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Blockchain in Healthcare

Supervisor:
Prof. Dr. Harald VON KORFLESCH

Second supervisor:
Manuel Etzkorn

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Submitted by:
Biplov K.C.

Statement of Authentication

I hereby declare that I have written the present thesis independently, without assistance from external parties and without the use of other resources than those indicated. The ideas taken directly or indirectly from external sources (including electronic sources) are duly acknowledged in the text. The material, either in full or in part, has not been previously submitted for grading at this or any other academic institution

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Abstract

The underlying characteristics of blockchain can facilitate data provenance, data integrity, data security, and data management. It has the potential to transform the healthcare sector. Since the introduction of Bitcoin in the fintech industry, the blcockhain technology has been gaining a lot of traction and its purpose is not just limited to finance. This thesis highlights the inner workings of blockchain technology and its application areas with possible existing solutions. Blockchain could lay the path for a new revolution in conventional healthcare systems. We presented how individual sectors within the healthcare industry could use blockchain and what solution persists. Also, we have presented our own concept to improve the existing paper-based prescription management system which is based on Hyperledger framework. The results of this work suggest that healthcare can benefit from blockchain technology bringing in the new ways patients can be treated.

Keywords: blockchain, healthcare, distributed ledger, data sharing

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Acronyms

API Application Programming Interface. 36, 69

DSCSA Drug Supply Chain Security Act. 34

EHR Electronic health record. 32, 49, 50, 52, 53, 59, 60, 67

EMR Electronic medical record. 27, 49–51, 53, 57, 58, 67

GDPR General Data Protection Regulation. 32, 65

HIE Health Information Exchange. 3, 31

ICO Initial Coin Offering. 1

IoMT Internet of Medical Things. 49, 51–53, 57, 60, 62

IoT Internet of Things. 26, 30, 34, 37, 51, 53, 57, 58, 60, 61, 63

IS InformtationSystems. 38, 43

IT Information Technology. 1

KYC Know Your Customer. 21

PBFT Practical Byzantine Fault Tolerance. 16, 19, 58, 66

PHI Personal Health Information. 49, 53

PHR Personal Health Record. 52, 57

POET Proof of Elapsed time. 16, 19

POS Proof-of-Stake. 16, 19

POW Proof-of-Work. 16, 18

PRISMA Preferred Reporting Items for Systematic Reviews and Meta-Analyses. viii, 5, 44, 45, 48, 72

QUOROM QUality Of Reporting Of Meta-analyses. 44

VBFT Verifiable Byzantine Fault Tolerance. 19

1 Introduction

Introduced in the fintech industry, Bitcoin [Nakamoto, 2009] was the first electronic payment system to truly exploit the power of blockchain technology. Since then, blockchain technology has been infiltrating various fields of Information Technology (IT). Blockchain's wave of disruption is beginning to shape the way information/value is exchanged in the financial sector, supply chain, healthcare system, and reputation system; to name a few.[Singhal, Dhameja and Panda, 2018]

"The potential benefits of the blockchain are more than just economic-they extend into political, humanitarian, social, and scientific domains-and the technological capacity of the blockchain is already being harnessed by specific groups to address real-world problems"[Swan, 2015, pg. viii]. Blockchain in principle is becoming an archetype of conducting business in a decentralized manner with more efficiency. Besides, it brings forward governance and, affirmation of all the activities from the involved entities within the blockchain, laying the foundation for a higher order of collaboration.

Many emerging new technologies are subject to the hype, and blockchain is no different. Gartner hype cycle[Gartner, 2019] helps to understand the emerging technologies via a hype cycle entitled "Gartner Hype Cycle" where they state that each technology goes through innovation trigger to start with, where early proof-of-concept are published and no usable products exist. The early publicity gained during 'innovation trigger' phase is followed by 'peak of inflated expectation' phase where the number of success stories produced along with some failures. Then the technology goes through 'trough a disillusionment' phase where investors continue to invest only if products improve to a satisfactory level. After that, the concept of how technology can benefit the enterprise start to become clear and newer generation of products start to appear from providers. In this phase, which is also known as 'slope of enlightenment' phase, more enterprise start to fund the project. Finally, the technology reaches 'plateau of productivity' where mainstream adoption takes place.

As shown in Figure: 1, Gartner has two divisions of blockchain in the hype cycle. Blockchain, in general, is almost at the end of the peak of inflated expectation according to hype cycle, and we have seen many Initial Coin Offering (ICO) come out in the market, out of which only a few have come up with the final product. Data security via blockchain is at innovation trigger phase according to the hype cycle, and both blockchain and blockchain for data security could take 5 to 10 years to reach the plateau.

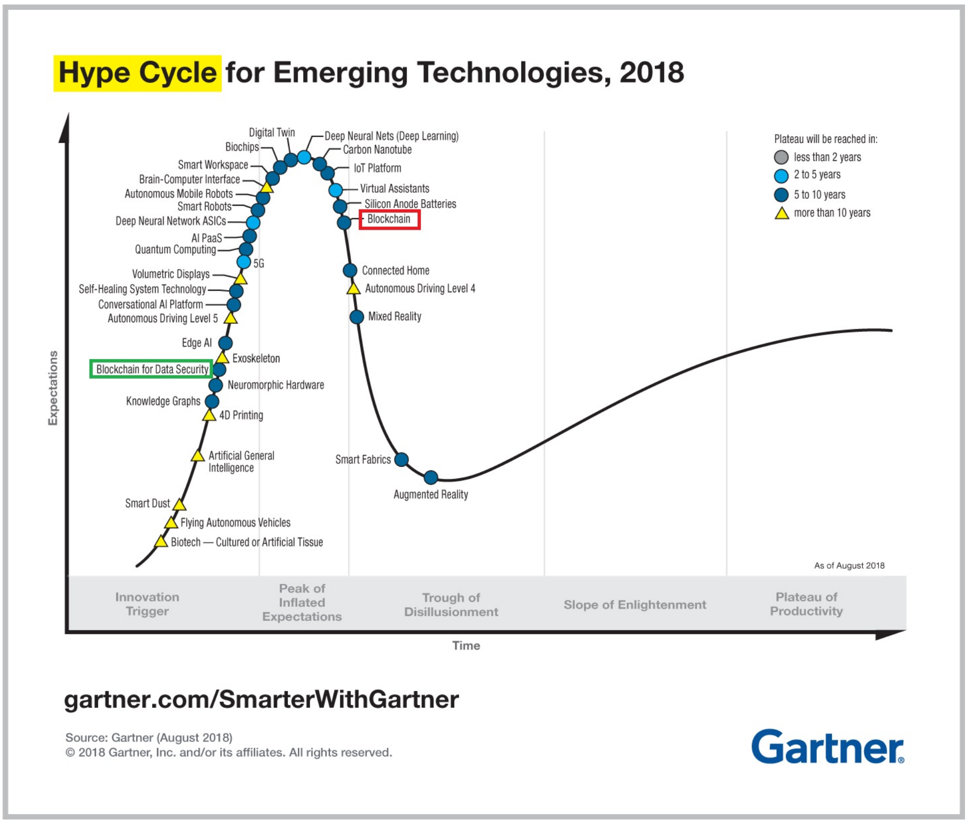


Figure 1: Gartner hypecycle for emerging new technology (2018)[van der Meulen and Costello, 2018]

1.1 Problem Statement

Healthcare is considered as one of the application areas of blockchain technology. But the technology adoption in the healthcare industry is relatively slow, and has been highlighted in the background paper on conceptual issues related to the health system, where the authors state that, “Pragmatic solutions already exist to address many of the greatest global health challenges, yet progress remains frustratingly slow because many health systems are constrained and cannot fully operationalize them.[Hoffman, Rottingen, Bennett, Lavis, Edge and Frenk, 2012, pg.6]”

Care coordintaion between patient and health care provider is increasing in complexity as various chronic conditions in the aging and growing population continue to rise. In many scenarios, the technology available in health care is not sufficient to capture all forms of care being catered. This is mainly due to use of old age technology to transfer information between relevant parties. Health care providers still use legacy systems, and paper-based medical records to retrieve and share medical data. Health care providers are still investing ample amount of resources into processing medical claims and administrative records when most of this can be eradicated using technologies such as BlockChain. Also, when it comes to patient-doctor interaction in Germany, paper-based prescription is still persistent. When someone gets ill and visits the doctor, the prescription for medicine is given in a piece of paper. This paper needs to be taken to a chemist to receive the medicines. In case of the loss of the paper containing prescription, the patient has to revisit the doctor.

In this thesis, we try to find the impact blockchain technology can have in the domain of healthcare. On the other hand, we will also look into the current state of blockchain technology and healthcare industry. We will then try to break healthcare into various subdomains (e.g Health Information Exchange (HIE), claims adjudication and patient billing management, drug supply chain integrity, pharma clinical trials, etc.) and explore how each section can be improved through blockchain.

1.2 Research Objective and Question

The main objective of the thesis is to gain deeper understanding of the blockchain technology and its potential for healthcare systems. To come up with purposeful conclusion, a fundamental research question is formulated:

"What is blockchain technology and how does it fit into current healthcare system?"

To answer the main research question, and conduct the study in structured demeanor, the research question is broken down into several sub-questions:

- *What is blockchain technology and what are its implications?*
- *What are the application areas of blockchain?*
- *What is the current state of healthcare systems?*
- *What is current state of blockchain in regards to healthcare industry?*
- *Which fields within healthcare sector can make use of blockchain technology?*

- *What solution concerning blockchain technology can be implemented in the healthcare sector to tackle current problems?*

- *What open issues exists and what are area for future research?*

1.3 Research Methods

To handle the research meticulously and, answer the research questions in a systematic way a research method entitled, "Research Onion"[Saunders, Lewis and Adrian, 2015] is chosen. This methodology contains various layers, as shown in Figure: 2. Selecting a strategy for each layer forms the overall approach in answering our research questions.

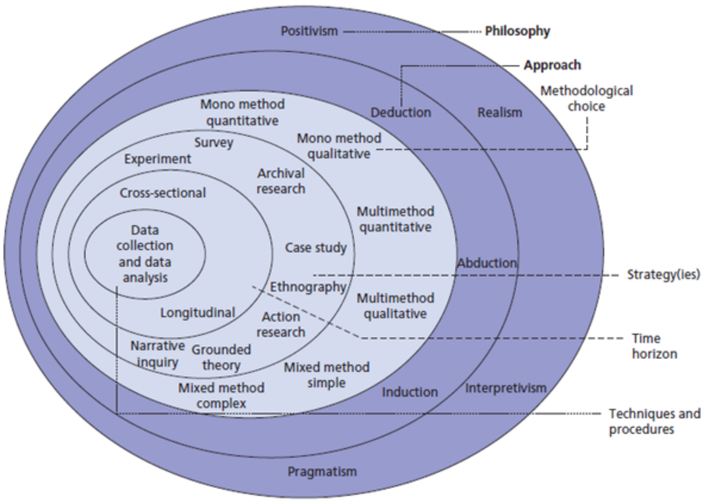


Figure 2: 'Research Onion' model Saunders et al. [2015]

The research philosophy forms the outer shell of the methodology. A possible option chosen in this layer will provide structure, guidance the way data are collected for analysis [of Derby, n.d.]. 'Pragmatism', as a research philosophy has been chosen for this project. Pragmatism can be understood as "an interest for practical consequences of knowledge" [Goldkuhl, 2011, pg. 20]. Since exploring the possible impacts and benefits blockchain technology in the healthcare industry is primary goal, pragmatism fits our research philosophy.

The research approach selected is ‘inductive’. Prevalent theories are yet to be formed, therefore, research questions of our own have been generated which will be concluded logically based on the premises(facts available). An inductive approach is also often referred to as “from the specific to the general”[Saunders et al., 2015]. This can be by reviewing literature to gather high level insights on a particular field of study. The information collected can then be examined for patterns in order to make conclusions.

Since our research will be dictated by Soft data(i.e. words, sentences, photos, symbols) rather than hard data(in the form of numbers)[Neuman, 2013], qualitative method will be used as a part of the research. Also, a systematic literature review will be carried using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) which will also be the preferred choice for the strategy layer of the research onion. As mentioned in PRISMA statement[Moher, Liberati, Tetzlaff and Altman, 2009] four-stage process namely Identification, Screening, Eligibility, and Inclusion will be used to review scientific papers. In order to find relevant papers scientific databases such as PubMed, IEEE Xplore and, Web of Science will be searched.

2 Blockchain technology and its application areas

2.1 Background

The need for a decentralized or a distributed system over a centralized system was highlighted by Paul Baran in his memorandum[Baran, 1964], as shown in Figure: 3.

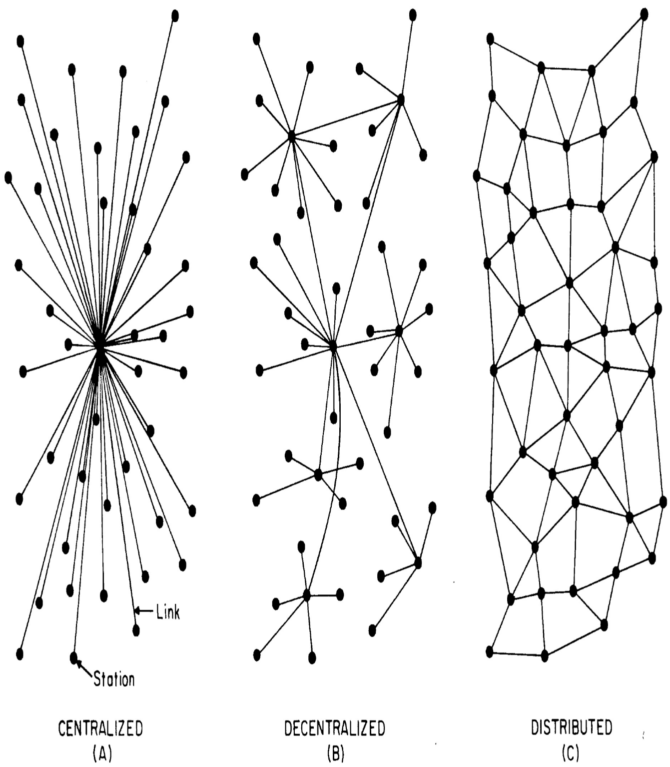


Figure 3: Information system types [Baran, 1964]

As the name suggests 'Centralized systems' are governed by a single authority. Such systems are easy to govern, maintain and design, but come with inherent problems. The biggest problem for this kind of system is that they have a single point of failure. In Figure 2.2 (A) it can be seen that, for two non-central nodes to communicate, the message has to travel via the central node. And, should the central node fail to function, communication between non-central nodes will falter. On top of that, from a security point of view, this kind of systems are less reliable too. Because, should the central node be corrupted, all the message sharing between other nodes would be compromised. Hence, centralized systems are less reliable.

Decentralized systems, on the other hand, consists of multiple central coordinators rather than a single central node. Theses coordinators coordinate with each other and non-coordinators communicate by coordinators. Here, one point of failure is solved by introducing various coordinating nodes. In case of a failure of one coordinating nodes, message communication can go through via other available coordinating nodes. Multiple failures can be tolerated in this architecture until the network is disconnected.

"A distributed system is a collection of independent entities that cooperate to solve a problem that cannot be individually solved." [Kshemkalyani and Singhal, 2011, pg. 1] The concept of a centralized coordinator is eradicated in distributed systems and, all the nodes take part in computation and information sharing collectively. A computer system can be classified as distributed if the participating nodes do have common physical clock, do not have shared memory, are geographically separated, and are autonomous and heterogenous [Kshemkalyani and Singhal, 2011].

A blockchain application can either be decentralized or distributed.

The basic concept of blockchain: using crytographically secure hash function to store information in the form of block is not a new one. The concept of timestamping a digital document [Haber and Stornetta, 1991] using a series of timestamps that represents the time a document was created or edited was discussed as early as 1991. The authors discussed how the history of a document can be maintained in chains of blocks via hash function using parameters such as sequence number, client ID, timestamp and, hashvalue from the previous block as shown in Figure: 4. Modern day blockchain technology derives this notion.

A blockchain is "an open, distributed ledger that can record transactions between two parties efficiently in a verifiable and permanent way"[Iansiti and Lakhani, 2017, pg. 4]. From this definition, it can be inferred that blockchain provides a platform that is accessible to everyone(open), not controlled by a single authority(distributed or decentralized), fast and scalable(efficient), provides validity of information(verifiable) and, is persistent(permanent) and tamper proof.

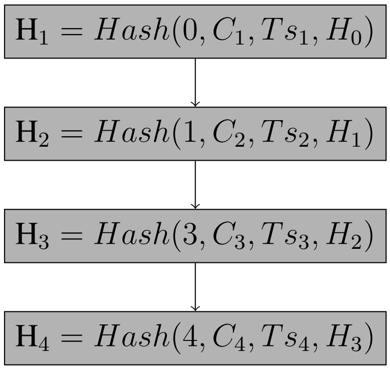


Figure 4: Information of document history using Cryptographic hash function in form of chain of blocks

2.2 Technical Background

In order to understand how blokchain technology works, it is important to understand the key components and concepts within blockchain that drives the technology. In the sections below we briefly discuss three concepts that stimulates blockchain.

2.2.1 Cryptographic Hash Functions

Cryptographic hash functions are the principal concept that drives information validity and persistency in the blockchain. Hash functions maps any given data of arbitrary length to a fixed length of the output. One way hash functions are used in the blockchain system. Consider the following equation:

$$y = F(x)$$

where ‘x’ is a string of arbitrary length and ‘F()’ is a one-way hash function and ‘y’ is the result. One way hash functions ensure that given ‘x’ and ‘F(x)’, result ‘y’ can be calculated. However, no deterministic algorithm should be able to calculate ‘x’ given ‘y’ and ’F(x)’ [Merkle, 1979]. In Figure: 5 we can see how a change in a single character can change the entire digest. How these feature aid in for tamper proof and secure blockchain systems is further explained in the section 2.2.4.

In addition, another important property of cryptrographic hash functions is that they produce an avalanche effect. This effect can be understood as "change in one

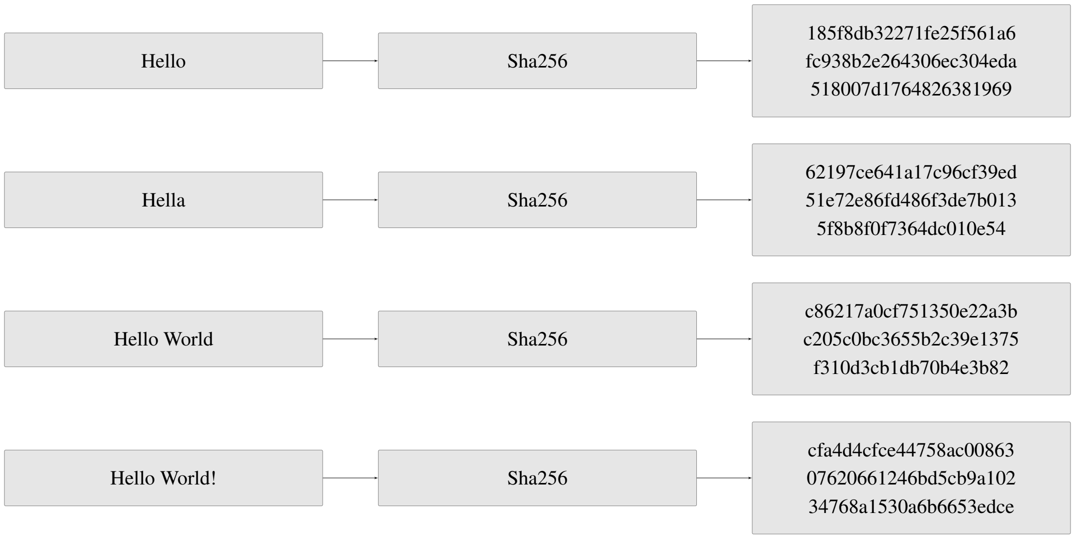


Figure 5: Avalanche effect of one way hash functions using Sha256 algorithm

input bit affects many output bits, a property that is called diffusion or the avalanche effect." [Paar and Pelzl, 2010, pg. 83]

2.2.2 Merkle Trees

Merkle trees play a vital role in verifying the integration of the blockchain system. They are widely used in theoretical cryptographic constructions and are specifically designed so that a leaf value can be verified with a publicly known root value[Szydlo, 2004].

Merkle tree can be considered as a tree structure, where the leaf node contains the hash of the document, and the non-leaf node consists of the combined hash of the child nodes as shown in Figure: 6 where D_1, D_2, D_3 and D_4 are the documents. L_1, and L_2 are the level of the depth of the nodes. Root hash is the hash of it's child nodes (i.e. H_0, and H_1). This tree structure can help verify the integrity of the documents in the child nodes. Any change made in any one of the leaf nodes results in the change of the root value. Therefore, through the root value, it can be easily verified that non of the leaf nodes (documents) have been tampered.

Merkle tree is also used peer to peer networks where it aids in the verification of data block received are not altered. In the case of Bitcoin implementation, it helps to verify that shared information is unaltered and no one can fake the transaction.

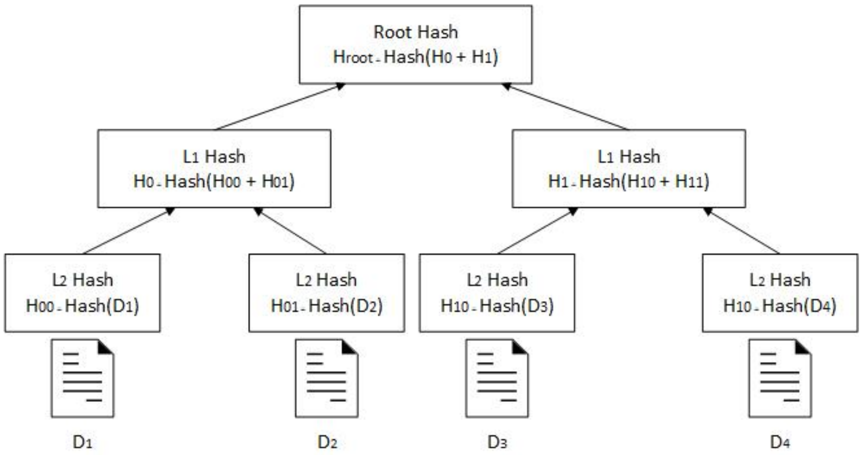


Figure 6: A binary merkle tree

2.2.3 Smart Contracts

Bitcoin revolution has got many institutions and companies interested in the blockchain technology. They are now building alternative systems around using the concept of blockchain. This movemenent from academia, coroprate industries, startups are also termed as Blockchain 2.0. This concept of blockchain 2.0 has given birth to another interesting concept called smart contracts.

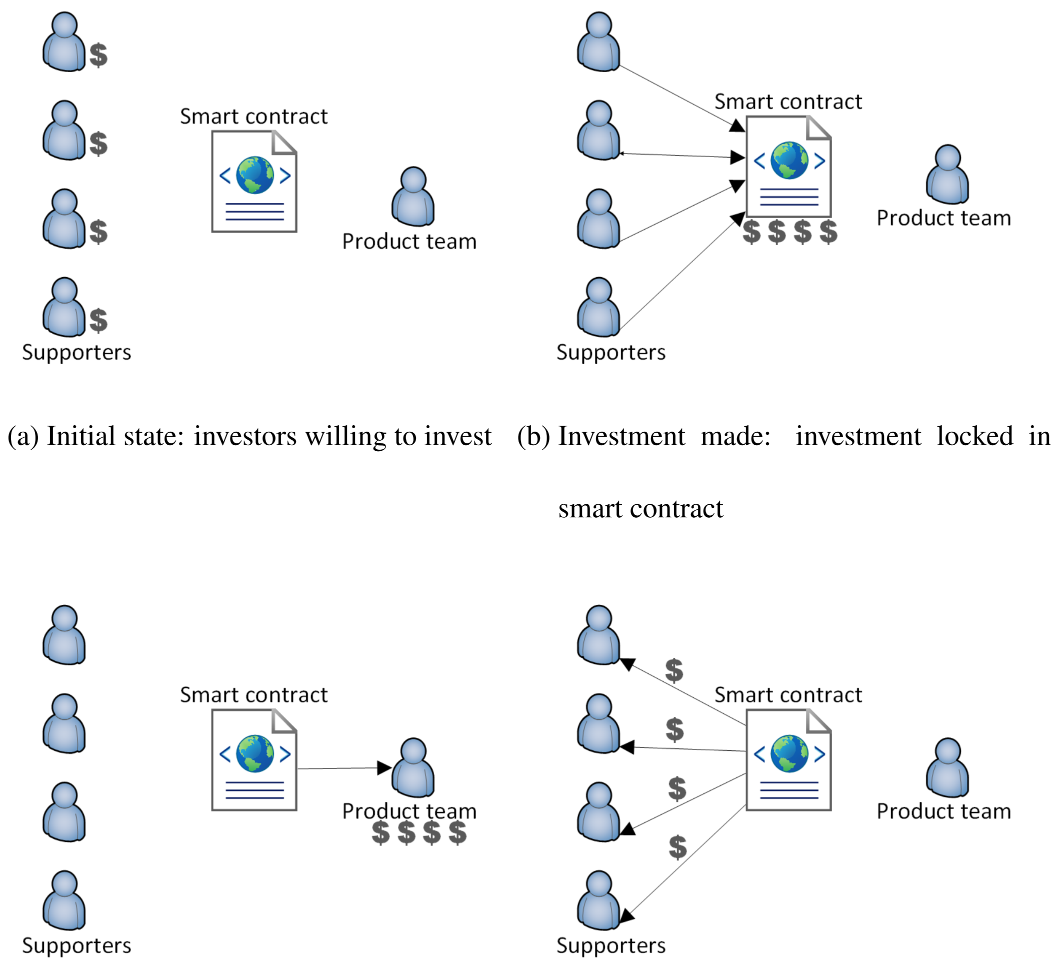
The concept of legal contracts in the form of paper that are enforced and verified by intermediaries has been around for a long time. ‘Smart contracts’ as the name suggests are also contracts, but are automated computerized protocol or piece of code that can sit inside the block of a blockchain and can be digitally invoked avoiding intermediaries in a decentralized manner. Smart contracts are faster, cheaper and more secure than normal contracts.

The term smart contract was first coined by Nick Szabo in 1997[Szabo, 1997]. In the article, he elaborates the similarities and differences between smart contract and traditional and static forms of contracts. He mentions that "By using cryptographic and other security mechanisms, we can secure many algorithmically specifiable relationships from breach by principals, and eavesdropping or malicious interference by third parties, up to considerations of time, user interface, and completeness of the algorithmic specification." [Szabo, 1997]. The article also points out that the smart contract can be realised via a public ledger. Since blockchain is a public ledger, it can be a pioneering technology to realise smart contracts.

Consider a crowdfunding platform like Kickstarter[1] where entrepreneurs with interesting project but insufficient funds submit their idea/projects. Multiple supporters then can pledge to support or provide certain fund for the project to be realised. Kickstarter takes the responsibility to provide a certain amount of fund to the developers when the specific goals are achieved. On the contrary, if the project fails to reach certain milestones within the allocated time, or if the project is scrapped, then the kickstarter returns the money to the investors. This kind of architecture is built on top of trust. Both the product team and the supporters need to trust the crowdfunding platform. Nonetheless, the centralized and trust based crowdbased platform who acts as the middleman, take significant charge to handle the entire operation.

This kind of crowfunding platform can be realised with the help of smart contracts without the need for trusted intermediaries. A smart contract is digital contract which is made of code and available to all the stakeholders through the blockchain platform. Since blockchain is immutable, everyone (including stakeholders) can verify the contract but cannot tamper the contract once inside the blockchain. This kind of smart contract can contain coded in such a way when certain milestones of a project is reached, the contract gets automatically executed. And this phenomenon can be verified by all the stakeholders. Thus, removing the need for any trusted third party. This phenomenon is also visualised in Figure: 7.

[1]https://www.kickstarter.com/



(a) Initial state: investors willing to invest

(b) Investment made: investment locked in smart contract

(c) Milestone reached: investment transferred to product team

(d) Milestone not reached: investment transferred back to supporters

Figure 7: Image showing various scenarios when a smart contract is triggered

2.2.4 Understanding how Bitcoin works in general

Based on the type of blockchain explained in section 2.4, and the consensus mechanism used, the internal mechanism of how the system works could differ. The high-level concept of how a blockchain system works among various environments remains the same. In this section provides a basic understanding of how a blockchain system works in general, with Bitcoin as an example.

The first step would be to install the Bitcoin wallet (a digital wallet that can hold bitcoins) on a computer or a mobile phone. Once the wallet is installed, a Bitcoin address is generated using elliptic curve cryptography[Singhal et al., 2018, chap. 2], which is a hashed version of the public key. This is address can be disclosed publicly, so that anyone can transfer the funds to this address in the form of bitcoin. An email address can be of good analogy in comparison to a bitcoin address. Multiple addresses can be generated as per need[BitcoinProject, 2019]. Example of public and private keys are shown in Table: 2

Public Key	xpub661MyMwAqRbcG3JUDHJwKgFfxBobyQuLo5GEsnnWS 6262kdL143MVph59nak3c4Cm16GG6KnCrQWua5TW75Q9LU 5d9x2P1zVMZNb46PTbWH
Private Key	xprv9s21ZrQH143K3ZE17FmvxYJwQ9y7ZxBVRrLe5QNt skV79xJBTWj6x2NbJUzV56UMZPfPcEu87N5YKjYcJccBtE WKDvQ7buKTCnyH4iPZpC

Table 2: Sample public key and private key for Bitcoin wallet

The entire Bitcoin network relies on a shared public ledger. All the confirmed transactions are included in the blockchain. Before a Bitcoin is spent (i.e. transferred from one wallet to another), the availability and the ownership of the Bitcoin is verified, so that a user cannot spend more than what he/she owns. Bitcoins wallet address makes the amount of Bitcoin contained in the wallet public, which makes it easy to verify the transaction and propose it to the new block to be added. The integrity and the order with which blocks are chained are enforced via cryptography[BitcoinProject, 2019].

A transaction between a spender and a receiver is the transfer of value between two Bitcoin wallets, which is reflected in the block of a blockchain. To make sure no fraudulent transfer occurs, it is mandatory to sign a transaction with the private key associated with the public key of the wallet owner. After a transaction is signed, a message digest is generated using SHA256 hash algorithm as explained in figure 5 which is unique to the private key (i.e. only the associated private key can generate that digest for that particular transaction). This makes sure that nobody can alter the transaction after it has been issued. The transaction is then broadcasted to the network, and within 10-20 these transactions start showing up in the newly generated block, through the process called mining[BitcoinProject, 2019]. A sample response to the block information from chainquery[2] for a given blockhash can be found in Appendix A.

Mining is a distributed consensus system which helps to confirm all the broadcasted transactions by verifying them and solving a mathematical puzzle posted by the network itself to publish the new block, which is then verified and added as the latest block in the blockchain. Transactions are added in the block only when they are cryptograhically verified by miners in the network. It imposes a chronological order in the blockchain and allows the systems taking part in the network to agree on a universal state of the system. The mining process also helps ensure that no one can control what is included in the block and none of the existing blocks can be tampered or edited[BitcoinProject, 2019].

2.2.5 Blockchain Architecture

The variants of blockchain are still evolving and maturing. There are no set of rules that break the blockchain in various layers but glancing through the bird's eye view, the blockchain can be divided into five fundamental layers: application, execution, semantic, propagation and consensus layer [Singhal et al., 2018].

Application layer

In this layer desired functionality for the end-user is coded. The technology stack can consist of client-side tooling, APIs, development tooling, etc. An ideal blockchain application would not follow the client-server model and no centralized server that a client would access, like bitcoin. A well-built blockchain could have heavy storage requirement taken care by the application layer, and the core blockchain would remain light and effective.

Execution layer

The instructions ordered by the application layer are executed in this layer. The instruction could be as simple as transferring an asset from owner 'X' to receiver 'Y' or could be complex ones in the form of smart contract execution which can contain multiple conditional operations. Every node in blockchain will have an application layer. The deterministic input and conditions to be executed always

[2] https://chainquery.com/bitcoin-cli/getblock

produce the same output. This helps to keep data persistent.

Based on the various implementation of Blockchain such as bitcoin, ethereum, hyperledger, etc, the scripts to be executed can differ. This is due to that fact that bitcoin is not turing complete whereas ethereum and hyperledger are.

Semantic layer

This layer can also be referred to as a logical layer. Transaction to be carried out and written in blocks as well as block generation happens in order. Regardless of transaction validity, it gets through the execution layer, but these transactions get validated only in the semantic layer. Consider, someone trying to send 1 bitcoin to another person. The validation of a person owning at least 1 bitcoin happens in the semantic layer.

Data structures and system models are also defined in this layer. The way blocks are chained with each other is also illustrated here. This layer can be further extended within. If complex functionality is required by the system then, additional layers can be added in the semantic layer.

Propagation layer

The core part of the system has been discussed, but another fundamental part of the blockchain system is for the peers to be able to find each other to form a network and propagate the message to one another. Propagation layer can be considered as a communication layer that enables peer to be discovered and message to be relayed. Every node in the system needs to have the latest state of the network. When a transaction is made, a message is broadcasted to the entire network. The messages are collected and a block is proposed. The proposal is then propagated to network so that other nodes could build on it. The speed at which messages are propagated and new blocks are formed depends upon the number of nodes participating in the network, network bandwith, and other factors.

Consensus layer

Once the message is propagated among participating nodes and new blocks are added in the system, the majority of the nodes should agree on the current state. Consensus layer's primary job is to get all the nodes to agree on one consistent state of the ledger. There are various ways for consensus to be achieved. Bitcoin's consensus mechanism Proof-of-Work (POW) depends upon the amount of computing power put to solve a puzzle [Jakobsson and Juels, 1999]. Since then multiple consensus mechanisms has been put forward among which Proof-of-Stake (POS), Practical Byzantine Fault Tolerance (PBFT), Proof of Elapsed time (POET) are the popural ones.

2.3 Implications of Blockchain Technology

One of the research question for this thesis was to understand the implications of the blockchain. Section 2.2.4 illustrated how blockchain takes advantage of asymmetric cryptography(public/private key), decentralization via distributed ledger system and data integrity through incentives or reward system to miners during mining process. The key characteristics of blockchain can be listed as:

- *Data immutability*: Any information added to the block of a blockchain is permanent and hence cannot be changed.
- *Validity of information*: Any information in the blockchain can be easily verified.
- *Decentralized*: Does not have any central authority or single point of failure.
- *Tamper proof*: Changes in existing blockchain or adding new blocks with fake information is almost impossible.

These features makes blockchain most efficient in following scenarios:

- More that two parties are involved in a ecosystem where the involved parties do not completely trust each other.
- The data gathered and shared among the parties needs to be permanently recorded and verified.
- Each activity from a party needs to be transparent.
- The cross-border business is desirable.
- The data authority needs to be verified.

Due to the aforementioned significance of the blockchain technology, it is used in various sectors as discussed in section : 2.5

2.4 Types of Blockchain

It is crucial to know and understand different types of blockchain that exists. A solution to an existing problem might be solved in efficient way by a blockchain implementation where requires trust among involved parties and, demands involved parties to have an identity unlike bitcoin implementation. Similarly, a blockchain that was specifically built for healthcare system may not fit into blockchain for financial systems.

Various and often conflicting categorisations of blockchain types can be found. This section of the chapter focuses on blockchain types based on the requirement of authorisation for data access, and ability to become a node that takes part in consensus as well, take part in block generation. Based on these requirements we can break down blockchain into three distinct categories:

1. *Permissionless* blockchains, where anyone can become a node taking part in consensus and contribute their computing power in return for a monetary reward.

2. *Hybrid* blockchains, where information in the block can be read, but only pre-selected enterprise/entities can take part in the consensus process.

3. *Permissioned* blockchains where information reading as well as becoming a node that takes part in consensus requires authorization and verification.

However, different categorisation can be found, where the blockchains are divided into public, consortium, and fully private[3] blockchains:

1. *Public* blockchains, where anyone can read, send transaction and take part in consensus.

2. *Consortium* blockchains are the ones where nodes involved in consensus are pre-selected, wehreas the right to read may be public.

3. *Fully private* blockchains where the permission to write in limited to one centralized organisation, and read permission maybe public or private.

To sum up, permissionless blockchains allow public access, while the permissioned blockchain tries to restrict the access of the data. Hybrid blockchains, however, lies somewhere between permissioned and permissionless, where information reading is public but taking part in consensus is not.

[3] https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/

Permissionless blockchain

The bitcoin network, which is the biggest example of blockchain, is 'permissionless'. Permissionless can be referred to as the ability to join the network without the need of authorisation for verification, and become the node to verify the transactions in the blocks as well as take part in new block generation, the participation of any unknown nodes are encouraged as well as incentivised in this kind of systems, as it makes the system more robust.

Consensus within the network can be obtained via diverse voting mechanisms, of which POW is the most common one. A permissionless blockchain can be useful in that it can [Swanson, 2015] support both anonymity or 'pseudonymous' actors and protect against a Sybil attack which is also known as identity-forging attack [Douceur, 2002]. One of the reasons for this type of blockchain system to be popular is because the participating nodes are incentivised for the verifying the transactions as well as publishing the new block. The incentive received for publishing transaction in blocks decreases based upon a predefined rule. This can result in costly transactions for people making an individual transaction.

Apart from Bitcoin, Ethereum[4], Litecoin[5], and Monero[6] are other examples of permissionless blockchains.

Permissioned blockchain

Permissioned blockchains are receiving a lot of traction lately across various fields. They are not built with native cryptocurrency in mind, which provides a good platform for various parties to share information in a decentralized manner. This category of blockchain has a group of trusted parties with an identity that carry out verification. Additional verifiers can be added if all the concerned party come to an agreement. [Swanson, 2015] points out that permissionless and permissioned blockchains differ through the features they provide.

Permissioned blockchains are built for a specific purpose, and therefore be built such that they are compatible with existing applications [Peters and Panayi, 2016]. They can be customised to be made fully private by restricting the read and write

[4] https://www.ethereum.org/

[5] https://litecoin.org/

[6] https://www.getmonero.org/

access within the organisation or selected organisations. Because the actors taking part in the network can be identified, they are legally accountable for their activity [Peters and Panayi, 2016]. Consensus can be reached using an algorithm such as POET, Kafka, etc. This type of blockchain usually handles off-chain assets such as titles of ownership, digital representations of securities and fiat currencies rather than on-chain assets, such as digital currencies or virtual currency tokens [Swanson, 2015].

One of the most popular permissioned blockchain called Hyperledger[7] is initiated by Linux foundation and is open-source.

Hybrid blockchain

Hybrid blockchain can be directly compared with consortium blockchains as explained by Vitalik Buterin where he mentioned that "a consortium blockchain is a blockchain where the consensus process is controlled by a pre-selected set of nodes; for example, one might imagine a consortium of 15 financial institutions, each of which operates a node and of which 10 must sign every block in order for the block to be valid"[8]. In this sort of blockchains, information ready is generally public and accessible to anyone whereas being part of the consensus process is not. Wide range of implementation of hybrid blockchains that are built from generic to specific use-case can be found as of today. Consensus can be reached using a wide range of algorithms such as VBFT, POS, and PBFT.

Ontology[9], NEO[10], and Tron[11] are the few examples of Hybrid blockchains.

2.5 Application Areas

Started as a solution for the financial sector with the concept of digital money, power of blokchain is not just limited in the financial sector but extends to other sectors such as government, supply chain, and healthcare which are briefly described below.

[7] https://www.hyperledger.org/

[8] https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/

[9] https://ont.io/

[10] https://neo.org

[11] https://tron.network/

2.5.1 Blockchain in finance

Bitcoin, harnessing the concept of blockchain technology was initially developed to disrupt the financial sector. The current underlying problem in the financial sector has been distinctly stated by Alex and Don Tapscott, where they state that "Our global financial system moves trillions of dollars a day and serves billions of people. But the system is rife with problems, adding cost through fees and delays, creating friction through redundant and onerous paperwork, and opening up opportunities for fraud and crime. To wit, 45% of financial intermediaries, such as payment networks, stock exchanges, and money transfer services, suffer from economic crime every year; the number is 37% for the entire economy, and only 20% and % for the professional services and technology sectors, respectively. It's no small wonder that regulatory costs continue to climb and remain a top concern for bankers. This all adds cost, with consumers ultimately bearing the burden."[Tapscott and Tapscott, 2017, pg. 2]. To solve this issue major banks and financial organizations are exploring routes to incorporate blockchain into their system due to its high cost-saving potential[Bashir, 2017].

Payments

To date, more than 2800 cryptocurrencies exist according to coinmarketcap[12]. These currencies cannot yet be considered as one of the legally accepted currencies such as USD($) or EUR(€) because they are neither fully accepted as a medium of exchange nor they are unit of account as of yet. Marketplaces such as Expedia[13], Microsoft[14] are accepting bitcoins as a mode of payment, and the number of companies that accept bitcoin is only increasing. But, they are not yet accepted in all our local supermarkets and convenient stores. Furthermore, cryptocurrencies cannot be considered as a unit of account. Merchants that accept bitcoin as payment, accept it via the current rate of conversion from Bitcoin to USD or EUR. For example, the price of bitcoin drops from 10,000$to 5,000$within a day, the amount of bitcoin that needs to be paid for a 10,000$worth of laptop rises from 1BTC(bitcoin) to 2BTC. However, cryptocurrencies are considered as a store of value (i.e. mode of investment) even though it could be considered as a speculative investment. Out of various existing blockchains with their native cryptocurrencies, some interesting

[12]https://coinmarketcap.com

[13]https://www.expedia.com/Checkout/BitcoinTermsAndConditions

[14]https://support.microsoft.com/en-nz/help/13942/microsoft-account-how-to-use-bitcoin-to-add-money-to-your-account

ones are Stellar[15] and Ripple[16]. Stellar is a decentralized, hybrid blockchain that has native asset known as Lumens. Stellar consists of anchors that act as bridges between a given currency and stellar network. They act as currency converters and allow users for cross-border payment. Internally stellar has a distributed exchange that allows a user to pay to the different currency that they have. For example, a person from Europe can in USD with EUR balance, and internally the network will automatically convert it to the lowest exchange rate available[17]. The target audience for stellar is end-user whereas the target audience for Ripple are banks. They help banks to settle payments in real-time through a distributed network. Cross-border payment via banks can take days and a significant amount of fess. Ripple aims to significantly improve this situation by providing confirmation in 5 seconds on average. More than 200 financial institutions including Santander bank have joined Ripple network, which allows cross border payment among 40 countries across 6 continents[18].

Compliance and Mortage

One important aspect of financial services is compliance. In order to open a bank account a customer has to go through a process known as Know Your Customer (KYC). A survey report from Thompson Reuters [ThompsonReuters, 2016] mentions that on average 60 million dollars are spent every year by financial institutions on KYC process, and they can spend up to 24 days to onboard a new client. It is a regulatory requirement in order for institutions to have knowledge of their customers. This information can be used to prevent fraud or AML(Anti money laundering)[Bashir, 2017]. Each financial institution maintains its own database of customer information and this information verification is done by centralized data providers. This can not only be time-consuming from the institution's perspective but it is also redundant process from the client's point of view. And, can lead to delays in the onboarding process of the potential new client. Having a blockchain that can securely store clients information that can be used by all the institutions not only make the KYC process efficient and cost-effective but also help meet regulatory and compliance requirements[Bashir, 2017].

Another use case in the finance sector for blockchain can be mortgage service. Mortage process is painstaking slow and manual. Even after going through rigorous

[15] https://www.stellar.org/

[16] https://www.ripple.com/xrp/

[17] https://www.stellar.org/overview#putting-it-all-together

[18] https://www.ripple.com/use-cases/banks/

paper works and efforts from both banks and customers, a lot of loan-related frauds happen. Situations where customers being unable to pay the mortgage persists even then[Acharya and Richardson, 2009]. Blockchain can bring transparent insights into the syndicate across all participants during the mortgage process, lower overall transaction costs and time and help accurately access risks, provide a reliable system to track status and ownership of syndicate loans and provide a system to investors to access data on underlying assets to assess credit quality.

Some of the existing blockchain-based soultions available are enlisted in Table: 4

Name	Overview	Url
Bitcoin	Open source Peer-to-Peer money	https://bitcoin.org/en/
Ripple	Blockchain technology for global payments—making it easy for financial institutions	https://www.ripple.com/
Litecoin	Litecoin is a proven medium of commerce complementary to Bitcoin, that enables instant, near-zero cost payments to anyone in the world	https://litecoin.org
Monero	Open-sourced, decentralized, cryptocurrency with primary focus on privacy	https://www.getmonero.org/
Dubai	Government documents management system to be enacted by 2020	Ongoing

Table 4: Existing blokchain based projects in the field of finance.

2.5.2 Blockchain in government

Blockchain technology has the potential to lay the foundation for government and society to realise the next step in e-government(electronic government) development[Ølnes, Ubacht and Janssen, 2017]. The concept is not a new one and several existing use cases can be found already. The features provided by blockchain namely: transparency, auditability, and integrity can pave the way to effectively manage government functions.

Border control

Illegal movement of goods/people from one country to another has been an underlying issue for many countries. A large number of people cross the borders and move from one country to another on a daily basis. This requires authorities to have an efficient, secure and scalable record keeping platform of entries and exits. When it comes to national security, there is no denying that these records need to be immutable against any attacks or alterations[Patel et al., 2018]. "Machine-readable travel documents and specifically biometric passports have paved the way for automated border control; however current systems are limited to a certain extent and blockchain technology can provide solutions. A Machine-readable Travel Document (MRTD) standard is defined in document ICAO 9303 by the International Civil Aviation Organization (ICAO) and has been implemented by many countries around the world"[Bashir, 2017, pg. 434]. The current underlying problem with the border control system is that they are centralized[Patel et al., 2018; Bashir, 2017]. This makes it difficult for a law enforcement agency to have data required to be readily available. Using smart contracts the arrival and departure record can be recorded and validated[Patel et al., 2018] in the respective country. Smart contracts can also be used to store information of blacklisted individuals[Bashir, 2017] to track suspected individual in an efficient manner.

Voting

Voting enables citizens to participate in the government selection process. The voting process has evolved but transparency is still an issue. Specialized voting machine that promise to provide security and privacy exists, but they still have vulnerabilities that are being exploited. E-voting is one of the secctions of e-government where blockchain can have positive effect[Kshetri and Voas, 2018]. The idea behind blockchain-enabled e-voting is straightforward. The authors[Kshetri and Voas, 2018] have put forward an idea of providing each voter a "wallet" with public and private key. Each voters are then provided a single "coin" that represents an opportunity to vote. Casting a vote denotes that the currency has been spent and transferred to a representative candidate. Opportunity to edit vote provided by a voter is available till the deadline[Dickson, 2016]. Anonymity is maintained during the voting process via the unique public key available to each voter.

Mobile based e-voting platform using blockchain technology is already provided by a Boston-based startup 'Voatz' where they employ smart biometrics and real-time ID verification. The distributed public ledger tracks each ballot cast by an individual and ties them to their ID, establishing a permanent, and immutable record[**?**]

Citizen identification(ID cards)

Digital services are continuously growing, paving the path for interconnected digital societies[Ienco, 2016]. Most of the digital service require some kind of identity to be provided from end-user. Digital identities are electronic IDs, and are not limited to just government-issued ID cards[Bashir, 2017].

Approximately 2.4 billion people around the world who suffer from poverty, are unable to answer the question, "Who are you?" to an entity associated with government. They do know who they are but are unable to prove their identity with tangible evidence[Mainelli, 2017].

Blockchain can act as a source of personal identification. Users will be able to see who has access to their personal information and for what purpose. A single identity provided by the government can be used as an identity source for multiple platforms. This can then also be used for various services provided by government such as pensions, taxation, or benefits using a single ID[Bashir, 2017].

Some of the government-led blockchain projects[Jun, 2018] are listed in Table: 6

Nation	Project	Status
Australia	Australian senators launch parliamentary friends of blockchain group.	Announced in August 9, 2017
Australia	The Australian Securities Exchange announced that they will use blockchain technology to clear and settle trades by replacing the outdate Clearing House Electronic Subregister System	Announced in December, 2017
China	Social security funds management system	Announced in 2016
China	Blockchain-based asset custody system (PSBC)	More than 100 successful business transaction since October 2016

Nation	Project	Status
Dubai	Government documents management system to be enacted by 2020	Ongoing
Dubai	Digital passport based on blockchain	Announced in June, 2017
Estonia	eID (electronic ID management system)	The government is currently upgrading existing system with blockchain technology.
Estonia	E-health (medical information management system)	The government is currently upgrading the existing system with blockchain technology.
Estonia	e-Residency (a first-of-a-kind a transnational digital identity)	Since 2015, more than 27,000 people from 143 countries have applied and 4272 companies have been established as of December 2017

Table 6: Existing blokchain based projects by government[Jun, 2018]

2.5.3 Blockchain in supply chain

To understand the impact blockchain can have on Supply chain we can look into the food contamination scandal that happened through Walmart in China[19]. After being unable to track which batch of pork was contaminated, where the meat originated from, and where the batch of meat ended up, Walmart had to recall all the pork in China. This resulted in significant big financial loss. This phenomenon of recalling faulty products is not just limited to the food industry but also the electronic industry, and the automobile industry.

Using IBM's blockchain solution, Walmart has completed two blockchain projects namely: pork in chain and mangoes in the Americas[IBM, 2017]. This solution enabled Walmart to trace origins of foods within the last seven days in 2.2 seconds, and promoted transparency in greater level across supply chain[Kamath, 2018]. This feature was called as "complete end-to-end traceability"[Kamath, 2018].

[19]https://www.bbc.co.uk/news/business-15245029

Blockchain concerning meat industry and Walmart provided tracking from farm and slaughterhouse, where pigs are tagged and are followed to packaged form. Using RFID(radio frequency identification) and cameras, help to capture the complete production process[Ralte, 2017]. Besides, the procurement manager can trace information ranging from the product expiry date to warehouse temperatures[Kaye, 2016]. Critical informations such as farm origination, batch numbers, processing data, soil quality and fertilizers, storage temperatures and shipping details can be linked to product package via QR code[Kamath, 2018].

As a customer being able to trace a product that is being consumed from farm-to-table is not only beneficial from the health point of view but also provides a competitive edge to industries providing the product.

Some of the existing blockchain projects targeting supply chain industries are listed in Table: 8

Name	**Overview**	**Url**
WaltonChain	Using RFID to create combination of Internet of Things (IoT) and Blockchain	https://www.waltonchain.org
Ambrosus	Blockchain-powered IoT network for food and pharmaceutical enterprises	https://ambrosus.com
Modum	Trusted digital system powered by IoT and blockchain	https://modum.io
VeChain	Powered by IoT chips, sensors, and blockchain tech to provide seamless integration of different business on the blockchain for SCM	https://www.vechain.org
Tael	Prevents counterfeiting of products by using anti-counterfeiting labels on them	https://taelpay.com

Table 8: Existing blockchains in the field of supply chain

2.5.4 Blockchain in healthcare

One of the biggest, frequently occurring, and most damaging security incidents is health-related data breaches[Dickson, 2018]. “Healthcare is the only industry in which internal actors are the biggest threat to an organization,”[Widup, 2018]. Healthcare industry is heavily fragmented. This results in inefficiency in the system and is also major hurdle as of now. Healthcare providers usually do not have the access to all the vital data of the patients that can be crucial during the process of diagnosis and treatment, which in turn, can comprise the health of the patient. Aforementioned issue is also one of the reasons why researchers struggle to find the data desired, as a consequence slowing down the research in the field of healthcare[Katuwal, Pandey, Hennessey and Lamichhane, 2018].

The principal perk of using blockchain in the healthcare industry is that it provides a platform for storing health-related data by maintaining privacy and immutability[Swan, 2015, chap. 4]. Following domains could profit from the introduction of blockchain:

Personal health record storage

Electronic medical record (EMR) system could be realised in the blockchain where a vast array of personal health records can be stored. Patients or individuals could be able to grant access to their health-related instantly to doctors, pharmacies, insurance companies and other parties[Yue et al., 2016]. In addition, currently large health services that use EMR system do not have a common format to store the information, therefore, the information is not sharable or interoperable. Hence, using blockchain platform as a storage repository for EMRs could give rise to universal data format that can promote a format that could be shared universally.[Swan, 2015].

Blockchain Health Research Commons

Another benefit of having EMR that are standardised and have universal data format is that they can contribute to research[Swan, 2015]. Furthermore, public health data commons could also be established, "Blockchain technology could provide a model for establishing a cost-effective public-health data commons. Many individuals would like to contribute personal health data—like personal genomic data from 23andMe, quantified-self tracking device data (FitBit), and health and fitness app data (MapMyRun)—to data research commons, in varying levels of openness/privacy, but there has not been a venue for this. This data could be aggregated in a public-health commons (like Wikipedia for health) that is open to anyone, citizen scientists and institutional researchers alike, to perform data analysis."[Swan, 2015, pg. 60]. Integrating health-related data from users and big data streams and training machine learning algorithms over them could be helpful for wellness maintenance and preventive medicine[Swan, 2014]. Users could also be remunerated in the form of digital currency for providing their data. Thus, encouraging users to provide their data while maintaining anonymity and helping the field of research.

Blockchain health notary

Providing proof-of-existence documents which are usually carried out by notaries can also be incorporated in the blockchain. For example, during the visa process, city registration and many other safety-related issues require us to provide the documents such as proof of insurance, conditions, physician referrals, treatment, status and many more. These sort of health related documents could be encoded in blockchain, which could be verified and confirmed in seconds by required party thus removing the need to visiting the respected company and getting the relevant paper as proof. Also, certain services and results delivery, such as STD screening, could be mare more efficient and secure.

Doctor Vendor RFP Services and Assurance contracts

Services such as Uber where drivers bid for assignments with customers could be easily realised in the blockchain where a doctor can be assigned to a patient creating a two-way market for all health services. This could also help facilitate the price transparency between doctor and patient treatment process.

Some of the existing blockchain-based healthcare solutions are listed in Table: 10

Name	Overview	Url
Solve Care	Built to redefine administration of healthcare and other benefit programs, globally	https://solve.care
Medibloc	Patient-centric and data-driven medical innovation	https://medibloc.org

Name	Overview	Url
Modum	Allows its users to earn cryptocurrency through proof of “walk” and wellness behaviours	https://joinwell.io/
Stem cell	Making regenerative medicine global	https://www.stemcell-pj.net/en

Table 10: Existing blockchains in the field of healthcare

To summarize, in this chapter we briefly discussed the important components of blockchain technology which helped us understand how the technology functions. Also, short highlight on different types of blockchain and architecture of the blockchain was provided. Our focus then was shifted to different application areas of the blockchain technology. Even though the the technology was originally used in financial sector, use of blockchain has spread out in various areas which is also briefly discussed above.

3 Healthcare and current state of blockchain in healthcare

3.1 Introduction

The health care industry is one of the biggest industries in the market. 11.2% of the total gross domestic product(GDP) was spent on healthcare in Germany, which was third highest in the world. Only countries that spent more were the United States at 16.9%, followed by 12.2% by Switzerland in 2018[OECD, 2018]. 35.24% of the total population in Germany is overweight and 21.29% are obese[DiBonaventura, Nicolucci, Meincke, LeLay and Fournier, 2018], the population worldwide is aging, and physician and nursing shortages are anticipated[Swan, 2012]. Hospitals are still spending a sizable amount of resources into processing medical claims and administrative records[Dhillon, Metcalf and Hooper, 2017, chap. 9].

Our world is becoming more interconnected and data-driven and so is healthcare. On the other hand, these changes are coming with the cost of high regulation, overhead cost and extra educational requirements for those who participate[Wehde, 2019]. Therefore, changes in healthcare are slower. By 2030, the way healthcare is delivered is expected to change drastically due to increased access to data, additive manufacturing AI, and the wearable and implanted devices to monitor our health[Wehde, 2019]. The evolution of e-health application and its ability to improve healthcare practices by electronic processes has had a positive influence on the healthcare sector[Staffa, Coppolino, Sgaglione, Gelenbe, Komnios, Grivas, Stan and Castaldo, 2018].

The range of body functions that can be tracked using wearable in growing. Body functions such as blood pressure, hydration, oxygen level, brain activity(EEG), glucose, respiration, temperature, heart rate, and variability and movement can be tracked through the wearable technology available today[McCluskey, 2017]. "From assistance for Alzheimer's patients to understanding complex knee injuries, wearable computing will transform how we understand pharmaceuticals, rehabilitation and preventative care."[McCluskey, 2017, pg. 32-33]. The health-related wearables devices for monitoring and managing the health and well-being of individuals outside the medical institutions are growing to support healthcare[Paganoni, 2019].

Health-related IoT promises many benefits and is already paving the way for better-personalised diagnosis, with healthcare evolving towards a system of predictive, preventive and precision care[Paganoni, 2019]. This technology also enables real-time monitoring of patients, fitness and well-being monitoring, medication dispensation and data collection for research in the field of healthcare.

3.2 Current state of blockchain in healthcare

In section 2.5.4, how blockchain can be used to help make healthcare more efficient was briefly discussed. Healthcare is a broad industry and can be divided into smaller sections. We explore these sub-divisions within healthcare and discuss the existing solutions or emerging concepts.

3.2.1 Blockchain in healthcare data management

One of the biggest impact blockchain can have in the healthcare industry is data management. Different approaches and tools are being used by health care organisations and health care personnel to exchange the patient's health information[Esmaeilzadeh and Mirzaei, 2019]. People move from one place to another due to multiple reasons, therefore they usually seek health care services from different providers in different regions. Health-related information can be fragmented and outdated which can lead to a poor connection between provider and patient's medical information for data exchange.

Given that HIE between organisations is possible, patients rely on HIEs to improve the speed of treatment process, enhance care coordination, and increase the quality of care[Patel, Abramson, Edwards, Cheung, Dhopeshwarkar and Kaushal, 2011]. Patient's trust in HIE is core, as security and privacy issue can occur during information sharing process, depending on the type of information system being used.

Blockchain can facilitate business transactions (i.e. information-sharing) in electronic context via a distributed ledger spreading in various locations rather than through a central authority. It can also provide data ownership to the patient, where they decide which data is to be shared to which organisation.

Existing projects

Some of the popular projects in the field of EHR are briefly explained below:

1. *Guardtime* and Estonian biobank announced partnership to deploy blockchain-based data access and governance tool for medical data[Guardtime, 2019*a*]. Thier MyPCR platform which is blockchain-based can be accessed from smartphone by 30 million NHS patients[Guardtime, 2019*b*]. The platform is expected to improve medication adherence with potential saving of 800 million GBP in the UK and 200 billion USD in US. MyPCR delivers immutable proof of health data provenance and integrity, and most importantly General Data Protection Regulation (GDPR) data rights management and aotomated verification of medication adherence.

2. *Philips Research* is working on "verifiable data exchange", which enables researchers in a network of hospitals and universities to request data that match their need for research[Dickson, 2018]. This is done around three disciplines that include data anonymity, data request and fulfilling request. The project aims to record all data exchanges and identity of people performing those exchanges. Philips researchers believe that the transparency in data storage and data exchange between involved parties will create a system of shared risk and responsibility.

3. *MedRec*, managed by MIT, is a open source project. It is a system that primarily targets patient agency, providing a transparent and accessible view of medical history[Azaria et al., 2016]. MedRec uses smart contract that links patients and providers to the addresses of existing records. They don't store the patient's health data directly but rather encode metadata that allows data to be accessed by patients securely. This metadata contains information about ownership, permission and the integrity of the data being requested.

4. *GemHealth*, is a network developed by Gem that enables application development and shared infrastructure for healthcare[Prisco, 2016]. As their first partner, philips and gem are working together in bringing patient centric approach in the field of healthcare. Gem's blockchain platform, also known as GemOS, provides a ecosystem for exchanging enterprise data in a peer-to-peer fashion, both within and across organisations, while creating unique global identifiers for the data assets such that they can easily be tracked between systems[Allison, 2017].

Projects focusing on particular domains such as genomics and imaging are also available. Genomics specifically has pulled a lot of interest from various organisations lately due to the rise in interest of personal genome sequencing, the importance of genomics data, and an immense possibility of monetization[Katuwal et al., 2018]. Startups such as Encrypgen[20], and LunaDNA[21] are creating blockchain-based data exchange platform, whereas 23andMe[22] and AncestryDNA monetize the genetic data by selling access to third parties.

3.2.2 Counterfeit drugs discovery and Supply chain

There is no denying that when it comes to curing a disease, drugs need to be genuine. There should be no compromise from raw materials and production, to stages of storage and distribution, monitoring and tracking. Re-labelling the expired drugs with new expiry date, and counterfeit drugs that put the quality of the intended drug in jeopardy. Carelessness from one single party in the supply chain process can threat to take one's life away. Therefore, there is no denying the importance of supply chain in the medical industry. Using blockchain systems, the aforementioned issued can be tackled.
A possible scenario for drug tracing and tracking is portrayed in Figure: 8.

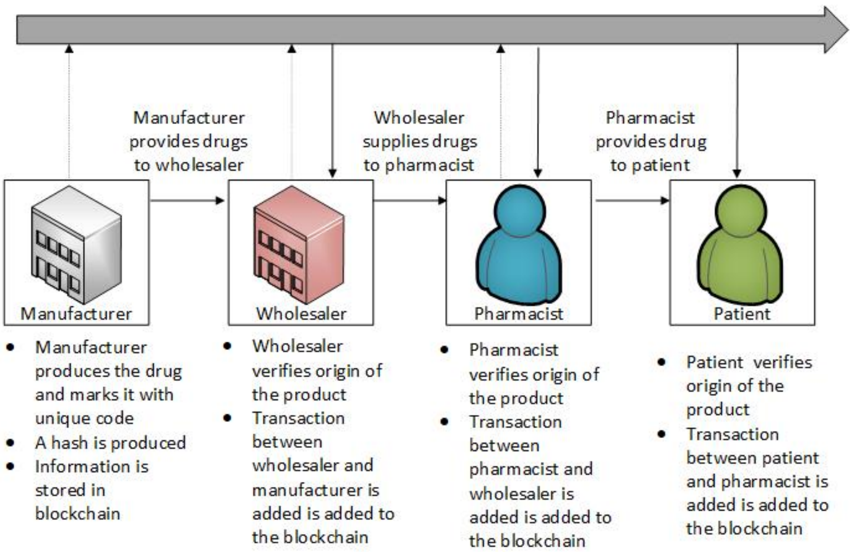


Figure 8: Blockchain in drug supply chain

[20]https://encrypgen.com/

[21]https://www.lunadna.com/

[22]https://www.23andme.com/en-int/

Existing projects

1. *SAP*'s information collaboration hub for life science, which was cloud based and designed to reduce drug counterfeiting by following directives issued by governments worldwide was made accessible to US supply chain via a blockchain-technology hub[SAP, 2019]. The hub authenticates pharmaceutical packaging returned from hospitals and pharmacies to wholesalers before products are resold. The article mentions that nearly 60 million drug return to wholesalers are made annually, accounting to estimated 7 billion USD. Their blockchain-based solution to tackle counterfeit drugs already comply with Drug Supply Chain Security Act (DSCSA), which is rolls out in November 2019.

2. *Accenture and DHL* experimented with their proof of concept of tracking and tracing of pharmaceutical products from manufacturing to patients successfully successfully[Accenture, 2018]. Keith Turner from DHL supply chain mentioned, "By utilizing the inherent irrefutability within blockchain technologies, we can make great strides in highlighting tampering, reducing the risk of counterfeits and actually saving lives."[Accenture, 2018]. DHL and Accenture created a blockchain-based serialization with nodes spreading across six geographic locations. The ledger holding the information of the medicines could be shared with stakeholders, including manufacturers, warehouses, distributors, pharmacies, hospitals, and doctors.

3. *Mediledger*, was also developed with the vision to meet the demands of DSCSA. The project's blockchain network consists of look-up directory which can be accessed through permissioned messaging network that allows companies to securely request and respond to product identifier verificiation requests[Mediledger, 2018]. Due the permissioned nature of the blockchain, only companies with proven identity can put products in the lookup directory. The system also provides a functionality that allows products that have been sold to other companies to transfer the accountability of the product before the NDC changes.

Other noteworthy projects are listed in Table: 12:

Project	Overview	Url
Ambrosus	Blockchain based IoT	https://ambrosus.com
Blockverify	Solution to track pharmaceuticals throughout the supply chain and to ensure the consumers receive an authentic product	http://www.blockverify.io/

Project	Overview	Url
Authentag	Authentag Platforms track thousands of product lines for hundreds of companies in 30 countries.	https://www.authentag.com/

Table 12: Existing blockchains in the field supplychain and drug counterfeiting.

3.2.3 Prescription management

Paper-based prescription is still prevalent in developed countries like Germany. This form of prescription has many flaws: paper-based prescription can be destroyed by natural phenomenon like rain, can be tore, and be easily misunderstood by a pharmacist. Prescription misuse has been on the rise in recent years leading to large-scale problems like Opioid crisis[Skolnick, 2018].

Existing projects

1. *BlockMedx* has three core focus: prescription fraud, abuse and non-adherence. They focus on tackling prescription fraud with proprietary e-prescribing and prescription monitoring capabilities using blockchain technology[CryptoRand, 2018]. They also provide mobile application for patient through which prescription can be tracked and managed. BlockMedx has its own token named MDX, this token is payed to patients as incentives to promote healthy behaviour.

2. *Project Heisenberg*[23] is an open source project available in Github. It is a decentralized identity management and ERP system which is built on top of permissioned Ethereum consortium network. Like BlockMedx this project also implements its own token. A decentralized smart-contract is created that defines the method for ownership and pharmaceutical script transfer. This helps to remove the possible prescription forgery, enable regulatory insight and create immutable record of the movement of pharmacy scripts.

3. *Scalamed*[24] is an Australian startup founded by Australian doctor and for-

[23]https://github.com/tylerdiaz/Heisenberg

[24]https://scalamed.com/

mer pharmaceutical executive. It allows patients to receive prescriptions directly from their doctors to their mobile phones. The technology from ScalaMed creates a patent-protected method to encrypt a prescription data of a patientBarbeler [2018]. This encrypted data is then transported to the e-prescription blockhain service through an APIs. After writing the information in blockchain, it is immediately available to the patient via an app.

3.2.4 Claim and billing management

Claim and billing involves finance, and this section of healthcare can encounter inefficiencies and controversies. These issues mainly occur due to lack of trust and transparency in the system. Blockchain provides an excellent opportunity to tackle these obstacles that are prevalent in current practice. Blockchain allows direct linking between patients and bearers. Smart contracts can ensure claim correctness and can prevent any fraudulent activity. This can also help remove the process of verification of claims from multiple parties to ensure the claim is authentic. Gem as explained in section 3.2.1 also provides a solution in claim management.

Existing projects

1. *Change healthcare*'s blockchain platform can process 30 million transaction per day using the hyperledger fabric framework. The company helps in claims settlement and payment through the blockchain platform. Apart from claims, the platform provides software and analytics, clinical services including medical records and patient engagement services like digital identity and consent management[Morris, 2018]. Eligibility check to find if a procedure will be covered by insurance, that could upto 14 days could be processed in matter of minutes through smart contract deployed in the blockchain.

2. *HSBlox*[25] combines machine learning and blockchain to provide secure, real-time information sharing and interventions. Smart contracts automate multi-party transactions.

3. *Smartillions*[26] provides different way of solving the claim settlement compared to the solutions offered by the projects mentioned above. They allow health care providers to settle claims with insurance companies without any

[25]https://hsblox.com/pages/solutions

[26]https://www.smartillions.ch/assets.html

monetary exchange. Rather, a digital asset backed by pension funds is exchanged through the blockchain platform. The digital asset as mentioned by Smartillions is not subject to inflation and generates the same returns as the underlying pernsion funds.

3.2.5 Medicine research

One of the domains that play a huge role in the overall development of the healthcare facility and cannot be understated is research. Blockchain can help in clinical research by helping in structuring transparent checkable methodology, and it can help check clinical trial integrity given that a set of core metadata is defined. Finally, it can lead to community-driven Internet of health data, gathering researchers and patient communities, social networks and IoT data flows, at a global dimension, with granularity and transparency and decentralisation[Mehdi and Ravaud, 2017]. Few concepts such as Scrybe[27] and LyfeScience[28] have been proposed to use blockchain in clinical trials. However, a concrete implementation of the blockchain technology in this field is yet to be found.
In this chapter we focused on healthcare industry. A small introduction to the healthcare industry was provided which showed that healthcare is one of the biggest industries in the world. We then looked into current state of blockchain in healthcare industry. For this, We broke the healthcare industry in small sectors and then explored what solution already exists in the market concerning blockchain technology. Our exploration showed us that even though some sectors already have blockchain solutions, whereas, for some sector there is still lots of research to be done.

[27] https://pdfs.semanticscholar.org/1801/f6861fe540ce4c65ebbfac59fbc6026f6741.pdf

[28] https://www.phusewiki.org/docs/Frankfut%20Connect%202018/TT/Papers/TT18-1-paper-clinical-trials-on-blockhain-v10-19339.pdf

4 Literature Review

Analysing and aggregating to construct an objective summary of existing research papers through empirical studies is important part of this thesis project. This chapter of the thesis explores the published journals that discuss the impact blockchain technology can have in the healthcare sector. To make the research and thesis scientific, systematic literature review is performed. Guidelines from David Budgen and Pearl Brereton's "Performing Systematic Literature Reviews in Software Engineering"[Budgen and Brereton, 2006] is followed to conduct the literature review.
Before diving into any specifics, a brief discussion on literature review is done in the section 4.1 in order or provide a high-level understanding of the topic. After explaining what literature review is, what is its importance, and what type of literature review exists we will dive deeper into the systematic literature review and the selected approach to carry it out.

4.1 Literature Review

Literature review is a well-known part of the research field as well as an important research method in multiple academic disciplines.This is also true in Informtation-Systems (IS) field. During the process of conducting a literature review various sources including books, scholarly articles are surveyed. This survey is specific to the purpose of a particular issue, area of research, or theory. This process helps to provide a description, summary, and critical evaluation of the works conducted concerning research problem being examined. Literature reviews help lay out the research that has already been carried out in a particular topic and demonstrate the reader how the research that is being carried out fits within a larger field of study. [Fink, c2014]

4.1.1 Importance

A literature review can comprise of summary of key sources, but a literature review generally has a pattern and combines summary and synthesis with specific conceptual categories. A summary can be a rundown of the crucial information of the source, but the synthesis is a re-organization, or a re-assemble, of the information in a particular way such that it informs how the author is planning to explore a research problem. Analytic feature and the purpose of a literature review [Fink, c2014; Ridley, 2012; Jesson and Lacey, 2011] can be listed out as follows:

The analytical features of a literature review might:

- Provide a new understanding of old work or combine a new with old understanding,
- Discern the scholarly progression of the domain, including major debates,
- Based on the situation, assess the source and direct the reader on the most pertinent or relevant research, or
- Identify the existing gaps in how the problem has been researched to date; usually in the conclusion section.

The purpose of a literature review is:

- Understand and present each work in the context of the contribution to the problem that is being studied.
- Explain the inter-connectivity of each work to the others under deliberation.
- Identify new ways to interpret prior research.
- Expose and gaps that underlie in the literature.
- Iron out conflicts amongst seemingly paradoxical studies made in past.
- Mark the way in fulfilling a need for additional research.
- Establish own research within the context of existing literature.

4.1.2 Steps Involved in Conducting a Research Literature Review

In order to successfully conduct a research literature it is important to approach the process systematically. These steps[Fink, c2014, ch.1] are laid out as follows, and is visualized in Figure: 9:

1. The first step is to select the appropriate research questions. A research question should be precisely stated question that guides the review.
2. Finding the bibliographic or article database, Websites, and other sources. A bibliographic database contains articles, books, and reports that are able to answer the reserarch questions.

3. Picking up the search terms. Search terms are the query keywords that are used to look up the information sources. These search terms frame the research questions and should be used with particular grammar and logic to conduct the search.

4. Filtering out the results. Preliminary literature searches generates many articles, of which only few are relevant. In order to retrieve the relevant articles certain criteria are set from which the literature are filtered.

5. Applying methodological screening criteria. This process includes criteria for evaluating scientific quality.

6. Conducting the review. This step requires abstracting data from articles, monitoring the quality of the review and pilot testing the process through a standardised form.

7. Synthesizing the results. The resulting literature review results may be synthesized descriptively. Descriptive syntheses is interpretation of reviewer's findings based on their experience and quality of content of the available literature.

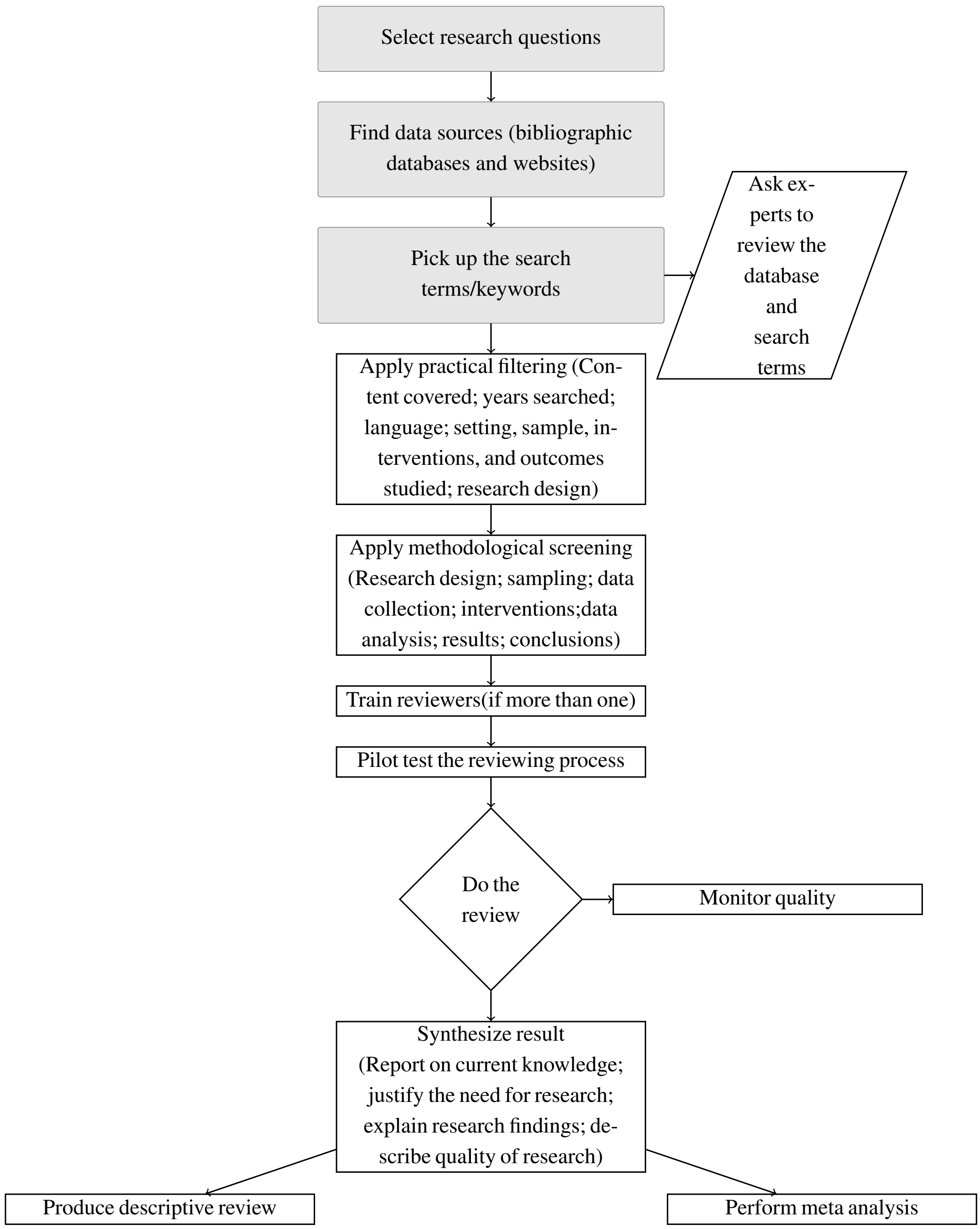


Figure 9: Steps involved in literature review (based on image from [Fink, c2014, pg.4])

4.1.3 Types of Literature Reviews

Knowledge that is available in a in a given field can be broken down into three sections. First section consists of the primary studies that researchers carry out and publishes. The second section comprises of the summary and provide new analysis generated from extended beyond the primary studies.On the third, there are the perceptions, conclusions, opinion, and interpretations that are shared informally that become part of the lore of field. During the process of creating a literature review, it is worth stating that the third layer of knowledge that is cited as "true" even though it often has only a loose relationship to the primary studies and secondary literature reviews. Given this, while literature reviews are designed to provide an overview and synthesis of pertinent sources that is explored, there are a number of approaches that could be adopted depending upon the type of analysis underpinning the study[UniversityOfSouthernCalifornia, 2019].

Argumentative Review

This style of review is carried out in order to support or contradict an argument, deeply ingrained presumptions, or philosophical problem already mentioned in the chosen literature. The intention is to come up with a body of literature that forms an opposing viewpoint. Given the value-laden nature of some social science research [e.g., educational reform; immigration control], argumentative approaches to analyzing the literature can be a well-founded and important form of article. However, it should be noted that they can also introduce problems of bias when they are used to make summary claims of the sort found in systematic reviews.

Integrative Review

This review form summarizes past empirical or theoretical literature in order to provide a thorough understanding of a particular phenomenon[Broome, 2000]. "Considered a form of research that reviews, critiques, and synthesizes representative literature on a topic in an integrated way such that new frameworks and perspectives on the topic are generated. The body of literature includes all studies that address related or identical hypotheses or research problems. A well-done integrative review meets the same standards as primary research in regard to clarity, rigor, and replication. This is the most common form of review in the social sciences." [UniversityOfSouthernCalifornia, 2019]

Historical Review

When it comes to history something remain in solitude. This type of literature review that is under microscope focuses on exploring research over a period of time, starting with the first time the theory, phenomena, concept or an issue came into written existence. Then the evolution of the topic is traced over time. In doing so, the literature review provides an excellent platform to its familiarity with current state-of-the-art developments and how things to evolve in future, which could pave the path for future research.

Methodological Review

This sort of review emphasises on method of analysis rather than findings. Sometimes it becomes important to figure out how people come up with the things they say in contrast to what they say. This phenomenon can help understand the way perception occur on people.
"Reviewing methods of analysis provides a framework of understanding at different levels [i.e. those of theory, substantive fields, research approaches, and data collection and analysis techniques], how researchers draw upon a wide variety of knowledge ranging from the conceptual level to practical documents for use in fieldwork in the areas of ontological and epistemological consideration, quantitative and qualitative integration, sampling, interviewing, data collection, and data analysis. This approach helps highlight ethical issues which you should be aware of and consider as you go through your own study."[UniversityOfSouthernCalifornia, 2019]

systematicReview Systematic literature review is a popular form of review in IS field. This type of reviews gives an idea of the research that has already been carried out in regards to the research question that is to be examined. The research that is carried out is done using pre-specified and scientifically accepted methods to critically support or criticize the existing suitable research, and to collect, report and analyze data. The main aim of carrying out this form of research is to studiously document, critically evaluate, and outline all the research for the research question that is to be answered. Generally it focuses on very specific question, which is presented in the form of causality. The causality phenomenon can also be formulated as, "To what degree does A contribute to B?" or "How can A affect B?".

Theoretical Review

Theoretical review analyzes the entirety of theory that has been collected in regard to an topic under scrutiny. This type of review can help to develop new hypothesis that is to be tested as aforementioned review type help to look into existing theories, the relationships between then, and to what extent are the existing theories have been examined. Usually this sort of literature reviews are carried out to demonstrate that existing theories are insufficient to explain new or upcoming research problems.

In this section high level of understanding on what literature review is and how a literature review is conducted is discussed. We could understand that literature review is carried out in order to gather the existing knowledge of a topic. Furthermore, different types of literature review were also highlighted, this highlight pointed out how certain type of literature review can be favorable in certain scenarios.

4.1.4 Methodology

In order to explore current research activities in the field of healthcare that leverages blockchain technology we conduct a literature review following the guidelines of systematic literature review. This review process is carried out together with the PRISMA statement[Moher et al., 2009].

PRISMA was developed in June 2005 where 29 participants, including review authors, methodologists, clinicians, medical editors, and a consumer gathered in order to revise and expand the existing QUality Of Reporting Of Meta-analyses (QUOROM)[Moher, Cook, Eastwood, Olkin, Rennie and Stroup, 1999] checklist and flow diagram. A systematic review is a review that consists of clearly formulated research question and leverages systematic methods to identify, select, and critically appraise relevant research, and simultaneously collect and analyze result from studies included in the review. Meta-analysis which could be used to analyze and summarize the result makes use of statistical techniques to incorporate the results of included studies[Moher et al., 2009].

To conduct our research and select the studies for systematic review we followed the flow diagram provided in PRISMA statement, which is also visualised in Figure: 10

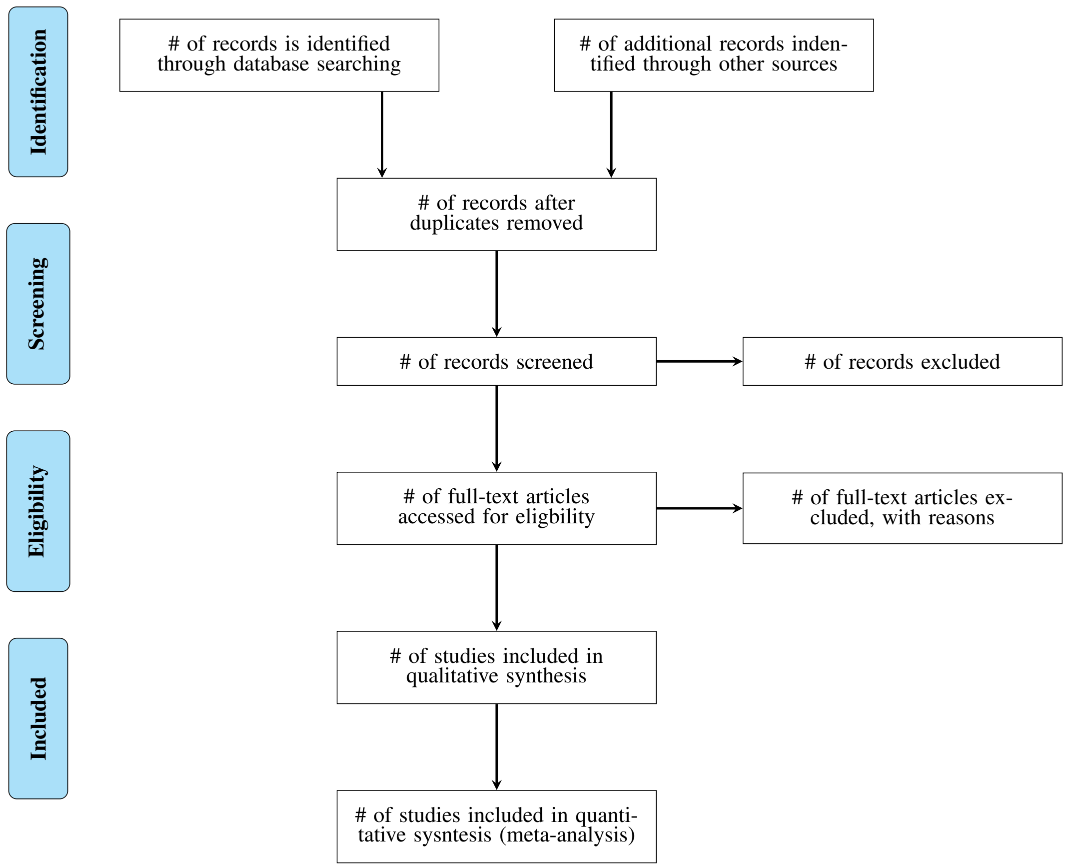


Figure 10: Information flow through different phases of systematic review as per PRISMA statement

Conducting Research(Identification)

The first step in conducting research was selecting the data sources. For our research and primary paper identification PubMed[29], IEEE Xplore[30] and Web of Science[31] was chosen. To search the databases we used following query string:

("blockchain") AND (health OR medic* OR pharma* OR drug* OR “ehealth” OR “e-health” OR “telehealth” OR “EHR” OR “EMR”)*

[29]https://www.ncbi.nlm.nih.gov/pubmed/

[30]https://ieeexplore.ieee.org/Xplore/home.jsp

[31]https://www.webofknowledge.com

We believe this query string with the wildcard includes wide area within health care sector. Ability to use wildcard for search was one of the reasons to choose the scientific databases as mentioned above. Scientific database such as ScienceDirect was not used because they did not support wildcard and we wanted to have a consistent query string for search throughout all the scientific databases. Since the topic is comparatively new, we did not restrict our search result to any specific time frame.

Screening of Relevant Papers

The results from query string were collected using Mendeley Web Importer[32]. We then used "*Check for Duplicates*" feature of Mendeley which is available in desktop version of the software which helped to remove the duplicate papers. We also encountered some advertisements in search results which was provided as search result and was removed manually. The next step for selecting the papers was to screen them to relevance. For this we set up exclusion criteria which is enlisted below:

- Paper that were duplicates.
- Paper that were not in English language(although all our search results were English).
- Paper without full text availability.
- Paper that were not published as Journal article.
- Paper whose primary focus was not blockchain and healthcare.
- Paper that focused on blockchain and healthcare along with other application areas such as finance, supply chain in general, government, etc.

In order to make sure the paper was relevant and was eligible for full text analysis we studied the title, abstract and the keyword of the papers. In case of uncertainty in some case introduction and conclusion was also studied.

Keyword based clustering

The next step involved clustering of the paper. For this step we came up with our own keyword/s for each paper after studying the title, abstract and in some case introduction and conclusion. After the keyword abstraction we classified each paper into a

[32]https://www.mendeley.com/guides/web-importer

individual cluster. Then, the papers were read in detail and, if the paper was wrongly classified or intended for a different cluster, the clusters were updated accordingly. The keyword based clusters which is specified as use case is listed in table: 16

Data extraction and Mapping

The last step involved information extraction from final selected papers for meta-analysis and address the research question. For this, we extracted the title of the selected paper, the year paper was published, authors of the paper, country the authors were affiliated to, publisher of the paper, use case of the paper, short summary that was self created or the abstract of the paper, and the publication type of the paper(i.e. if the paper came from academia or industry or both).

#	Extracted item	Description
1	Authors	The authors of the paper
2	Country	The country main author is affiliated to
3	Publication source	Academina/Industry/Both
4	Publisher	The channel through which paper was published
5	Summary	Self generated summary or abstract
6	Use case	Specific field within health care that paper targets
7	Year	Year the paper was published

Table 14: Data item extracted from the selected papers

4.1.5 Results

Our querystring provided total of 777 results of which 144 were from PubMed, 386 from IEEE Xplore and 247 from Web of Science. After removing duplicates from Mendeley 486 results were left, which was reduced to 470 after removing irrelevant links. Next step was removing all the web articles, book section, thesis papers, and conference proceedings. To sum up, we only selected results that were published as journal articles. The total result then came down to 188. After screening relevant papers we read the title, abstract and in some introduction and conclusion. This filtering process resulted to 86 papers. Then paper which did not have full text available was removed and full text was studied, this brought our result down to 53 papers.

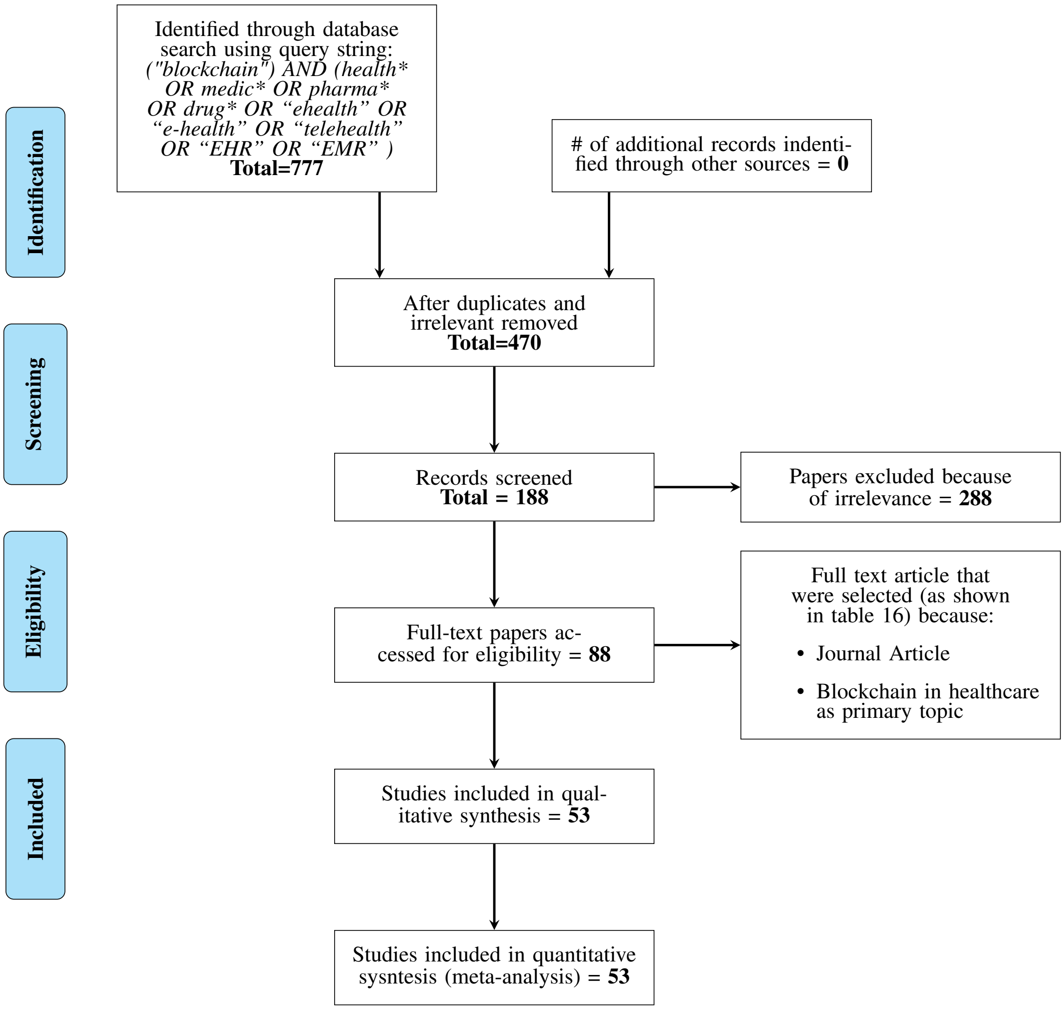


Figure 11: Mapping result with PRISMA information flow

The selected paper that were eligible for review and meta-analysis is presented in Table 16:

	Title	Author and Ref	Use Case	Year
1	Improving data transparency in clinical trials using blockchain smart contracts	Nugent et al.	Clinical trials	2016

	Title	Author and Ref	Use Case	Year
2	Healthcare Data Gateways: Found Healthcare Intelligence on Blockchain with Novel Privacy Risk Control	Yue et al.	EMR	2016
3	A Secure System For Pervasive Social Network-Based Healthcare	Zhang et al.	EHR	2016
4	Hitching Healthcare to the Chain: in the Healthcare Sector	Engelhardt	EMR	2017
5	MeDShare: Trust-Less Medical Data Sharing Among Cloud Service Providers via Blockchain	Xia, Sifah, Asamoah, Gao, Du and Guizani	EMR	2017
6	From blockchain technology to global health equity: can cryptocurrencies finance universal health coverage?	Till et al.	Crypto-currency Funding/ Research	2017
7	Tamper-Resistant Mobile Health Using Blockchain Technology	Ichikawa et al.	EHR/ Insomnia therapy	2017
8	BBDS: Blockchain-based data sharing for electronic medical records in cloud environments	Xia, Sifah, Smahi, Amofa and Zhang	EMR/Data Sharing	2017
9	A systematic review of the use of blockchain in healthcare	Hölbl et al.	Review	2018
10	Continuous Patient Monitoring with a Patient Centric Agent: A Block Architecture	Uddin et al.	IoMT/ Patient Monitoring	2018
11	Blockchain-Powered Parallel Healthcare Systems Based on the ACP Approach	Wang et al.	Parallel health care systems	2018
12	Blockchain technology for providing an architecture model of decentralized personal health information	Rahmadika and Rhee	PHI	2018
13	A Blockchain-Based Notarization Service for Biomedical Knowledge Retrieval	Kleinaki et al.	Health data notarization service	2018

	Title	Author and Ref	Use Case	Year
14	Spatial Blockchain-Based Secure Mass Screening Framework for Children with Dyslexia	Rahman et al.	Clinical research	2018
15	Healthcare services across China – on implementing an extensible universally unique patient identifier system	Cheng et al.	EHR	2018
16	A Blockchain Approach Applied to a Teledermatology Platform in the Sardinian Region (Italy) †	Mannaro et al.	EHR/ Dermatology	2018
17	Converging blockchain and next-generation artificial intelligence technologies to decentralize and accelerate biomedical research and healthcare	Mamoshina et al.	Machine learning	2018
18	Fingernail analysis management system using microscopy sensor and blockchain technology	Lee and Yang	Biometric recognition	2018
19	FHIRChain: Applying Blockchain to Securely and Scalably Share Clinical Data	Zhang et al.	EMR/ Clinical data sharing	2018
20	BAQALC: Blockchain Applied Lossless Efficient Transmission of DNA Sequencing Data for Next Generation Medical Informatics	Lee et al.	DNA sequencing/ Genome	2018
21	MIStore: a Blockchain-Based Medical Insurance Storage System	Zhou et al.	Medical Insurance	2018
22	A Blockchain-Based Medical Data Sharing and Protection Scheme	Liu, Wang, Jin, Li and Li	EHR	2019
23	Research on electronic medical record access control based on blockchain	Zhang et al.	EMR	2019
24	Comparison of blockchain frameworks for healthcare applications	Agbo and Mahmoud	Bitcoin vs Ethereum vs Hyperledger Fabric	2019

	Title	Author and Ref	Use Case	Year
25	Prototype of running clinical trials in an untrustworthy environment using blockchain	Wong et al.	Clinical trial	2019
26	Healthybroker: A trustworthy blockchain-based multi-cloud broker for patient-centered ehealth services	Kurdi et al.	eHealth Service/ Patient centered care	2019
27	A Decentralized Privacy-Preserving Healthcare Blockchain for IoT	Dwivedi et al.	IoMT/ Patient monitoring	2019
28	A fog computing-based architecture for medical records management	Silva et al.	EMR	2019
29	A framework for secure and decentralized sharing of medical imaging data via blockchain consensus	Patel	Medical image sharing	2019
30	A novel EMR integrity management based on a medical blockchain platform in hospital	Hang et al.	EMR	2019
31	A Novel Medical Blockchain Model for Drug Supply Chain Integrity Management in a Smart Hospital	Jamil et al.	Drug supply chain	2019
32	A Secure and Scalable Data Source for Emergency Medical Care using Blockchain Technology	Hasavari and Song	Emergency medical care	2019
33	A secure occupational therapy framework for monitoring cancer patients' quality of life	Rahman et al.	IoMT/ Quality of life monitoring	2019
34	An adaptive biomedical data managing scheme based on the blockchain technique	Hussein et al.	Biomedical Imaging	2019
35	An attribute-based access control model in RFID systems based on blockchain decentralized applications for healthcare environments	Figueroa et al.	IoMT/ IoT	2019

	Title	Author and Ref	Use Case	Year
36	Applications of Blockchain Technology for Data-Sharing in Oncology: Results from a Systematic Literature Review	Dubovitskaya et al.	Review	2019
37	BinDaaS: Blockchain-Based Deep-Learning as-a-Service in Healthcare 4.0 Applications	Bhattacharya et al.	EHR	2019
38	Blockchain Applications for Healthcare Data Management	Dimitrov	General overview	2019
39	Blockchain-Based Access Control Model to Preserve Privacy for Personal Health Record Systems	Thwin and Vasupongayya	PHR	2019
40	Blockchain-Based Personal Health Records Sharing Scheme With Data Integrity Verifiable	Wang et al.	PHR	2019
41	Cloud Health Resource Sharing Based on Consensus-Oriented Blockchain Technology: Case Study on a Breast Tumor Diagnosis Service	Zhu et al.	Cloud health data sharing	2019
42	Dwarna: a blockchain solution for dynamic consent in biobanking	Mamo et al.	Biobanking	2019
43	EdgeCare: Leveraging Edge Computing for Collaborative Data Management in Mobile Healthcare Systems	Li et al.	EHR	2019
44	Efficient and secure attribute-based heterogeneous online/offline signcryption for body sensor networks based on blockchain	Iqbal et al.	IoMT	2019
45	eHealth integrity model based on permissioned blockchain	Hyla and Pejaś	EHR/ Data integrity	2019
46	False image injection prevention using iChain	Ahmed	Imaging	2019
47	How to Use Blockchain for Diabetes Health Care Data and Access Management: An Operational Concept	Cichosz et al.	Clinical research/ Diabetes	2019

	Title	Author and Ref	Use Case	Year
48	MBPA: A Medibchain-Based Privacy-Preserving Mutual Authentication in TMIS for Mobile Medical Cloud Architecture	Liu, Ma and Cao	EMR	2019
49	MedChain: Efficient healthcare data sharing via blockchain	Shen, Guo and Yang	IoT/ IoMT	2019
50	Privacy-preserving image retrieval for medical IoT systems: A blockchain-based approach	Shen, Deng, Zhu, Du and Guizani	IoMT/ Image retreival	2019
51	Proof-of-familiarity: A privacy-preserved blockchain scheme for collaborative medical decision-making	Yang et al.	EMR/ PHI	2019
52	Towards a Stakeholder-Oriented Blockchain-Based Architecture for Electronic Health Records: Design Science Research Study	Beinke et al.	EHR	2019
53	‘Fit-for-purpose?’– challenges and opportunities for applications of blockchain technology in the future of healthcare	Mackey et al.	EHR/ Clinical trials/ Drug supply chain	2019

Table 16: Selected papers for review

5 Meta Analysis and Potential of Blockchain in Healthcare

5.1 Meta Analysis

In this section we perform meta analysis for our selected literature. We have chosen different criteria and for each criteria, relevant papers are filtered and presented .

5.1.1 Publication Year Distribution

This part of meta-analysis shows how research in blockhain technology concerning healthcare sector is evolving over time. During our search we found that first paper that mentions blockchain technology and healthcare appeared in 2016[Nugent et al., 2016], which shows that the topic we are dealing with is comparatively new. However, number of articles that is published is constantly increasing which is also reflected in our paper selection as shown in Figure:12. This shows that interest in blockchain technology in regards to healthcare is rising and attracting attention. What we found was 5.66% of paper were published in 2016, 9.43% were published in 2017, 24.53% of selected papers were published in 2018 and, 60.38% of paper were published in 2019.

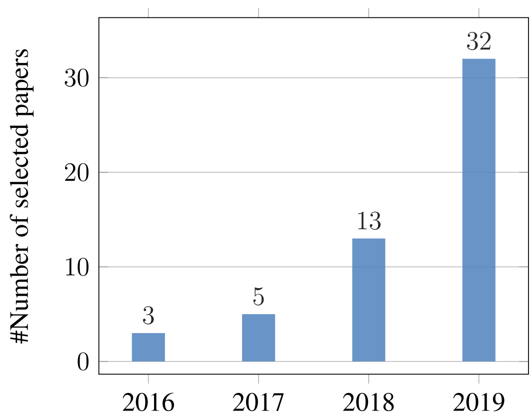


Figure 12: Publication year of the selected papers

5.1.2 Geographical Distribution of Selected Papers

Geographical distribution could paint the picture of how global is the interest in blockchain technology and healthcare. To sort the papers geographically, paper were assigned to country where the author or the university/industry the author was affiliated. In case of authors from various origin, majority vote was taken. Though the selected papers were widely distributed, most of the scientific papers came from China which accounted to 26.42%. Next in line were USA and Korea with 16.98% and 9.43% simultaneously.

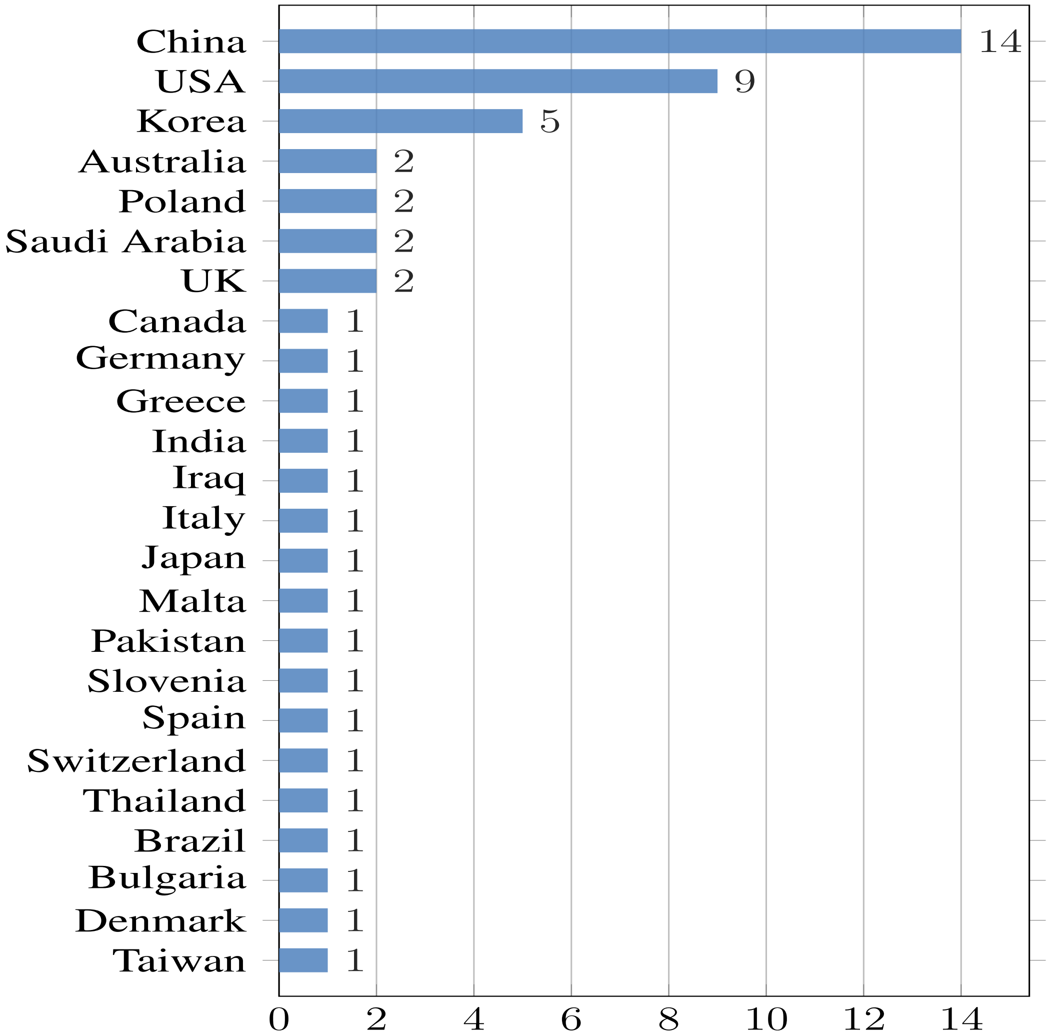


Figure 13: Publication paper count per country

5.1.3 Publication Source Distribution

In this distribution we look into distribution of papers between academia, industry or both. What we found was only 5.66% of selected paper came from industry. This could mean either research coming out from industry are not being published as journal article or they are too reluctant to step into blockchain technology in healthcare sector. Moreover, 62.26% of research paper originated from academic field. Also, we can see that industries and universities work together to come up with combined research which results to 32.08% of the selected papers.

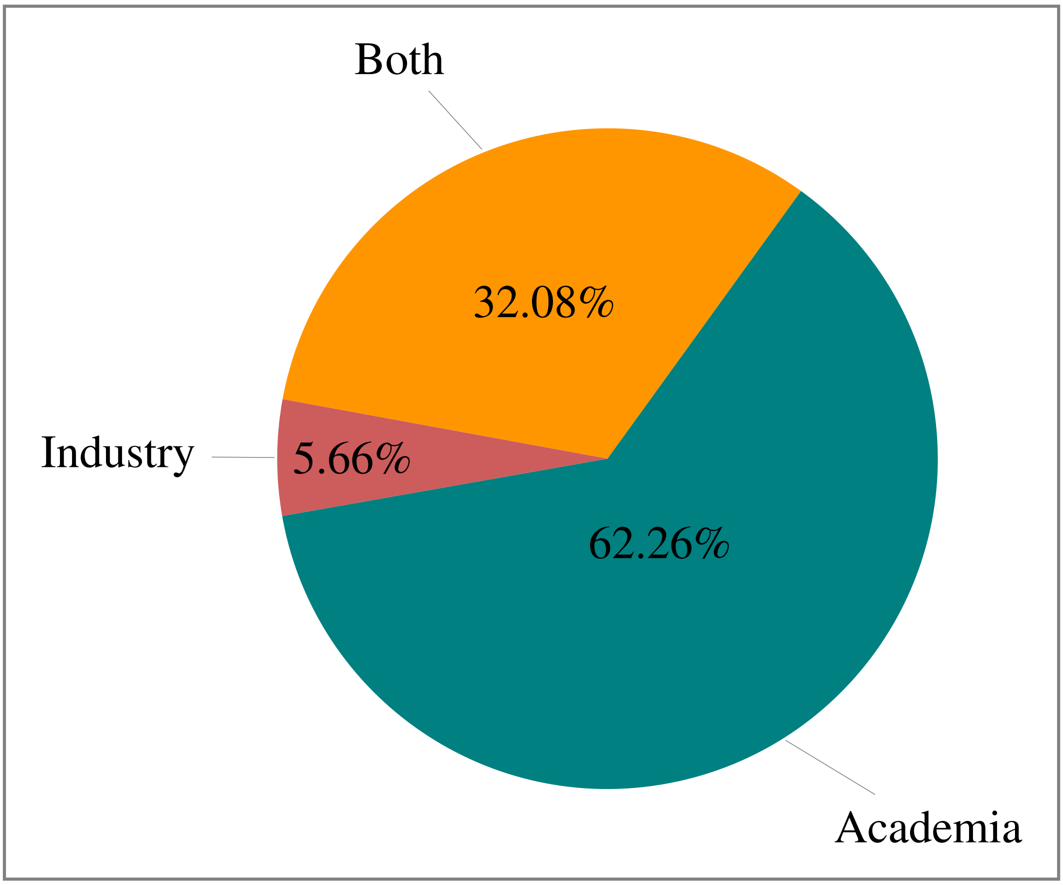


Figure 14: Publication source distribution

5.1.4 Publisher Distribution

This analysis shows that there were 18 different channels through which the paper that we selected were published. Of all the publications 'MPDI AG' published the most number of papers which is 28.30% which was followed by IEEE Xplore which resulted to 20.75%.

Publication Channel	Reference
BioMed Central Ltd.	Mackey et al.
BMJ Publishing Group	Till et al.
Carleton University, MacOdrum Library	Engelhardt
Elsevier B.V.	Zhang et al., Kleinaki et al.
Faculty of 1000 Ltd	Nugent et al.
Hindawi Limited	Silva et al., Thwin and Vasupongayya
IEEE Xplore	Rahman et al., Wang et al., Zhang et al., Liu, Wang, Jin, Li and Li, Bhattacharya et al., Li et al., Liu, Ma and Cao, Xia, Sifah, Asamoah, Gao, Du and Guizani, Shen, Deng, Zhu, Du and Guizani, Uddin et al., Wang et al.
Impact Journals LLC	Mamoshina et al.
JMIR Publications Inc.	Ichikawa et al.
Journal of Medical Internet Research	Zhu et al., Beinke et al.
Korean Society of Medical Informatics	Dimitrov
MDPI AG	Hussein et al., Lee et al., Hyla and Pejaś, Mannaro et al., Hang et al., Xia, Sifah, Smahi, Amofa and Zhang, Yang et al., Ahmed, Figueroa et al., Dwivedi et al., Rahman et al., Shen, Guo and Yang, Kurdi et al., Hölbl et al., Jamil et al.
Nature Publishing Group	Wong et al.
Oncology	Dubovitskaya et al.
SAGE Publications	Zhang et al., Cichosz et al., Rahmadika and Rhee, Lee and Yang, Iqbal et al., Patel
Springer	Zhou et al., Yue et al.,Hasavari and Song, Mamo et al.
Taylor and Francis Ltd.	Cheng et al.
Wiley	Agbo and Mahmoud

5.1.5 Classification of the Selected Papers

In section 4.1.4 under Keyword and clustering how we extracted keyword/s based on title, abstract or the entire paper and put the similar paper into individual cluster as shown in Figure: 15. In the following section of this paper we will be presenting these cluster and discuss them in brief.

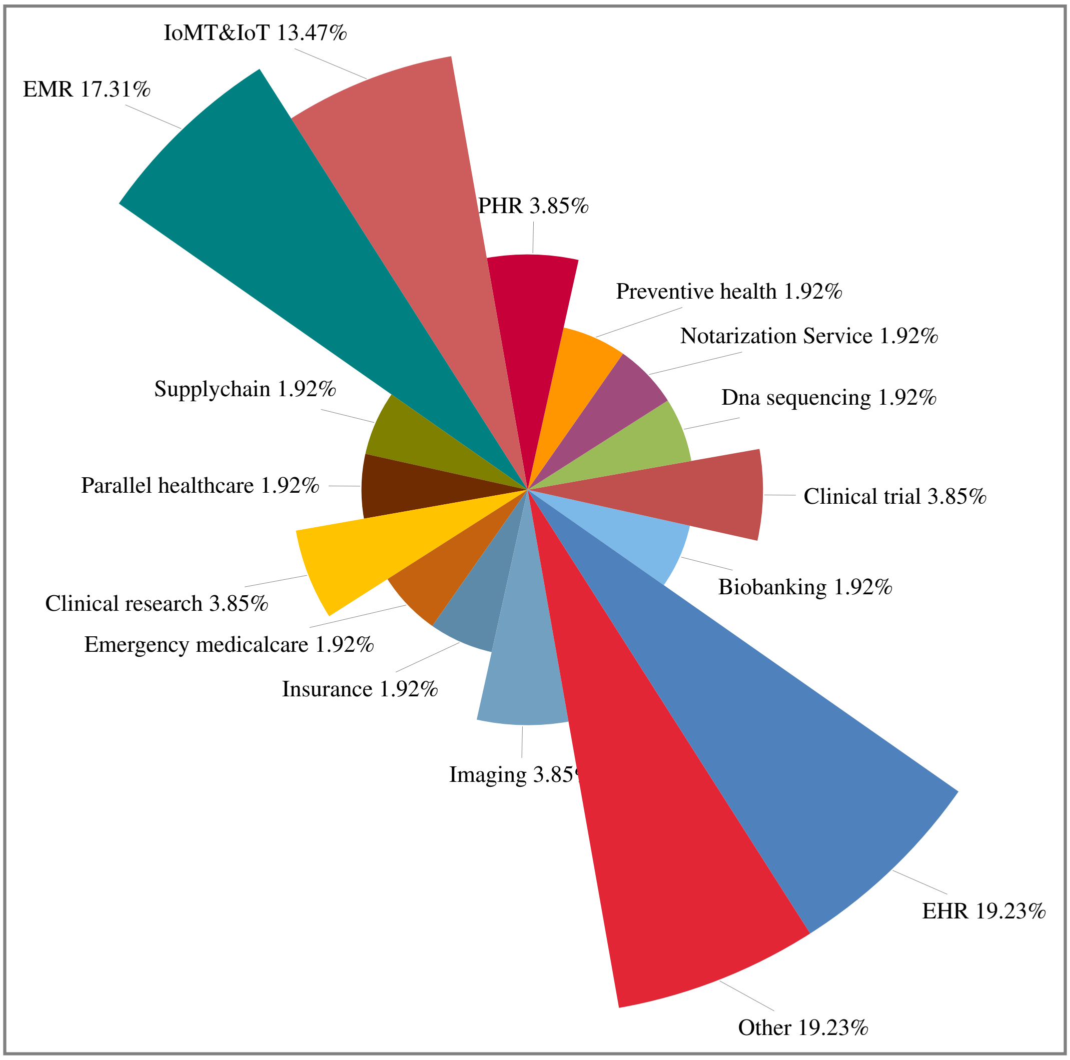


Figure 15: Use case distribution

Electronic medical record (EMR)

EMR is one of the most common and widely researched field withing healthcare concerning blockchain technology. Most of the selected papers for the literature review also consisted EMR related papers. The well implemented EMR system can be tracked by multiple healthcare providers securely. EMR also help provide efficient and precise healthcare. The nature of EMR system, that require sharing of patient's data among multiple healthcare providers requires data integrity and security.

For managing medical records a fog computing-based architecture was introduced by Silva et al. introduce blockchain concept withing fog layer. In the paper authors discuss four layers for their system namely; sensor, application, fog and cloud. According to author's description fog layer consists of multiple fog node that is responsible to act as miner node to validate transaction and information to blockchain. For layer plays crucial role in this architecture where the nodes contain software modules that manage subset of data from patient's record and also are responsible for authorizing stakeholders. Finally, they synchronize the data and authorization with cloud layer. Liu, Ma and Cao also present similar structure to fog layer and name it MediBchain network. The concept behind MediBchain and fog network seems to be similar and they both talk to cloud server. The concept in MediBchain is more specific where the authors even mention about using PBFT consensus mechanism.

The concept of medical data sharing is provided by Hang et al.. The authors conceptual architecture involves blockchain layer preserving a complete up to date medical data, visits to doctor, prescriptions, billing, and IoT data. The medical data lake is also described as a independent data repository and would be valuable for analysis. The communication with data lake is done via blockchain layer. A case study for a hospital is taken and a permissioned network is built on top of Hyperledger Fabric framework which has a great potential to accelerate decentralized digital healthcare system. Similarly, Zhang et al.; Xia, Sifah, Smahi, Amofa and Zhang; Xia, Sifah, Asamoah, Gao, Du and Guizani present different architecture for that uses permissioned blockchain system for EMR data management.

A different concept of 'healthcare data gateways' which resides in data management layer is proposed by Yue et al.. Authors have given a precise example of how the healthcare data gateway would function. If a patient visits a doctor, he/she can allow doctor access to specific data (blood sugar level, white blood cell count, etc) regarding the patient. This data would be stored in database for the doctor and would be only valid for a day by default. This time restricted concept of health care data is an interesting concept but can be vulnerable too. Since the healthcare information in data usage layer is fetched from blockchain and stored in traditional database, they can be susceptible to external attacks.

Yang et al. propose a decision-making-system among the stakeholders(patient, cured patients, doctors and insurance company). For this decision system a new associated consensus gathering algorith called proof-of-familiarity(POF). In the paper, authors state that before the treatment begins, a patient goes through a collaboration process with previously cured patients, doctor and insurance company. The timestamp of collaboration among various parties are stored in blockchain and authors believe that through this process, a patient can receive a decent treatment.

A specific blockchain based approach was created by Mannaro et al. in the Sardinian region of Italy. This blockchain based approached was used in treatment regarding dermatology. The solution included a web portal where patients could upload a picture and could choose skin care specialist who are registered in the portal. For the workflow, a request for consultation by patient and consultation availability by consultant would be stored in blockchain. Once the pairing between patient and consultant is settled, medical record is provided to the consultant. The diagnosis result would then be stored in blockchain which can be accessed by patient. If the patient accepts the diagnosis the reputation of the consultant would be updated in the blockhain. In case of disagreement the patient could look to different specialist for further diagnosis. This is a novel approach and goes on to show that even in remote places where healthcare providers may not be readily available, how using blockchain and online technology patients can still be treated safely and securely.

Electronic health record (EHR)

EHR can include wide range of data of a patient. These data can contain but are not limited to medical history, allergies, laboratory test results, immunization status, age, weight, etc. These are personal information and should be handled with care. Any tampering to this kind of data can have grave impacts towards the health of a patient. Therefore, it becomes absolutely necessary that only authorized people are allowed to access this kind of data and all the changes or updates regarding a patients data be safely stored.

A concept of combining blockchain and deep learning is proposed by Bhattacharya et al.. The authors propose two distinct phase for this concept. First steps includes introducing blockchain based EHR system that maintains privacy, security and maintains trust and second step involves applying deep learning technique on the stored EHR records to predict future ailments. This is a unique idea of combining two different technologies for the sake of better healthcare system for an individual.

Cheng et al. propose implementing an universally unique patient identifier system. This identifier system could be used across a city or state or even an entire nation. The original proposal is based for China where a health record of a person cannot be identified accurately among various hospitals. Authors mention that even though the concept of unique patient identifier system exists in some hospitals, it is not available all over. The authors also do not provide a direct approach on using blockchain technology for this proposed system but mention that universally unique patient identifier system could make use of blockchain system.

IoT and IoMT

IoT and IoMT have huge potential to change the way patients are treated. The application range of these technology range from devices, wireless sensors and services. These devices help detecting changes in our body and stream the information to remote server that are often located in cloud or are stored in a server in a single location. Tracking these can of data can have huge impact in healthcare service in underdeveloped or developing countries where health services are not readily available.

Zhang et al.; Iqbal et al.; Shen, Deng, Zhu, Du and Guizani; Figueroa et al.; Uddin et al.; Dwivedi et al.; Rahman et al.; Shen, Guo and Yang discuss the need for data privacy and present different different concepts of handling IoT and IoMT data using blockchain. Zhang et al. talk about Wireless body area network(WBAN) and Pervasive social network(PSN). WBAN consists of all the sensors within a human body. A patient or person to be monitored can have multiple sensors within his/her body. These sensors are linked securely with a mobile device, then a master key is generated for sensors and patient. The data from sensors are broadcasted via the mobile device to the PSN network. The information are verified by miners withing the network and recorded in new block of the blockchain. This concept can be useful withing closed network where the health care providers are within the PSN network and can access patient's data securely and provide feedback. Iqbal et al.; Uddin et al. also talk about WBAN concept but, use the term Body sensor networks(BSNs). However, the process of adding and fetching the information from blockchain is different. Iqbal et al. authors put forward the idea of generating user's private key via two parties, the first one being a third-party called Key generator center(KGC) and other being the user itself. The information captured by body sensors transmit the data to medical servers using 3G/4G network. The medical server then encrypts the patient information and transmits the data to blockchain. All the external users(hospital, insurance companies, doctors) can access the patient's from cloud via their user ID and assigned password in secure manner from the cloud.

The concept of image retrieval for medical IoT system using blockchain proposed by Shen, Deng, Zhu, Du and Guizani is brief. The system model proposed consists of five entities. Hospitals act as image provider, and uploads the image data (after feature extraction and encryption) to the blockchain. Third parties can access the data uploaded, and Regulatory authority makes sure the authentication information for hospital and third parties are legal. Miners are responsible for verifying the integrity of the data uploaded to blockchain.

The concept of using Radio-Frequency Identification(RFID) systems based on blockchain decentralized application is proposed by Figueroa et al.. The implementation of this concept is carried out in Ethereum platform. The need for the implementation was to prevent unwanted assets entering wrong area due to individual error. The proposed concept which was tested in Ethereum uses Attribut-Based access control(ABAC) that handles access control from a decentralized application running on top of blockchain architecture. This access control system are not role-based like traditional systems that are built on centralized architecture.

In order to preserve privacy and maintain security while maintaining the decentralized nature of blockchain Dwivedi et al. propose a modified model of blockchain. The authors argue that blockchains are computationally expensive and are not suitable for IoT devices. The solution involves storing the IoT data cloud storage rather than blockchain. Each user has a block in cloud, where his/her data are stored. Every time data is added or updated, a new hash of the block is created using merkle tree. The data is then sent to overlay network that comprises of multiple nodes of which one node is the master node and is responsible for verifying the identity of the nodes within the network and broadcasting to other overlay network if necessary. Once the hash is verified the hash is added and linked with previous hash. Healthcare providers for a patient can be chosen by insurance companies or by patients themselves. Also, smart contracts are supported and allow creation of agreements in IoT devices.

Shen, Guo and Yang put forward "Medchain" which introduces session-based healthcare data-sharing via blockchain. This concept of session-based data access includes healthcare provider collecting the healthcare data from a patient through IoMT and sensors. The collected data is sent to blockchain as a event and stored in new block. The event hash is sent back to healthcare provider via blockchain service. A new entry is then added to patient's inventory which can be accessed by the patient using his/her private key. The patient then can create a session using the directory service and share the information he wants to be shared through a session.

Imaging

Medical imaging can be another interesting use case for blockchain. Ahmed, Patel and Hussein et al. discuss about Imaging in healthcare using blockchain. Ahmed's paper is a concept paper therefor do not present concrete solution. On the other hand, Hussein et al. provide some solution on technical implementation. Patel provide a framework for cross-domain image sharing that uses blockchain and stores patient-defined access permissions.

Hussein et al. propose unique way of handling text and biomedical images. The proposal includes two blockchain as a base where, the second blockchain generates a secure sequence that is used in first blockchain, this ability to communicate between two blockchain helps the authors to handle two different types of data in text and images. The proposed block structure consists for block header and system payload as two components. System payload contains the data which is encrypted and patient ID. The system payload also consists what encryption type was used to encrypt the data. The authors don't mention about any off-chain data storage in their paper. Saving all the information in blockchain can increase the size of blockchain significantly with time and data retrieval can be slow as the information grows.

Ahmed discuss how malicious entity can tamper with the existing medical images and how the tampering could be mitigated. The paper highlights different types of tampering that can be done to the images namely; cut-paste, copy-move and erase-fill. The paper goes on to propose a blockchain for storing the images by naming blockchain framework as Image chain (iChain). The authors mention that saving the image in blockchain and saving the hash of the block will help prevent the attack as any tampering of the image will change the hash of the block. However, this framework is just a conceptual framework and does not consider scalability. Storing the image vector in block of a blockchain can result in huge block size and affect the performance of the system.

Patel define three actors(hospital, patient and physician). Hospitals handle image retrieval requests. For physician to access patient's data, physician sends a request to patient to get access of their data, the patient then proves the authority of the data requested and allows/denies request and informs hospital to allow access for the data. All these flow of information is stored in blockchain. Authors do not provide a concrete implementation, however the theory provided is clear and easy to implement.

Clinical Research

When it comes to treating existing and new diseases, clinical research plays a important role in finding out patterns to help cure the diseases. With the enormous data being generated from smart wearable devices it becomes important that these data be handled properly so that the owner of the data can maintain anonymity and the data is not skewed. Two of our selected paper discuss aforementioned domain using blockchain. Rahman et al. discuss about mass screening framework for children with Dyslexia and Cichosz et al. explain how blockchain can be used in Diabetes healthcare data and access management.

In the article for blockchain-based secure mass screening framework for children with dyslexia Rahman et al. mention IoT-based environment that can capture user interaction data during dyslexia testing. For the implementation the authors mention that they tested out Ethereum and Hyperledger platform and also tried open source bridging framework ark.io through which both ethereum and hyperledger network can communicate with each other. But, the authors do not mention what was their final choice. It is stated that timestamped history of the dyslexia tests or test history from users containing multimedia big data is linked with blockchain via cryptograhpic hashes.

In the article where Cichosz et al. discuss about using blockchain for diabetes health care data and access management use blockchain in different fashion as compared to Rahman et al.. For diabetes health data and access management the blockchain platform is used as multisignature account where patient and a trusted party control the number of keys needed to change the multisignature contract. Hospitals and general practitioner only hold one private key which only allows them to read and initiate transactions from and into the ledger. Once the private key is provided, data references and decryption keys can be fetched from blockchain which then allows the responsible parties to fetch the encrypted data from data lake.

Clinical Trials

Outcomes from clinical trials can be misleading due to the fact that the data generated might have been tampered, some data might have been lost and data might have been dredged. Wong et al. and Nugent et al. discuss exact in their paper.

The solution provided by Wong et al. and Nugent et al. do not contain any architecture. Therefore, finding out the actual use of blockchain in their proposal is difficult. Through the portal picture presented by Wong et al. we assume that blockchain is used as transaction keeper where blocks of blockchain are timestamped and attached with the file of transaction and identities of participating parties. The block of proposed system is meant to track the sender, receiver, file contents, hash of previous block, current hash of block and current timestamp in immutable fashion. Authors do not mention if their proposed blockchain leverages existing blockchain framework or if they built their custom blokchain. On the contrary, Nugent et al. propose a permissioned Ethereum blockchain network in their paper to conduct clinical trials. This network is to be maintained by regulators, pharma and contract research organizations.

Drug Supply Chain

Drug supply chain is one of the ares in healthcare domain where blockchain can have significant impact. Expired and counterfeit drugs can have deadly results. Therefore, the necessity of authentic medication plays vital role in improving the health of a patient. Blockchain can be one of the tools that can be used to track and validate drugs that was prescribed, amount of dosage and the authenticity of the drug itself.

Our search result included only one paper that targeted drug supply chain. In the selected paper, Jamil et al. mention that around 30% of the drugs that are sold in Africa, Asia and South America is counterfeit. The authors then go on and propose their blockchain based solution for supply chain that incorporates data storage for drug related information, pharmacy, pharmacist, medical prescription, doctor, patient, nurse, and drug dose. The architecture proposed also includes a data lake layer where off-chain data are stored. This layer can be used for analytics, visualisation, and reporting of medical data.

The implementation of proposed solution is done via Hyperledger Fabric framework. The REST server exposes distinct endpoints for participants(doctor, patient, nurse and, pharmacist), assets (drug, prescription, order and repository) and, transaction(prescription, drug, order, repository). The implementation and endpoints are also secured by distinct rules which allows access to users with specific roles.

The author's primary objective was to provide a solution for drug supply chain that involves the prescription from doctor and user treatment from nurses. This implementation does not consider the validity of the drug itself, which is also a crucial application area of blockchain.

Biobanking

Biobanks are repositories that store biological samples. These samples are generally from humans and help in research. Our selected paper included one article that discusses the use of blockchain in Biobanking.

Mamo et al. discuss about their web portal which harnesses blockchain for dynamic consent. The authors use the term 'research partner' which includes partnership between participants and researchers. The project incorporates GDPR which gives the ownership of the data to the participants. The architecture proposed contains a blockchain that stores the consent between the participant and research team. Storing the consent in blockchain allows the participants to be the owner of the data i.e. third parties can only access the data when the owner of the data allow them to. The authors chose Hyperledger Fabric as blockchain platform.

Futhermore, the real-life identities of the research partners are stored physically at the biobank and not in blockchain. Therefore, even if someone had access to all the data from Dwarna, it would still maintain the anonymity of the research partners.

Parallel Healthcare

Parallel healthcare came as a unique concept and something that had not crossed our mind. This form of treatment involves running physical healthcare and artificial healthcare side by side. Parallel healthcare system works by using physical patient's description and using it on artificial healthcare patient. Through description patient multiple prediction patients are created then this information is passed to artificial prescriptiveness patient. The prescriptiveness intelligence can then be used by physical doctor. The physical doctor then provide description intelligence to artificial description doctor which then is used to train prediction doctors and finally prescriptiveness doctor.

The framework presented by Wang et al. point out that parallel healthcare systems help improve diagnostic accuracy and treatment of the physical patient. The framework is combined with consortium blockchain by chaining patients, healthcare providers and medical experts. The paper also shortly discuss the possibility of decentralized parallel healthcare organizations where autonomous organizations run the blockchain through series of open and fair rules and no external intervention.

Notarization Service

In the field of biomedical research and clinical decision the data and their usage becomes crucial. Kleinaki et al. have proposed a lightweight wrapper for the conventional systems that use databases for storage and introduce a blockchain technology which offers a database query notary service.

Their proposed solution which includes a blockchain contract service acts as a supplement that behaves as a mediator between conventional databases and data consumers. In the paper, two schemes are discussed where the first scheme is basic scheme where each request made by data consumer results in deploying new contract to the blockchain structure. The second scheme, which is an optional scheme but helps in versioning of queries which helps in tracking how a response to particular query changes. This together help in maintaining a system that can assure data integrity, database non-repudiation, data consumer non-repudiation and data versioning.

Medical Insurance

Claiming medical insurance can be a complicated process. In some cases medical bills are directly charged from the insurance company. Whereas, in some cases the patient has to pay the medical bills by themselves first and then send the bill to insurance company and claim for refund. Zhou et al. propose a blockchain-based medical insurance storage system called MIStore.

Proposed system consists Hospitals, Patients, Insurance company and servers and actors of the system. Hospitals are responsible to initialize a transaction and send information about expenses to servers. User's and insurance companies can query the blockchain network to get information about a patient's spending record. The proposed solution is deployed in Ethereum's network and uses PBFT as consensus mechanism. Therefore, the assumption is 2/3 of the servers running as the blockchain node are always honest. And, insurance companies should only agree upon a response when more than 2/3 of the node's give same query result.

Dna Sequencing

DNA sequencing and genome sequence has significantly become cheaper in recent year. This has led to bigger advances in genetic industry. Due to aforementioned reasons, managing large volume of data generated in the field is an existing issue. Lee et al. propose a mechanism where the compressed DNA data are stored in blockchain.

In the paper authors do not explicitly mention if the blockchain framework is public or private. However, the mention that Biomedical Researchers will be able to act as miners and will be responsible to broadcast, verify and mine the blocks. The non mining nodes who be responsible to sync and update the data in blockchain will run the compression and decompression algorithm on the DNA data. Whenever healthcare users with require DNA Analysis report, they will request the biomedical researcher node, which in turn will get the compressed DNA data from blockchain, then decompress and send the report to the user.

The detailed implementation or a running project is not provided in the paper. It clearly states how the blockchain could be used to store the DNA data in blockchain efficiently. Important issues such as data authority and data validity is missing from the proposed solution.

5.1.6 Potential of Blockchain in Healthcare

We found out that there are many areas within healthcare where blockchain can be implemented. Any field that requires data exchange and involves more than two parties can benefit from blockchain. Our research findings point out that EMR and EHR are the two widely researched field withing healthcare where blockchain can be used. Realising the fact that these aforementioned fields requires handing patients data and making sure that they are not tampered and shared securely, they definitely are the prime candidates where blockchain can have an impact.

The drugs patient consume in order to get better from their existing ailment and improve their health should be free from mixture and improper handling. Cases where expired drugs are re-labelled and re-distributed are common in underdeveloped or developing countries. Blockchain technology can help tracking the drug supply chain and making sure that all the drugs that are circulating in the market are not expired.

Smart wearable devices are becoming part of our daily life. The data coming from these devices can help doctors provide better personalised healthcare plans. However, in case of data breach and data corruption and manipulation of an individual data can lead to serious problems. These problems can be mitigated via blockchain as it can provide data consistency and data security.

Moreover, in scenarios such as clinical research and clinical trials where new data are very important, it can be difficult to get these data. Through blockchain data sharing can be done while maintaining anonymity and the person sharing data can be incentivised accordingly.

6 Proposal

The Prescription system is Germany is still paper-based. Every time a patient visits a doctor and requires medicine, a prescription is written in a piece of paper that is to be taken to the drug store. The drug store then provides the medicine based upon the paper. This paper-based prescription is outdated and has multiple flaws. First of all, paper-based prescriptions are not reliable, as they can be easily lost. If the prescription is lost, a patient has to make a new appointment with the doctor which can take days, weeks or months. Also, the paper-based prescription is easy to forge. In case the patient wants to visit different doctor in future, he/she can allow the access of his/her past prescriptions to the doctor so the doctor can have better understanding of the medication being taken or already taken in the past. In this chapter we will present our concept of blokchain based prescription system based on hyperledger fabric.

The reason for choosing Hyperledger Fabric platform to build the blockchain-based prescription system is primarily due the fact that the platform is open source and permission-based. Unlike bitcoin and ethereum, hypeledger platform works on trust. Every party within the system has its identity. This identity can be handled by third parties or can be setup by the involved parties. Every time a transaction is added or requested, a user's identity is verified by the identity provider which prevents false or unauthorized data access. Hyperledger also supports channel based communication, which allows any new party to join an existing channel with various parties and query the information from the blockchain. Furthermore, hypeledger was originally built to exchange data and not for token-based monetary value exchange.

For our concept, we define four entities, namely; patient, doctor, drug store and the insurance company. These entities can interact with the web application which in turn communicates with Hyperledger Fabric SDK or API. The message is stored in the blockchain. We also propose an off-chain database that can store documents related to diagnoses such as images or videos. The conceptual architecture is presented in Figure: 16

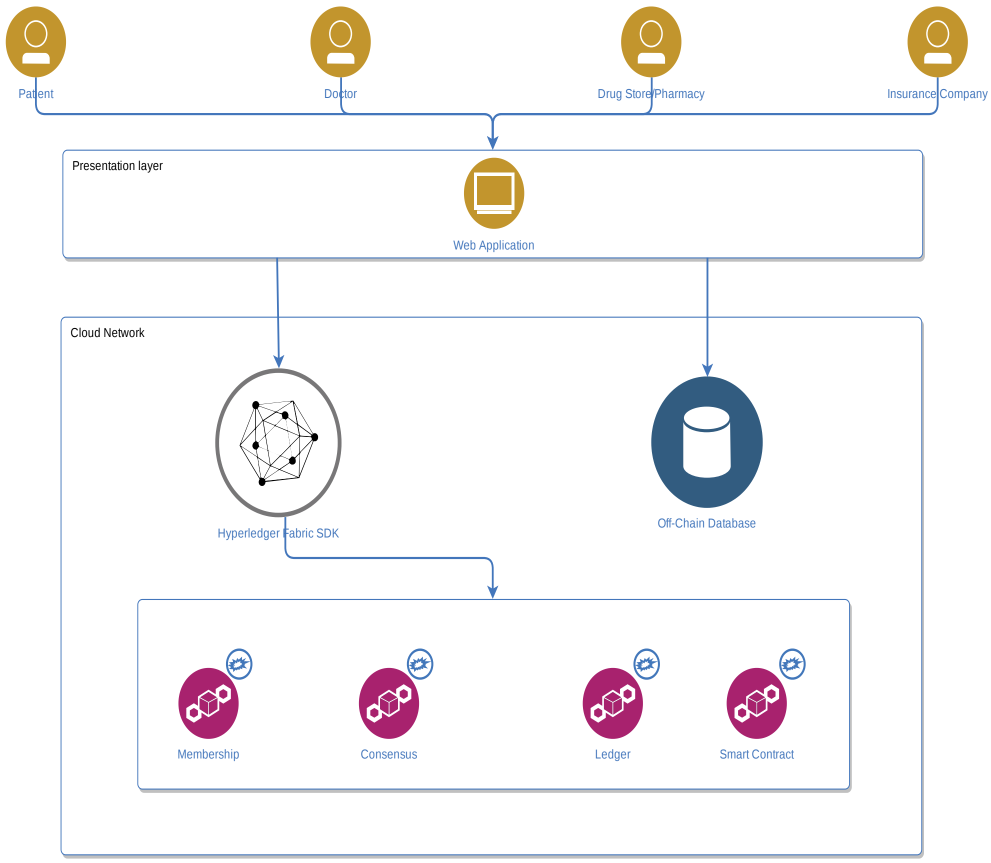


Figure 16: Proposed blockchain architecture using Hyperledger Fabric

The prescription based system could work in following fashion:

1. Patient visits a doctor to get his/her ailment checked. After a thorough investigation, the doctor provides the prescription which then is added to the blockchain via a web application.

2. The doctor can also set an expiry date to the prescription such that the patient does not miss use the prescription in the future.

3. The user then goes to the drug store and requests for medicine prescribed by the doctor and proves his identity. The drug store then checks if the prescription is still valid and provides the drug is the prescription is valid else rejects the request for the drug.

4. If need be, the drug store can share the prescription to the insurance company and claim expenses.

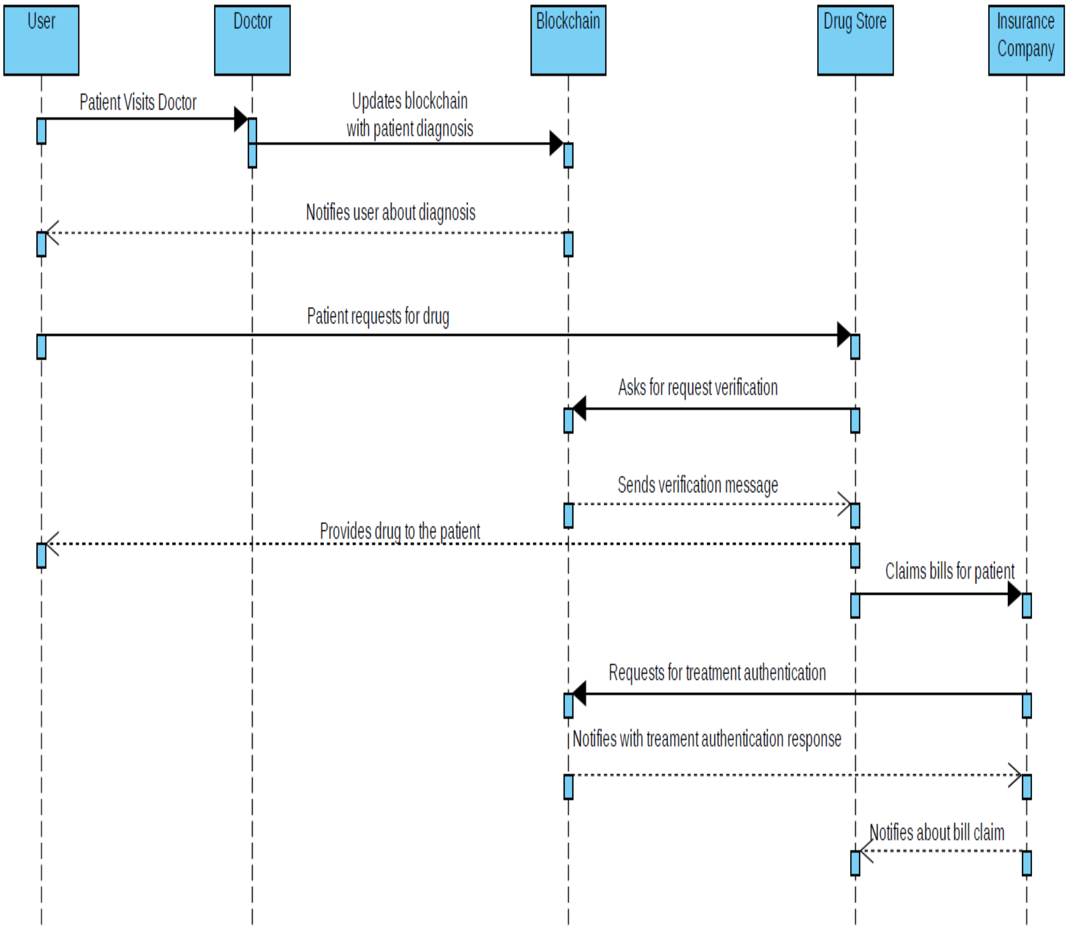


Figure 17: Process flow between patient, doctor, drug store, insurance company using blockchain

To summarize, in this chapter we briefly discussed how the current prescription system works and what are the underlying problems in it. We then conceptualized a prescription system using blockchain technology which can make the entire prescription system secure and smooth.

7 Conclusion and Future Work

During this thesis, we explored the current situation of the healthcare sector and explored how blockchain technology can make the healthcare system more efficient and secure. We realised that any scenario that includes data exchange where multiple stake holders are involved can be a good use use case for blockchain. Sharing health records, medical records and research data among multiple parties is a common thing in healthcare. Hence, we believe healthcare can be a good application area for blockchain.

Firstly, we looked into the blockchain technology from a general perspective to understand how the technology works and looked into the different layers within blockchain. After having the basic understanding of blockchain technology and why it is gaining popularity, we looked into the different sectors where blockchain technology has had an impact or is starting or have an impact. For this, we discussed how different sectors can leverage blockchain and what solution already exists concerning blockchain.

In addition, the healthcare industry was divided into small sub-sectors to study how each individual sector can leverage blockchain technology. For this, we briefly described how each sector can be made more productive through blockchain and provided some existing solutions. One of the most important and major parts of the thesis was to do a literature review where we looked into published scientific journal papers that discuss how blockchain technology can be implemented and incorporated with the healthcare sector.

Using the PRISMA method we discovered 777 literature works of 53 papers were selected. We performed some meta-analysis and put these papers into different clusters. This helped us figure out which section within health care has a higher number of research compared to others and which section lacks research compared to others. Also, we came across different approaches and architectures as a proposal to integrate blockchain within healthcare.

A recommendation was made where a conceptual architecture was provided on how prescription management can be made more efficient in comparison to the current scenario in Germany. This was accompanied with a brief data flow diagram that included all involved parties and how information between different entities can be handled. This proposal also included a preferred choice of implementation framework which highlighted why it was the preferred choice.

It can be argued that blockchain is still in its infancy when it concerns healthcare, which is strengthened by the fact that the first scientific literature in this field was published in 2016. As highlighted during the literature review many authors have come up with their concept and implementation of blockchain for the different sectors within healthcare. Multiple blockchains can introduce the problem of data compatibility during data sharing. For a start, further research can be carried out in the field of blockchain implementation within the entire country. For example, a common blockchain network could be rolled out for all the hospital and healthcare providers which could provide seamless data transfer from one hospital to another.

In addition, during our literature search, we found that scientific research concerning prescription management is rare. Further research could be carried out on finding out how different types of blockchain types (permissioned, permissionless, or hybrid) can be implemented and what are their pros and cons in regards to prescription management.

A Bitcoin block information


```
{
    "result": {
        "hash": "0000000000000000079c58e8b5bce4217f
                 7515a74b170049398ed9b8428beb4a",
        "confirmations": 224726,
        "strippedsize": 479,
        "size": 479,
        "weight": 1916,
        "height": 371623,
        "version": 3,
        "versionHex": "00000003",
        "merkleroot": "01a5f8b432e06c11a32b3f30e6cc9a1
                       2da207b9237fddf77850801275cf4fe01",
        "tx": [
            "ee6bc0e5f95a4ccd0f00784eab850ff8593f9045de
             96c6656df41c8f9f9c0888",
            "29c59ec39fc19afd84d928272b3290bbe54558f7b5
             1f75feb858b005dea49c10"
        ],
        "time": 1440604813,
        "mediantime": 1440602851,
        "nonce": 3431621579,
        "bits": "181443c4",
        "difficulty": 54256630327.88996,
        "chainwork": "00000000000000000000000000000000000000
                      00000998b7adec271cd0ea7258",
        "nTx": 2,
        "previousblockhash": "0000000000000000027d0985fef71cb
                              c05a5ee5cdbdc4c6baf2307e6c5db8591",
        "nextblockhash": "000000000000000013677449d7375ed22f9c
                          66a9494032808141217979 5a1ac5"
    },
    "error": null,
    "id": null
}
```

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