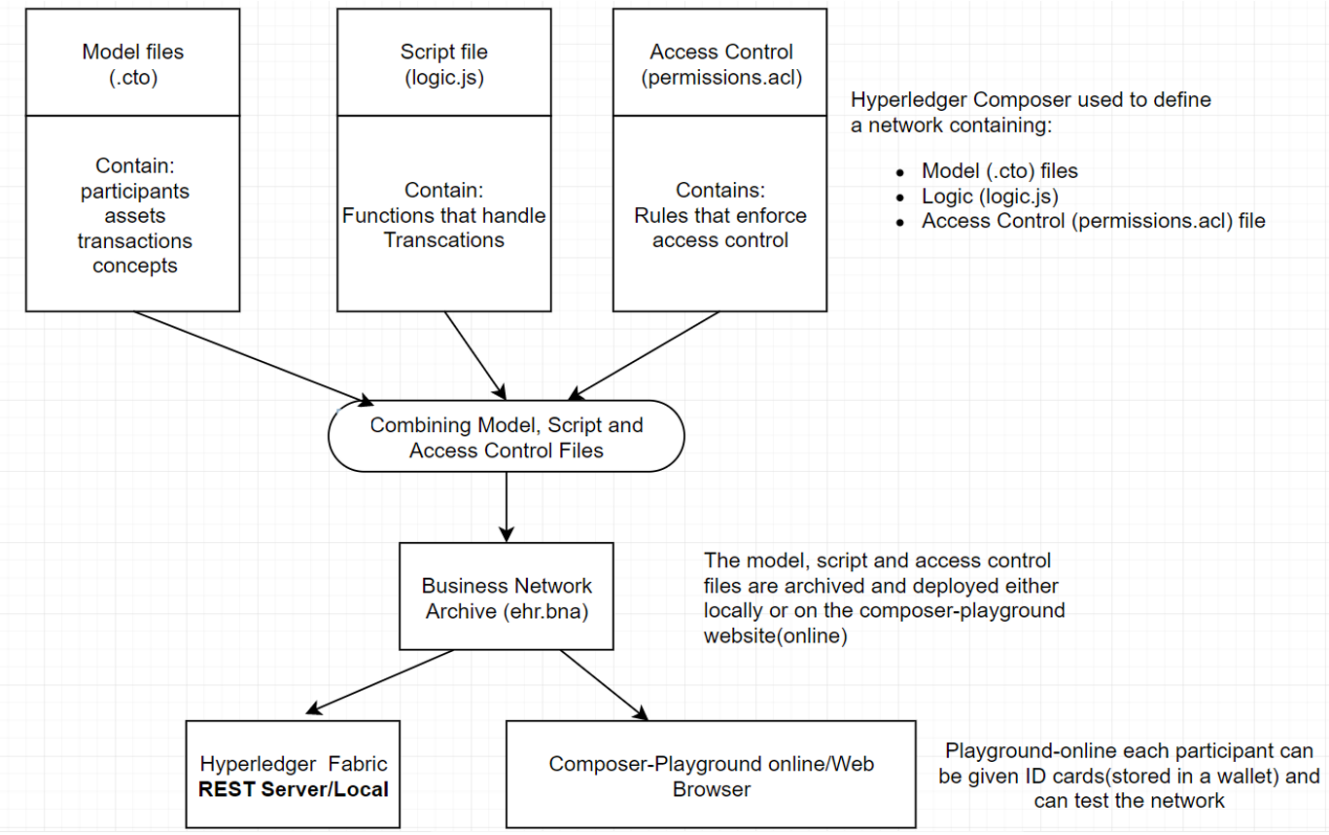


Figure 3.1: The systems architecture

Figure 3.1 shows how the project works. We built three model files for the system

- **ehr.cto**
  Consists of the participants of the system, the assets and transactions they involve
- **appointments.cto**
  Consists of the assets and transactions involving the system.

- **economics.cto**
  Consists of concepts,assets and transactions that involve the economical/financial side of the system

Chapter 4

Requirements

This section introduces the requirements of the project

4.1 Functional Requirements

S.No.	Requirement Description	Priority	Status
FR-01	System uses blockchain to store EHRs	Must Have	**Completed**
FR-02	System should be able to append data to a blockchain	Must Have	**Completed**
FR-03	System shall allow authorised healthcare personnel to submit the patients medical report to the blockchain	Must Have	**Completed**
FR-04	System shall allow the medical report submitted to the blockchain to be accessible only to the patient and authorised healthcare personnel	Must Have	**Completed**
FR-05	System shall use Hyperledger Blockchain (more modular ,i.e, transactions can be made visible only to those who have access to the data)	Must Have	**Completed**
FR-06	System shall use relevant smart-contract models set up on the blockchain	Must Have	**Completed**
FR-07	The smart-contract model designed for the system must be set up on a private blockchain network	Must Have	**Completed**
FR-08	A private blockchain network shall be made to evaluate the system	Should Have	**Completed**
FR-09	Patients can only read their medical reports and not edit them **	Must Have	**Completed**

4.2 Non-Functional Requirements

S.No.	Requirement Description	Priority	Status
NFR-01	All actors in the system are provided with user-friendly interface to interact with **	Must Have	**Completed**
NFR-02	Data saved by the system should be immutable	Must Have	**Completed**

Bibliography

[1] Investopedia. *What is a 'Blockchain'*. https://www.investopedia.com/terms/b/blockchain.asp. [Online; accessed 14-April-2018].

[2] Allison Berke. *How Safe Are Blockchains? It Depends*. https://hbr.org/2017/03/how-safe-are-blockchains-it-depends. [Online; Accessed: 23 Nov. 2017.]

[3] Bitcoin.org. *How does bitcoin work?* https://bitcoin.org/en/how-it-works. [Online; last accessed: 15 April. 2018.]

[4] Matthias Mettler. "Blockchain Technology in Healthcare - The Revolution Starts Here". In: *2016 IEEE 18th International Conference on e-Health Networking, Applications and Services(Healthcom) (2016)* (2016). Accessed: 22 Oct. 2017. URL: http://ieeexplore.ieee.org/document/7749510/.

[5] Techracers. "Hyperledger v/s Ethereum". In: (2017). Accessed: 15 Nov. 2017. URL: http://www.techracers.com/hyperledger-vs-ethereum.

[6] Tori Adams. *Blockchain, Smart Contracts, and Health: Booz Allen Hamilton and the Blockchain Revolution*. https://www.linkedin.com/pulse/blockchain-smart-contracts-health-booz-allen-hamilton-tori-adams/. [Online; Accessed: 25 Nov. 2017].

[7] Healthcoin. *Healthcoin*. http://www.tmc.edu/innovation/companies/healthcoin/. [Online; Accessed:26 Nov.2017.]

[8] Nolan Bauerle and Maria Kuznetsov. *What is the Difference Between a Blockchain and a Database?* https://www.coindesk.com/information/what-is-the-difference-blockchain-and-database/. [Online; Accessed: 26 Nov. 2017.]

[9] Gideon Greenspan. *Blockchains vs centralized databases*. https://www.multichain.com/blog/2016/03/blockchains-vs-centralizeddatabases/. [Online; Accessed:26 Nov.2017.]

[10] USF Health. *Differences Between EHR and EMR*. https://www.usfhealthonline.com/resources/key-concepts/ehr-vs-emr/. [Online; last accessed 15-April-2018].

[11] Tal Rapke M.D. "Blockchain Technology and the Potential for Its Use in Healthcare A visionary approach". In: (2016). Accessed: 13 Oct. 2017. URL: https://oncprojectracking.healthit.gov/wiki/download/attachments/14582699/24-Blockchain%2520Technology_Tal%2520Rapke%2520MD.pdf%3Fversion%3D1%26modificationDate%3D1474475152000%26api%3Dv2+&cd=1&hl=en&ct=clnk&gl=us.

[12] Chris Burniske et al. *HOW BLOCKCHAIN TECHNOLOGY CAN ENHANCE EHR OPERABILITY*. Tech. rep. GEM, 2017.

[13] Gurmeet Chahal. *Redefining Healthcare with Blockchain Technology*. https://www.hcltech.com/blogs/redefining-healthcare-blockchaintechnology. [Online; Accessed:15 Oct. 2017.]

[14] Sherin Sebastian et al. "REMOTE PATIENT MONITORING SYSTEM". In: *International Journal of Distributed and Parallel Systems (IJDPS) Vol.3, No.5, September 2012* (2012). Accessed: 15 Oct. 2017.

[15] Fitbit Tech. *Fitbit*. https://www.fitbit.com/purepulse.. [Online; Accessed:17 Nov. 2017].

[16] Bowhead Health. *The Future of Digital Health.* Tech. rep. Bowhead Health, 2017.

[17] Xiao Yue et al. “Healthcare data gateways: found healthcare intelligence on blockchain with novel privacy risk control”. In: *Journal of medical systems* 40.10 (2016), p. 218.

[18] Deepmind Health. *Redefining Healthcare with Blockchain Technology*. https://deepmind.com/applied/deepmind-health/working-nhs/how-were-helping-today/. [Online; Accessed:17 Nov. 2017].

[19] Rebecca Campbell. *Blockchain-Styled Solutions for Health Care on the Rise*. https://bitcoinmagazine.com/articles/blockchain-styled-solutions-health-care-rise/. [Online; last accessed: 15 April. 2018.]