# 13 Blockchain in Health Services to Record Medical Data and Treat Diseases and Pandemics.

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**A possible solution using the Proof of disease algorithm and the Internet of Medical Things**

## 13.1 Abstract

Since 2019 we are facing a global unprecedented medical crisis due to the pandemic of the new coronavirus (COVID-19). This crisis has caused serious effects on societies and economies, as well as on the health systems worldwide, since it has put great pressure on them and has exposed their vulnerabilities.

Recent advances in information and communication technology (ICT) such as Blockchain, Internet of Things (IoT) give us powerful means against the COVID-19 crisis, and any future threat.

This review paper focuses on Blockchain technology and its features (decentralization, controllability, integrity, data confidentiality, variability and traceability) which give us a significant advantage in developing efficient tools that can distinctively aid us in the aforementioned areas. We analyze the benefits as well as the challenges of using Blockchain in the healthcare industry. Furthermore, we examine a complicated general healthcare data process implementation with the use of blockchain and of the consensus protocol "Proof of Disease" (PoD). Also, a general healthcare data process implementation that combines the blockchain and the Internet of Medical Things (IoMT) technologies, in order to address the IoMT issues of security, accessibility and handling large amounts of data, analysing also the distinctive challenges of combining the two technologies.

**Keywords:** Proof of disease, IoT, Blockchain, Health Industry, Proof of disease, Internet of Medical Things

## 13.2 Intoduction

The exponential increase in data processing, transmission, and storage capacity brought about by the digital revolution, and the concomitant reduction in costs per unit, marks the start of the “Age of Data.”

The use of blockchain technology in the health care industry offers considerable technical advantages, such as built-in fault tolerance, disaster recovery, open-source reliability and robustness, compatibility with commodity hardware, interoperability, multi-source data entry support, cost efficient high scalability, standardized cryptography and data encryption algorithms, as well as user-centric accessibility and control policies. Furthermore, it offers distinct health care advantages, such as health data single storage location, real-time data tracking, data security, diversity and comprehensiveness, treatment personalization, and clinical care coordination and emergency medical response improvement.

These benefits of blockchain usage can be furthered enhanced if we combine the blockchain technology with other cutting edge algorithms and systems. More specifically: The Ethereum based future ready Proof of Disease (PoD) is a consensus protocol with a computer understandable single instance of truth. It will solve many challenges that electronic health records (EHR) or health information exchange (HIE) have failed to address. This medical system will help achieve all the complex needs of P6 (Participatory, Personalized, Proactive, Preventive, Predictive and Precision) medicine and finally reduce the disease burden.

The Internet of Medical Things (IoMT) offers an infrastructure of smart medical equipment and software applications for health services, which promotes remote medical diagnosis and timely health services. The patients can use their smart devices to create, store and share their Electronic Health Records (EHR) with a variety of medical personnel including medical doctors and nurses.

## 13.3 Proof of Disease (PoD) Protocol for Healthcare Data Process

Non-communicable diseases (NCD) are caused due to lifestyle, environment, or genomic causes over a long period of time with confusing signs and symptoms. A significant proportion of their diagnosis is erroneous or unnecessary. To reduce the disease burden (which involves unwarranted medical treatments and unnecessary lab tests) and improve public health, algorithmic support is essential. For this, health data must be computer understandable, secured and interoperable. However, medical and data entered into computers are unstructured natural language texts with medical jargons which a computer normally cannot understand. Furthermore, Electronic Medical Records (EMR) are data silos in the hospitals and do not interoperate: They can be interpreted only by medical experts, they are not algorithm ready, do not possess any intelligence and often fail to detect simple data entry errors.

### 13.3.1 Healthcare Data and its Process

Effective treatment of any disease relies on obtaining and accessing health related data of a person on a spatial and temporal basis from the day of birth, illness and disease episodes and their outcome analysis, lab test results that are outside of the normal range, genomic data, environmental, health events, lifestyle related data, and therapeutic data including toxicity or side-effects. The health data must be secured via anonymity, privacy and confidentiality procedures, possess single instance of truth, be available and accessible anywhere anytime by authorized stakeholders, and be machine understandable and exchangeable. For their effective process there should be a protection mechanism towards fraudulent attack or hacking, a recovery facility so that the data it still accessible when the data owner is unable to access it (in case of trauma or loss of security key), and a proper medical care system where this data will be integrated. This system needs to be participatory, personalized, proactive, preventive, predictive and precise (P6 Medicine(P6M)). P6M will reduce disease burden and promote the cause of evidence-based medicine (EBM) and precision medicine. It will need algorithmic support of interoperable temporal and spatial data of health and disease, both of an individual (n=1) to be available for examination, as well as of the population (n=N) as evidence.

In order to achieve the aforementioned effective process of the proper health care data, a solution is proposed that includes the following steps: The health care data gathered are examined in order to reach a consensus, so that the current state of a person's health is ascertain. This consensus is based on a consensus protocol called Proof of Disease (PoD). Then, by using PoD, Artificial Intelligence and Big Data Analytics, a blockchain based medical care system (according to P6M) is created for the effective process of the health care data. [1]

### 13.3.2 The proposed medical care system and the PoD consensus protocol

The medical records are classified in three distinct generations: The first Generation (1G) had handwritten “human readable and human understandable” medical notes, the second Generation (2G) has “computer readable and human understandable” notes and the third Generation (3G) health care systems will have “computer readable and computer understandable” algorithm ready medical notes.

This medical care system is an Ethereum based blockchain technology deployed in the cloud which allows data from multiple 2G sources like EMR, diagnostic centers, clinicians, genomics, Internet of Things (IoT), etc. It interoperates with various healthcare stakeholders such as patients, doctors, hospitals, laboratories, advocacy groups, pharmacists, and insurers to access and interact with medical information with necessary security, privacy, and anonymity in a peer-to-peer (P2P) approach. Finally, it allows accurate, immutable, auditable, transparent, secure, and machine understandable (controlled vocabulary/ontology based) interactions.

PoD is designed for medical care blockchain. It can address all the above needs, because it provides a computer understandable single instance of truth, and it combines evidence-based medicine and AI/KM (Artificial Intelligence/Knowledge Management). The philosophy behind PoD is to provide assurance of high quality medical care quickly and cheaply, by ensuring that the disease and health information entered into the ledger is accurate (certified and validated by qualified medical miners).

The implementation details of PoD are as follows:

a. Computers and smartphones are used as user devices. The server is a cloud based application where client and server communicate through JSON (JavaScript Object Notation) objects.

b. Following standard authentication, the patient, the doctor, or even a IoT device, enters pathophysiological details of the disease in simple English. The server then runs any spell checker and morphological analyser designed for languages with rich morphology and complex word compounding, on the entered text, using customized medical dictionary corpus.

c. Using UMLS (Unified Medical Language System) and Metathesaurus the entered text is parsed and converted into multiple UMLS CUI (Concept Unique Identifier).

d. The disease's name and symptoms are extracted through masks like "Find", "Disease", etc.

e. The UMLS CUI is converted into International Classification of Diseases (ICD10) and SNOMED Clinical Terms (CT) codes. The ICD is a health care classification system, providing a system of diagnostic codes for classifying diseases. [7]

   The SNOMED CT is a systematically organized computer processable collection of medical terms providing codes, synonyms and definitions used in clinical documentation and reporting. SNOMED CT provides the core general terminology for electronic health records. [8]

f. The vital information and the disease history are taken from the EMR. In case EMR data is not available, vital information is entered by the user online.

g. The SNOMED CT codes, obtained from Step e, are used to determine the disease network and the disease trajectory of an episode.

h. The overlapping (union) SNOMED CT subgraphs from different disease episodes of the past are the domain of morbidity and disease penetration.

i. SNOMED CT is integrated with phonemics databases to discover the core disease concepts in machine understandable ontologies using graph analysis.

j. In the final stage, the results from above phases are passed to a team of specialists. Medical specialists function as a medical miner (MM) in the blockchain system.

   Medical miners validate and confirm the results from the above steps (i.e. the integrity of the illness or health data), by comparing with population data, public health data and evidence based medicine knowledge body. They also identify the likely trajectories of the disease with evidence. Then, they commit the results into the health blockchain system, ensuring a single instance of truth about the health state at a certain instance of time.

k. In case the proof of disease cannot be ascertained, big-data biological databases (e.g. Human Phenotype Ontology (HPO), are added and iterated over. [10]

### 13.3.3 Types of mining activities in the health chain system

In the health chain system, there are three types of mining activities: Two types of medical mining, and one type of financial (coin) mining. [2]

The medical mining consists of the medical transaction or episode mining (MEM), where the consensus is about a disease episode, and the health state mining (HSM), where the consensus is about the overall health. The HSM involves medical experts, statisticians and evidences from literature and biological databases. It deals with illness, chronic, or acute medical conditions, and it includes examination, recommendations, and referrals if necessary. From this evidence, the experts identify and analyze the total path of care in terms of cost, quality, risks and best possible actions (with the goal to reduce the disease burden), and on the other hand they modify the care continuum in order to reduce unwarranted diagnostic tests, treatments, hospital admissions and readmissions, to decrease length of hospital stays, and to improve cost-effective prescribing. On top of that, the medical miners check and assure that the medical transactions and health status entered into the blockchain ledger are correct and satisfactory. They are paid by the users having the token purchased from the medical blockchain system.

Since the medical miners are paid for their services, there is an additional mining activity in the blockchain network for the payment procedure: The financial mining. Here, for the consensus (payment for the PoD service), Ethereum's native coin consensus is used. The coin miners check the financial transactions to avoid Sybil and double spending attacks, and they follow the process of Ethereum platform for transaction fee and rewards. In health chain system the coin mining and medical mining are done by the same organization.

## 13.4 Blockchain and the Internet of Medical Things (IoMT)

### 13.4.1 Problems

One problem that needs to be solved in regards of IoMT is that unless the underlying communication within IoMT is secured, malicious users can intercept, modify and even delete the sensitive EHR data of patients. Also, IoMT devices require gigantic storage infrastructure for real-time processing because of the enormous amount of medical records. Currently, most IoMT institutions store the collected medical data and deploy their application servers in the cloud. However, implementing IoMT using the cloud is not always convenient, because on one hand cloud servers are not fully trusted, as data could be removed or altered, and on the other hand patients lose full control of their EHR since most health services within IoMT are constructed under a centralized platform outsourced in the cloud. [3]

### 13.4.2 Proposed Solutions

There has been recent interest in providing a secure IoMT generated healthcare data supervision by utilizing blockchain, since a blockchain based data structure can be explained as a virtually incorruptible cryptographically connected blocks where critical patient related data can be stored. In other words, a temper-prove distributed ledger (Blockchain) can offer a way to secure the IoMT, by recording the transactions of digital communication. Also, a decentralized blockchain based methodology would overcome many of the problems associated with the centralized cloud approach. [3]

The whole system operates as follows:

a. The IoMT & Blockchain based system is created by connecting computers and all the participants with each other.

b. The doctor is present even in a remote location, observing the patient activities and advising the patient through the IoMT & Blockchain based system.

c. The medical precisionist from the diagnostic center uploads the EHRs, which are eventually added to the patient's history.

d. The doctor analyzes the real time statistical reports, which are generated in the diagnostic center and shared on the distributed ledger.

e. Patients are also monitored through wearable tracking devices, which sense the changes in the patients' bodies and send this real time data to the doctor and the care takers via the IoMT.

f. The doctor then advises the patient according to the condition.

g. The EHRs and the treatment documents of the patient are shared on the distributed ledger and viewed by every node of the patient's network. Diagnostic labs also generate and add EHRs to the blockchain, since they are part of the IoMT network. Whenever a new patient record is created, a new block of data is initiated in the patient's blockchain network.

### 13.4.3 Internet of Medical Things (IoMT) and Blockchain Combination Challenges

*13.4.3.1 Conflict Challenges*

Certainly, blockchain technology is beneficial to the IoMT in terms of security. However, integrating both technologies is not trivial at all and is facing several challenges due to the conflicting requirements in these two technologies: As far as processing is concerned, mining process and complex cryptography in blockchain are resource-hungry, demanding intensive computation and high energy consumption which cannot be afforded by resource-constrained IoMT devices that already suffer from resource shortage and energy limitations. Also, there is the issue of mobility: Blockchain was designed for a fixed network topology. However, implantable/wearable medical devices are in constant movement which continuously change the topology. Furthermore, IoMT applications are generally critical and require a real time and immediate response. Grouping these streams of data on blocks while respecting real time requirement is challenging. Finally, in regards of traffic overhead, blockchain nodes communicate continuously to synchronize, which creates significant overhead traffic. This is not affordable by bandwidth-limited IoT devices. [4]

*13.4.3.2 Technical Challenges*

The integration of blockchain and IoMT opens the way to many relevant applications in the health field. However, the adoption of this integrated technology is complex and requires in-depth interdisciplinary combination of low-level technical knowledge (e.g. management of

IoMT devices and configuration of blockchain to meet IoMT requirements), with high-level technical knowledge, including sharing, storing and treating IoMT data. In this context, it is crucial to conceive an abstraction layer that will hide all these complexities, as well as provide developers with new application programming interfaces (APIs) and middleware to allow them to easily implement decentralized and secure applications for healthcare using IoMT. Most of existing solutions do not yet reveal any technical details that could address the above challenges. There is a need that researchers demystify all the technical details of the blockchain integration into IoMT. [4]

*13.4.3.3 Maturity Challenges*

The literature review shows that there are some significant research gaps. There are several problems that must be addressed in order for the collaboration of blockchain technology and IoMT to reach maturity and be efficient. Lack of standards is one of the problems, because the proposed solutions are proprietary and do not define standard protocols which would promote interoperability: It is crucial to provide universal and platform-agnostic solutions that govern the interaction between IoMT devices, blockchain, cloud computing and end-users. Another problem is limited application scope, since the majority of existing works are only focusing on healthcare applications related to remote patient monitoring and IoMT data management, including data sharing and storage. However, it is also crucial to conceive tracking applications that prevent counterfeit drugs and medical errors. In this context, the use of blockchain technology accompanied by the IoMT can be an effective solution to control the activity of doctors and manage the drug supply chain. [4]

## 13.5 Benefits of Using Blockchain in the Health Industry

### 13.5.1 Technical Benefits

The use of blockchain technology in the health care industry offers considerable technical advantages:

a. The blockchain architecture has built-in fault tolerance and disaster recovery, and the data encryption and cryptography technologies are widely used and accepted as industry standards.

b. The blockchain would be developed as open-source software. It is reliable and robust under fast changing conditions that cannot be matched by closed, proprietary software.

c. The blockchain would run on widely used and reliable commodity hardware. Commodity hardware provides the greatest amount of useful computation at low cost. The hardware is based on open standards and manufactured by multiple vendors.

d. The blockchain addresses the interoperability challenges within the health IT ecosystem: Health IT systems would use Open APIs to integrate and exchange data with the health blockchain. Open APIs are based on industry best practices, are user friendly and would eliminate the need for development of complex point-to-point data integrations between the different systems.

e. Blockchain data structures can support a wide variety of health data sources including data from patients' mobiles, wearable sensors, EMR’s, documents and images. The data structures are flexible, extendable and able to accommodate whatever data will be available in the future.

f. Data from cheap mobile devices and wearable sensors is growing at an exponential rate. Distributed architectures based on commodity hardware provide cost efficient high scalability. As more health data is added to the blockchain, cost efficient commodity hardware can be easily added to handle the increased load.

g. Blockchain works with standard algorithms and protocols for cryptography and data encryption. These technologies have been heavily analyzed and accepted as secure and are widely used across all industries and many government agencies.

h. In a health care data processing system based on blockchain technology, the user would have full access to his data and control over how his data would be shared, would assign a set of access permissions and designate who can query and write data to his blockchain, and would be allowed, by a mobile dashboard application, to see who has permission to access his blockchain. Also, the user would be able to view a log of who accessed his blockchain (including when and what data was accessed), give and revoke access permissions to any individual who has a unique identifier, and finally setup specific control policies about who has access, about the allotted time frame for access and the particular types of data that can be accessed. These control policies would also be securely stored on a blockchain and only the user would be allowed to change them. [5]

### 13.5.2 Health Care benefits

The use of blockchain technology in the health care industry offers also distinct health care advantages: [5]

a. Creation of a single storage location for all health data, tracking personalized data in real-time and the security to set data access permissions at a granular level would serve research as well as personalized medicine.

b. Health researchers require broad and comprehensive data sets in order to advance the understanding of disease, accelerate biomedical discovery, fast track the development of drugs, and design customized individual treatment plans based on patient genetics, lifecycle and environment. The shared data environment provided by blockchain would deliver a broad diverse data set by including patients from different ethnic and socio-economic backgrounds and from various geographical environments. On top of that, as blockchain collects health data across a patient's lifetime, it offers data which is ideal for longitudinal studies.

c. A health care blockchain would expand the acquisition of health data to include data from populations who are currently under-served by the medical community or do not typically participate in research. The shared data environment provided by blockchain makes it easier to engage these populations and develop results more representative of the general public.

d. Blockchain data structures would work well for gathering data from wearable sensors and mobile applications and, thus, would contribute significant information on the risks versus benefits of treatments as well as patient reported outcomes.

e. Combining health data from mobile applications and wearable sensors with data from EMRs and genomics will increase the medical researchers' ability to classify individuals into subpopulations that respond well to a specific treatment or who are more susceptible to a particular disease.

f. Daily, personalized health data will likely engage patients more in their own health care.

g. The ability for physicians to obtain more frequent data (i.e., daily blood pressures or blood sugar levels versus only when a patient appears for an appointment) would improve individualized care with specialized treatment plans based on outcomes/treatment efficacy.

h. Blockchain would ensure continuous availability and access to real-time data. Real-time access to data would improve clinical care coordination and improve clinical care in emergency medical situations. Real-time data would also allow researchers and public health resources to rapidly detect, isolate and drive change for environmental conditions that impact public health. Epidemics could also be detected earlier and contained.

### 13.5.3 Challenges and opportunities for blockchain technology in healthcare

Despite blockchain's potential as an emerging technology to be innovative and disruptive, it remains immature, particularly in healthcare. Reflecting the fact that it is still early days for health blockchains, there are few real-world examples of blockchain systems that have gone into production and that also have strong commercial or user adoption in healthcare.

Although the core characteristics of decentralization, security, provenance, transparency, trust, and better management of data consist clear benefits to address acute healthcare needs, we need to ask what core blockchain characteristics and design principles need to be taken into account, and how can they address the diverse healthcare challenges and the real-world legal, regulatory, privacy, business, provider-centric and patient-centric considerations that are unique to healthcare. In an attempt to address these challenges, a ‘fit-for-purpose’ health blockchain design framework is proposed, which includes fundamental questions regarding basic blockchain design principles, data sharing and management, governance decisions, technological choices which enhance blockchain function, and last but not least, regarding the ultimate goal for the blockchain solution. If these questions are appropriately mapped, there is a higher likelihood that the blockchain approach will be ‘fit-for-purpose’ for whatever healthcare challenge has been identified. The framework questions are based on six principles: [6]

1. Design decisions, meaning whether the blockchain will be public (generally open to participation by anyone and not permissioned), private (involving limited participation and having permission structures), or hybrid (blockchain system with both public and private designs).
2. Data sharing and access requirements, since in healthcare, is subject to various privacy, legal, and regulatory requirements, such as the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR).
3. Governance, i.e. the need to define the nodes, users, peers and validators of the blockchain, define whether the blockchain will be comprised of only trusted partners or of a consortium of participants, define if and what type of data will be shared among these participants, whether data will be stored on-chain, off-chain, or on a side-chain, the type of permission structures that will be utilized, whether the blockchain will include public entities, regulators, patients and consumers, and how these actors will make decisions about how to govern the blockchain (including choices regarding consensus mechanisms, permissions, and data governance).
4. Enhancement decisions, meaning the addition or not of technologies that improve the blockchain function, including the development of an application layer that interfaces with the blockchain, the use of smart contracts to automate processes when certain agreed upon conditions are met, and the use of a cryptocurrency & tokens to incentivize participation that ideally provides shared benefits to all participants.
5. Ultimate healthcare goal of the blockchain: Although it may seem obvious, a critical issue that must be addressed is the definition of the ultimate goal of the blockchain to improve healthcare. Beyond the core benefits of a distributed, immutable, transparent and higher trust system, the unique benefits blockchain can provide for healthcare processes over other existing technologies must also be assessed: Not all blockchains will have the same goal(s). Some may be designed to simply lower healthcare transaction-related costs by improving and automating processes (such as the use of smart contracts), removing intermediaries, or reducing administrative burden. Others may emphasize on the creation of mechanisms to drive revenue generation, or the improvement of data processing (collection, use and sharing) from patients, consumers, and providers through the offer of incentives (such as tokens).

Furthermore, some may focus on more indirect benefits (such as increasing compliance or preventing fraud), while others may be designed to achieve multiple goals, yet may start with the most pragmatic use first.

6. A final question may simply ask whether the healthcare-related challenge or goal really needs a blockchain.

## 13.6 Conclusions

The main challenge of the healthcare industry worldwide is that it consists of complex interconnected entities, each of which, as a rule, has separate, siloed information systems. As a result, the administrative costs of these systems contribute distinctively in the overall, constantly increasing, healthcare delivery cost. Blockchain is the technology which, thanks to its unique features that we reviewed in this paper, can address many of the challenges that the healthcare industry faces. Nevertheless, the potential of blockchain for healthcare highly depends on its acceptance by the healthcare ecosystem, so that the proper technical infrastructure can be created. Though there are specific concerns and speculations regarding blockchain's integration with current healthcare systems and its cultural adoption, the technology is beginning to prove popular in the sector. [9]

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