Connected Health Systems Supported by Blockchain: An overview

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Abstract - This paper analyzes the application of blockchain based approach for exchange of healthcare data within ambient assisted living systems, transforming them into connected health systems. When it comes to the consequences of abuse to the complex health-related data, their portability and discretion ask novel approaches in management of healthcare data. This paper analyzes the possibility and the potential of the blockchain technology in the systems dealing with healthcare data exchange. The purpose of this research is to justify the reasoning why to use distributed consensus introduced by blockchain technology in the domain of the connected health systems.

I. INTRODUCTION

Rapid development of the data and communication technologies, together with recent COVID 19 pandemics, pose new opportunities and challenges in the healthcare sector. The advances in mobile technologies and wireless sensor networks can revolutionize the way health related data is gathered, disseminated, and used by healthcare policy makers, providers, patients and citizens in general. The ubiquities of these technologies can transform the healthcare services from the services that are tightly coupled to the health ordinations and hospitals into pervasive connected health services. Activities and services that require physical presence of the patients can then be performed at any-time and any-where. This can provide additional flexibility in patients' life. It can also help the healthcare policy makers and providers to focus on preventing diseases and promoting health.

The main goal of this paper is to present connected health data exchange cycle based on blockchain technology. The rest of this paper is organized as follows. Section II explains the background and related work in Connected health area while Section III introduces connected health data exchange cycle. Section IV elaborates on blockchain data exchange principles deployed in connected health. Section V summarizes the technical challenges related to authentication, trust and access control, while section VI concludes the paper.

II. BACKGROUND AND RELATED WORK

The development of health information technologies in the last decade creates a broad range of new opportunities to improve the access to health services for citizens and especially healthcare delivery [1], [2]. The other trend to consider is increase of healthcare costs [3]. Healthcare stakeholders should control costs while maintaining the quality of health care services on the same or higher level.

Implementation of electronic health records (EHR), electronic medical records (EMR) and personal health records (PHR), is viewed as a step towards achieving improvements in the health care system in many European countries [4]. EHR is defined as: 'a repository of information regarding the health status of a subject of care in computer process able form, stored and transmitted securely, and accessible by multiple authorized users' [5], [6]. EHR can be understood as a repository of patient data in digital form, which stored and exchanged securely. PHR is a health record where the patient himself maintains health data and information related to the care of a patient. PHR provides a summary of an individual's medical history which is accessible online, under strictly defined access permissions.

Ambient and Assisted Living (AAL) covers range of activities starting with creating care models and algorithms, continuing with different ICT solutions connected with AAL (robotic assistance for the elderly, measurement and sensing technologies, and devices connected to internet of things within the smart housing) [7]. The typical AAL services include but are not limited to monitoring of elderly people vital signs, home rehabilitation, robotic assistance for the elderly, as well as, people with chronic conditions, peoples with different impairments, or wider population [8]. If we take into consideration the environmental factors that influence on wide population as health disturbance factors, measured by many instruments and IoT sensors connected with data collection, we have a huge pool of big data that have to be considered as the health factors [9].

AAL systems need to ensure high-quality-of-service. Essential requirements of AAL systems are usability, reliability, data accuracy, cost, security, and privacy [10].

According to [11], in order to achieve these requirements, it is essential to involve citizens, caregivers, industry, researchers, and governmental organizations in the development cycle of AAL systems, so that end-users can benefit more from the collaborative efforts. The use of ambient intelligence can provide environment adoptable to the user and influence the ability for AAL systems to express the power of a human being. In this context, the usage of advanced information and communication technologies (e.g. social networks) could help connect people and organize community activities within AAL.

Connected Health (CH) describes the new paradigm of a technology-enabled model of health and lifestyle management. It is extension of AAL set up to provide, besides conventional healthcare, preventive or remote treatments, resorting to an electronic information structure based on internet, sensing, communications and intelligent techniques in support of health-related applications, systems and engineering. It refers to a conceptual model for health management, wherein devices, services or interventions are designed around patients' needs, being health related data shared in such a way that patients, caregivers, policy makers, education and research, companies, third sector organizations and funders in the health and welfare sectors, are seamlessly connected in order to provide healthcare in the most proactive and efficient manner possible [12].

CH services increase the quantity and complexity of healthcare information. Therefore, developing information systems that are capable not only to store and retrieve health data, but offer continuous monitoring of health data that is very important for both healthcare stakeholders. For these reasons, extracting data according to healthcare established standards is important [13].

CH systems also should support the process of decision making and diagnosing, searching through large amounts of health data and facts, classifying them and identifying issues that directly relate to a given medical condition. In this way they could offer citizens to be directly involved in their health care, providing information that will assist in making decisions about their own health. Patients will have a greater role in the decision-making processes related to their health as they could be empowered with the ability to gain access and manage information that fits with their personalized needs. Ultimately, they will be able to shape their health as a reflection of the health model of the whole community [14].

III. CONNECTED HEALTH DATA EXCHANGE CYCLE

One of the advantages of CH systems should be integrating data from AAL systems and smart homes with data from EHR, EMR or PHR. Presenting these health-related big data can lead to more efficient and informed decisions by physicians, nurses, patients, and informal caregivers [15]. Aggregating data from different sources, including medical devices and integrating them with data from health records enables a more comprehensive view of health data, but creates various data integration challenges [16]. A convenient way to integrate data from EHRs, PHRs, AAL, home care, and self-care systems is to integrate them in a highly connected, robust, and reliable edge-based platform, offering uninterrupted availability and taking care of data throughput, network efficiency and data privacy [17].

A general architecture of CH systems uses mobile devices for collecting data from environmental and body network sensors, but also for easy access to specific personal data. Raw data is preprocessed, filtered by noise, and then integrate them with different EMR. These data can be then processed using healthcare algorithms that transform them into relevant information which is distributed and used by different services. This model includes the processing of data aggregated from social networks needed to give different recommendations to the users and medical centers along with data collected by different sensors [18].

The exchange of the original data and the CH services results between the CH stakeholders is one of main task in CH. This process focuses on connecting patients, healthcare providers, policy makers and other relevant stakeholders, with an aim to guarantee the smooth data flow between them. The purpose of CH is timely sharing, patients' condition monitoring and accurate information presenting through smart combining uses of health data, devices and communication software/hardware platforms. In this way, CH aims to bring patients, clinicians and health science researchers all together to help the society to answer one question: how to connect patients, therapists and caregivers to deliver the optimum health results in an era of stretched resources and increasing demands [19].

Figure 1 shows typical date exchange in CH. The end users normally include patients/outpatients and the elderly. The sensing devices are used for collecting health related data and providing real time monitoring results. The healthcare providers can use the sensed data from the end users for predictive analysis [20]. During this process, the data converges from the end users to the healthcare institutions. Based on the provided data, CH propose suggestions and summative conclusions to the healthcare professionals, and in return, they can give more accurate and personalized treatments for the end users based on the feedbacks and analysis results from the CH systems. Through this way, the predictive analysis results obtained using machine learning (ML) or Artificial Intelligence (AI) in general, are distributed to the end users, who benefit from contributing their own personal data.

CH system stakeholders can be of different size and form, including but not limited to clinical centers, hospitals, laboratories, insurance companies, pharmacies, emergency centers, nursing homes, and public health centers. The data that is subject to transfer is typically structured in different formats and described with different terminologies, making the interfaces and integration process more complex and with high cost. Additionally, the data that is subject to a transfer is scattered across the storages of the organizations that are involved in the process, which often leads to inconsistent data handling processes and erroneous and incomplete data records.

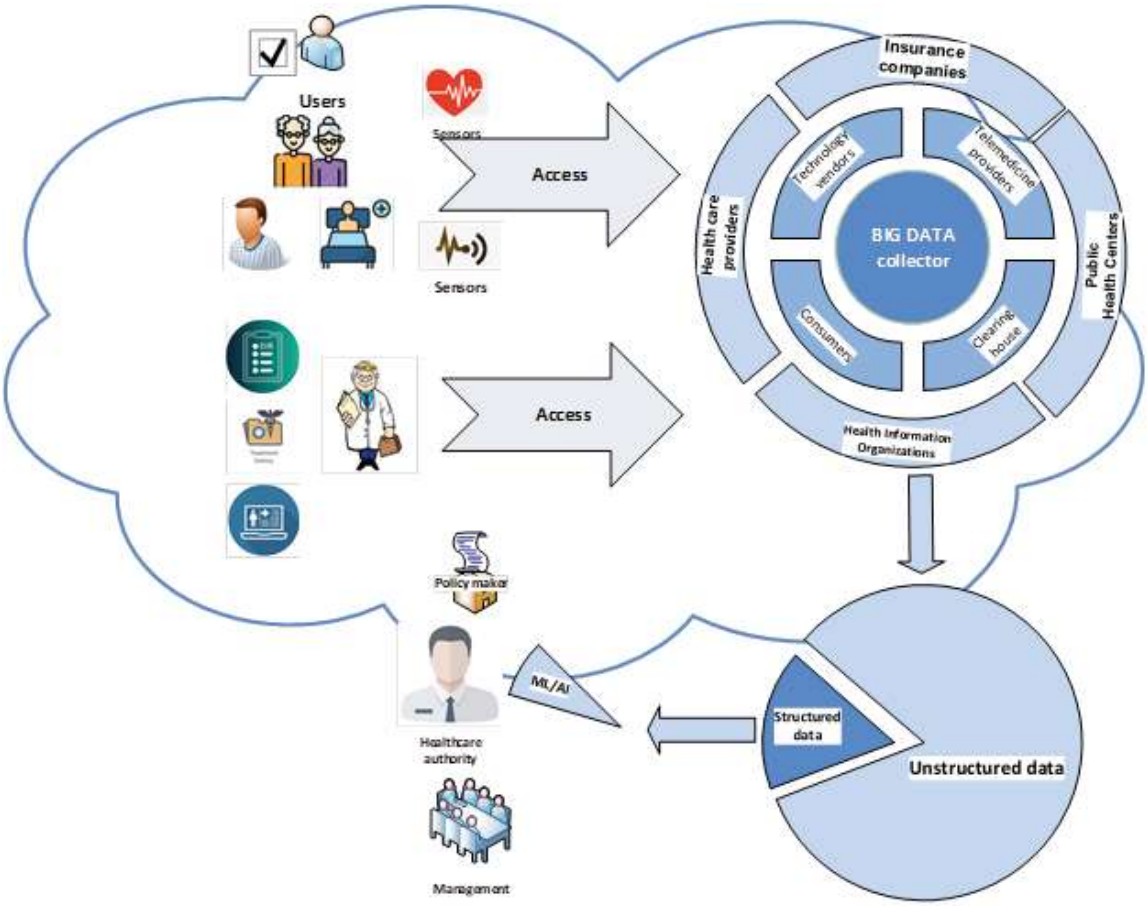

Figure 1. Connected health information exchange

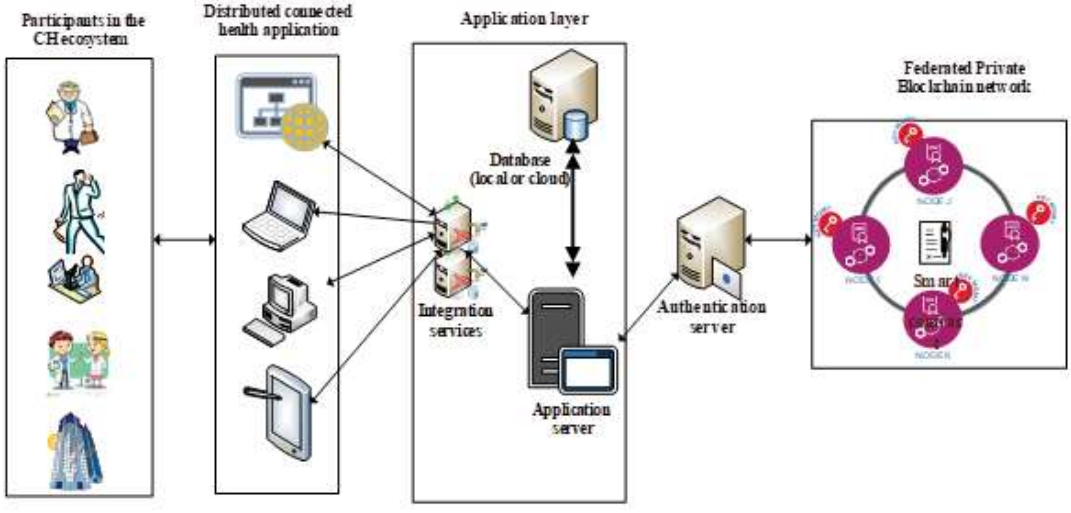

Figure 2. Logical architecture of the blockchain model for CH

The data gathered from EHRs is holding a huge amount of useful information that can be transformed into lifesaving actions. In addition, with different analytical approaches of the data, the costs of the diagnostics and treatments can be greatly reduced with more focused and predicable management [21].

As the research in CH matures, data generated from medical devices will benefit from the analysis by well-established machine learning techniques. There is also potential that new research in machine learning and artificial intelligence can be used on data generated from the sensors used in CH [22].

CH cannot only provide services in evidence-based medicine but can also educate patients to gain health knowledge to achieve better self-management and self-care. As recently data analysis has been becoming more and more popular, this technology has been applied widely to assist health problem discovering and clinical decision making [23].

IV. BLOCKCHAIN BASED DATA EXCHANGE PRINCIPLES

The blockchain infrastructure can be used to create a powerful catalog of health-related records that references different data sources and connect the patients, healthcare providers, laboratories, researchers, health insurance organizations and many other participants in the CH system. Blockchain can help to simplify the way how the parties involved in the CH system exchange the data and collaborate between themselves.

Blockchain in its essence is a distributed system that stores records for specific transactions. It is a distributed ledger of peer-to-peer transactions, which are grouped in blocks that are connected between them. Each block contains a hash, or numeric digest of its content, that verifies the integrity of the containing transactions. The hash of the next block in the blockchain network is dependent on the hash of the current block; the hash of the current block is dependent on the hash of the previous block. This effectively makes the entire blockchain history immutable, as changing the hash of any block would also change the hash of future blocks. The functioning blockchain does not depend on a central, trusted authority, rather than, the responsibility of functioning is distributed to all nodes which participate in the network. Because is missing central authority that will verify the validity of the blockchain, a mechanism for reaching network consensus must be employed. The smart contract plays a vital role in performing the agreement among various stakeholders involved in the CH system. A smart contract is an integral and inseparable part of the blockchain-based applications. A smart contract represents a computer protocol that follows specific rules, codes and constraints agreed by all participants. It is an agreement made among various involved stakeholders in the defined CH system. The CH data can be encrypted and shared with the whole ledger available within the respective network.

These core principles enable decentralized interactions (processes of storing, exchanging and accessing data) between each participant in the network, bypassing the need for intermediaries and regulatory bodies to ensure trust [24].

Blockchain technology provides a transparent, decentralized, authenticated platform that applies a consensus-driven approach to facilitate the interactions of multiple entities in the network through the use of a shared ledger. Because is missing central authority that will verify the validity of the blockchain, a mechanism for reaching network consensus must be employed. By using the permission mechanism for tracking which organization is able to see which medical records in the ledger, we can utilize the blockchain infrastructure to create an immutable chain of content, supported by decentralized network. The blockchain "smart contract" can execute exchange logic on the distributed layer and connects patients with healthcare providers and guarantee the privacy and visibility of data only upon approval (or notification) [25].

I this way blockchain technology can offer a solution that not only helps to securely store and sharing of medical and healthcare data but also to assure the confidentiality of each patient's data by giving the patients, as well as their medical and health data ownership [26]. Many current development projects in healthcare have blockchain technology in the center of their development [27].

V. BLOCKCHAIN MODEL

To implement the blockchain technology in CH, decentralized identity management built on top of a multi-block consortium private network can be used. Identity management system is using the decentralized smart-contract standard that defines the method for ownership and transferability of the referrals.

The Figure 2 represents a logical architecture of the blockchain model for CH [28,29]. Application layer, a Database, and an authentication and authorization server are the main components of the model. Authentication and authorization of the users, system make by validating transactions in the blockchain network. The users (the patient, doctor, physician, pharmacists, researchers, employees in clinical centers, hospitals, laboratories, insurance companies, emergency centers, nursing homes, public health centers) communicate with the system through the CH applications. This CH application can be web, mobile, or a standalone application that interacts with the application server via integration services to perform the desired functions. For delivering a requested medical and health data, the application server needs to communicate with the database and the authentication server. To accomplish these activities, users must be authenticated and authorized.

Authentication server receives work from the application server, to check the authenticity of the user and to authorize access to the database. After receiving a permission validation from the authentication server, user's access to the database from the application server is allowed. Authentication server authenticates and authorizes the user and able to interact with the blockchain network. It has an intermediary role between the blockchain network and the application server and vice

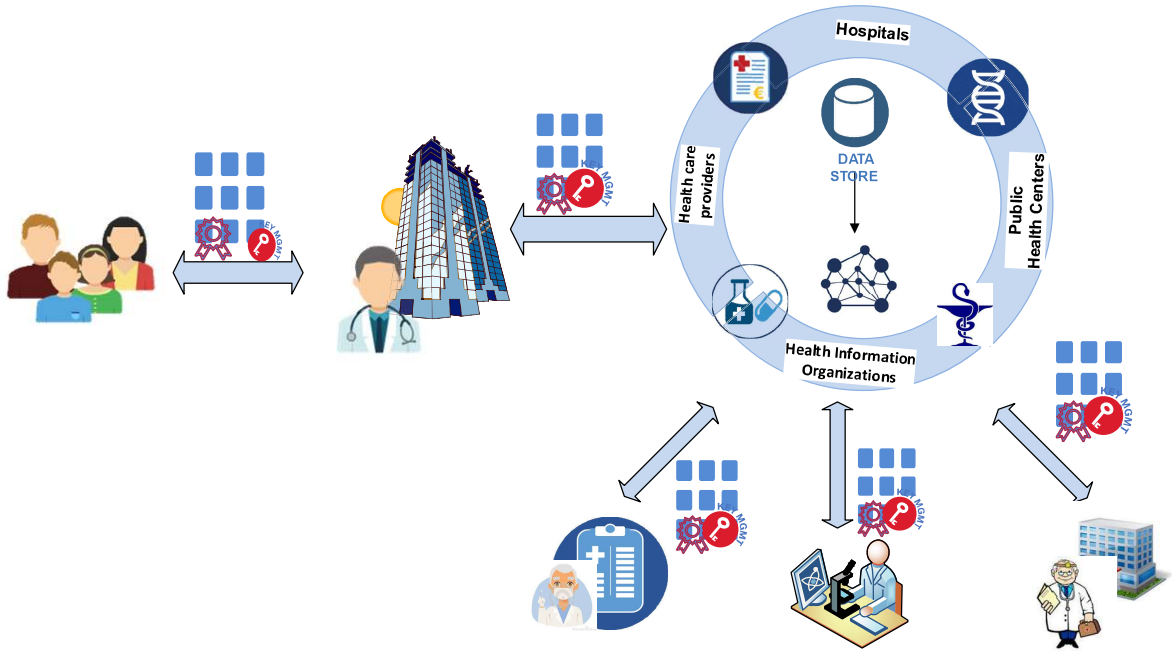

Figure 3. Creating shared data in blockchain based CH marketplace

versa. The data operations and various data access requests for immutability and integrity protection are recorded by the blockchain network. The nodes in the blockchain network follow the rules in the smart contract, validate and broadcast transactions. It keeps the network in running state, maintain the ledger and run the consensus protocol.

The user first must registers in the trusted services offices by providing personal details (such as ID, Biometrics, and PIN), together with the user's public key. Since the registration process is a one-time process, users provide their details using their mobile devices or web application.

Patients produce data by executing a smart contract in private blockchain network that tokenizes a trusted data and decide who to share it with. During this process are used metadata such as user's ID, quantity, healthcare institution, ID of the users of that data (see Figure 3). Patients digitally sign consent forms deciding who has access to their medical data. Healthcare providers and patients produce data from various sources: imagery, biological exams, connected medical devices, genetic tests, surveys and questionnaires.

CH system stakeholders (healthcare organizations, clinical centers, hospitals, laboratories, insurance companies, pharmacies, emergency centers, nursing homes, public health centers) store data “off-chain” and list it on the blockchain along with permissions given by the patient. Healthcare organizations receive a token representing a valid data issued by the patient and after that store in private blockchain network.

A Big data marketplace is built between CH system stakeholders and healthcare providers. Each stakeholder (healthcare authorities, policy makers, scientist doctor, and physician) queries the database to gain access to the information they need. Upon receiving the request query by the blockchain network from the user side, it will check the validity of the user's rights and whether the patient has granted the access permission to that particular user. If the check is successful, it performs the query operation.

VI. CONCLUSION

The existence of diverse health devices and apps with a combinations of the Internet of Things have contributed to transfer of a large amount of medical data daily. Access and sharing health care data before, create basis for novel healthcare services that utilize those large amounts of data. This extensive connected but distributes database of citizens' health information creates significant privacy, security, and availability issues.

Blockchain technology in healthcare information systems has brought immense opportunities in terms of not only providing secure and efficient data storage but also sharing and control access to the data. System model for identity and access management using blockchain technology is proposed in this paper. With the progress in electronic health and interoperability, healthcare data store in the cloud and patient data privacy protection regulations, new opportunities are appearing for health

data management, as well as patients' opportunity to access and share their health data. This is possibility that enable each of the healthcare players to protect their data in the CH systems.

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