Blockchain-Based Secure Digital Twin Framework for Smart Healthy City

Abir EL Azzaoui, Tae Woo Kim, Vincenzo Loia, and Jong Hyuk Park

Abstract Nowadays, Digital Twins (DTs) are being integrated into various sectors thanks to the continuous progress of computing power and data science. We are surrounded by a tremendous number of sensors and connected objects that produce data regularly. These data represent the fuel for a DT as they are used to represent the most accurate digital model of a system or an object and to predict and simulate all the possible scenarios. Recently, DT has been adapted into the healthcare sector as well for an accurate medical and surgery simulation and medical resources' orchestration. However, DT technology is still a novice to the healthcare system and security threats urge immediate consideration. To this end, we propose in this paper a Blockchain-based secure Digital Twin framework for a smart healthy city. We discuss as a case study the current COVID-19 pandemic and argue on the help of DT to control the situation, prevent future cases, and personalize the treatment.

Keywords Digital twin · Smart healthcare · Blockchain · Security · And privacy

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1 Introduction

Physical models have been continuously developed in recent years. However, thanks to the advancements in computer science and the unceasing evolution in the Industrial Internet of Things (IIoT), the classical physical systems are now shifted to digital models, which is called scientifically by Digital Twins (DT). DT is a real-time data-informed virtual digital replica of a physical device or a complex system, used to model test scenarios before applying them to the physical entity. The term of DT was proposed in 2003 [1, 2] and was adopted mainly for industry 4.0 to model and simulate complex physical entities such as airplanes or even rockets. Nowadays, many researchers have studied DT for various sectors including Health care. A DT in the Health care system can be defined as the digital representation of a person, medical resources, and hospitals at large. A doctor can practice his upcoming heart surgery on the DT of his patient and simulate on it all the possible scenarios to choose the most suitable one for the condition of the patient. A hospital can have its DT system to help to manage and orchestrating human resources such as medical staff and physical resources such as medical machines and beds. DT can transform 1traditional and smart healthcare systems by reducing the time, cost, and provide more personalized treatment for the patients. Liu et al. [3] proposed a framework of the cloud healthcare system based on digital twin healthcare named (CloudDTH). The proposal aims to achieve interaction and convergence between medical physical and virtual spaces using the concept of DT. Rivera et al. [4] discussed the importance of DT for a personalized healthcare system and treatment and elaborated on the definition of internal structures for DT to support precision medicine techniques in the context of continuous monitoring and personalized data-driven medical treatments. Jimenez et al. [5] argued om the necessity to integrate DT into the healthcare sector to enhance their capabilities and offer better solutions, they provide as well some definitions of Medical Cyber-Physical Systems (MCPSs) and Digital Twins along with technological enablers such as cloud and IoT.

DT is indeed a solution for a smart and more precise healthcare system. However, it triggers various security threats. A DT urges continuous data uploading to come out with the best results. In the case of the healthcare sector, these data engender patient's personal information and medical history. Such information needs to be secured, non-falsified, and should never be leaked. Thus, in this paper, we propose the use of Blockchain to secure the user's identity and make the data available anonymously only to healthcare providers and professionals for real-time data analytics, medical researches, and personalized treatments. Using Blockchain-based DT, we can create a secure and anonymous database shared between healthcare providers to improve the accuracy of treatments, predict future diseases, and control them.

The contribution of this paper is as follows:

- We present a secure Blockchain-based Digital Twin framework for smart healthy cities.

- We propose as a case study the application of this framework on COVID-19 pandemic to discuss its usability and integrity.
- We explain the scenarios of the framework using a detailed methodology flow.

In Sect. 2, we present an overview of the proposed framework. We discuss the scenarios and sequence diagram in Sect. 3 and conclude this paper in Sect. 4.

2 Proposed Framework

In this paper, we propose a secure Blockchain-based Digital Twin framework for the future of the smart healthy city. As a case study, we decided to discuss how Blockchain-based Digital Twin can help to control the current pandemic of COVID-19. The proposed framework shown in Fig. 1 is composed of three layers: (1) Device Layer, (2) Blockchain Layer and (3) Application Layer.

The Device Layer: This layer includes the Digital Twins of persons (in this case the DT is the user's Smartphone, as it is cheap, everywhere and easy to use by a regular person) and hospitals. The physical entity (person) is responsible for feeding its respective DT (Smartphone) with accurate data. The hospitals participate as well by sending data regarding medical resources to the Blockchain Layer.

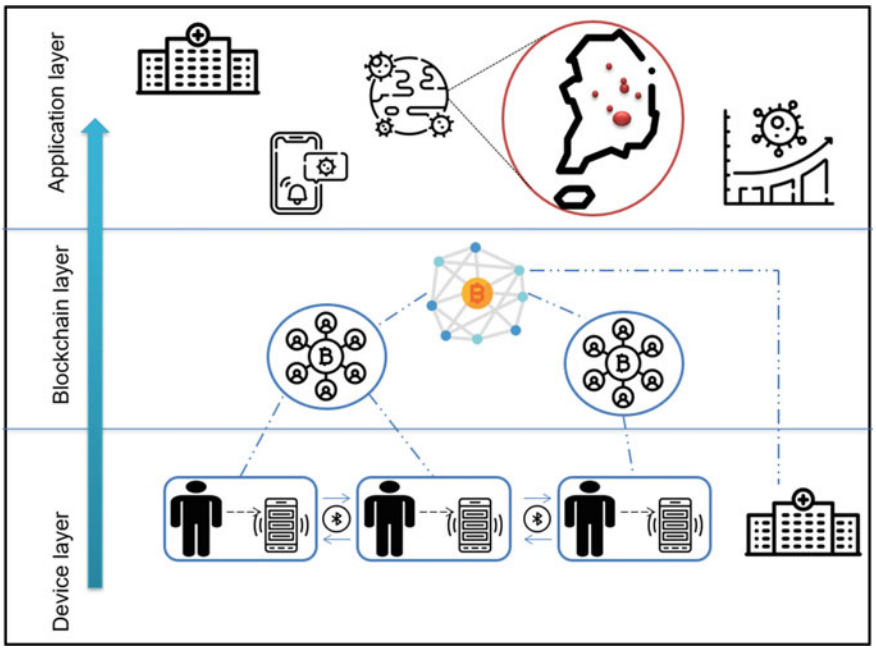

Fig. 1 Blockchain-based digital twin framework for Smart Healthy City

The Blockchain Layer: This layer has two main components, Consortium Blockchain, and Private Blockchain. Consortium Blockchain is controlled by the city's hospitals and are responsible of validating the accuracy of test results based on the giving test identification, in this context, if a person undertake a COVID-19 test in the hospital, the hospital associate his test with a unique identifier and use it to check if the data sent by the DT is accurate (if the person has indeed take the test and if the result is positive). Consortium Blockchain assures the accuracy and non-falsify of data as it is controlled by a group of approved entities [6]. Besides the Consortium Blockchain, this Blockchain layer includes as well a Global Blockchain, this Blockchain is Private and managed by one trusted organization (World Health Organization for example), however, it is visible for all the health institutions all over the world. The data collected in Blockchain are sent to the application layer. This method creates an openly shared database that can serve for future researches for a better understanding of the virus and more precise medication.

The Application Layer: Based on the data sent by the Blockchain layer, the map is updated in the application layer to show new patients' locations securely, a notification is sent to all the DT who have been around the patient's DT (based on the public keys, we explain this method on the third section) and the user's symptoms are being analyzed for better understanding and prediction.

3 Sequence Diagram

To understand how this framework works, we present a sequence scenarios' diagram as shown in Fig. 2. For clarification and simplicity, we consider in this scenario only two DTs and one hospital. The public key exchange is via Bluetooth and we consider a scenario where every smartphone has a secure secret key associated with a public key used as DT identification. The encryption and public/private key generation algorithms fall out of the scope of this study.

Step 1: The user is responsible for his own Digital Twin' data uploading, these data are divided between static data that can be added once to the user's DT such as user name, age, gender, most frequent locations such as home and work or school, and some of the user's underlying health issues. And modular data that can be changed based on the user's current symptoms; these data include Boolean data type (yes or no) that covers the usual COVID-19 symptoms such as:

- Losing sense of smell or taste.
- Trouble breathing.
- Pain in through and/or chest.
- Dry cough.
- Extreme fatigue.

A float data type for the temperature, date and time data type for the timestamp to track the change of the symptoms, a Boolean type for COVID-19 test (0 for a

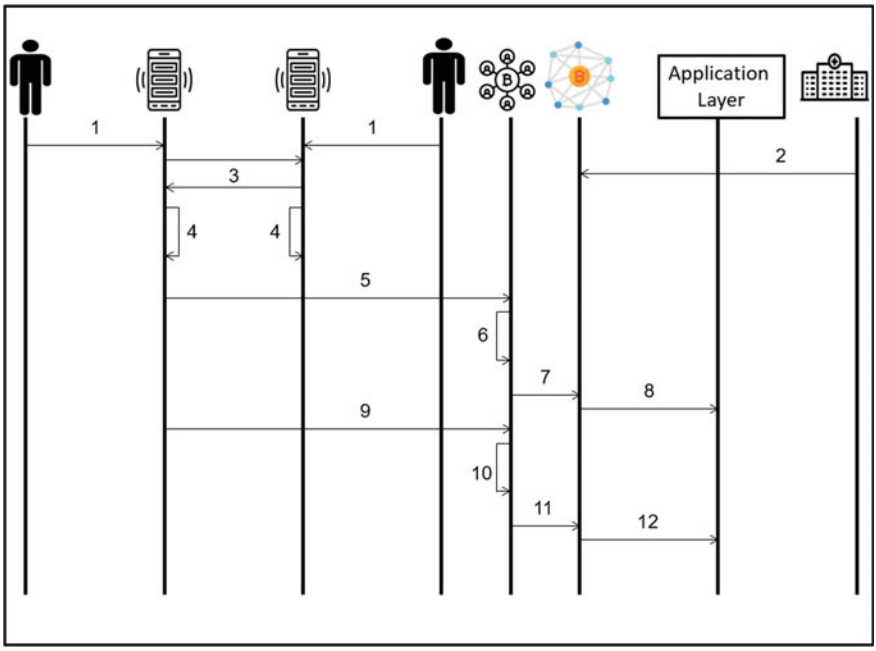

Fig. 2 Sequence diagram for the proposed framework

negative test and 1 for a positive test), and an integer data type for test identification in case a user undertook a test. All the above-mentioned information is being kept in the DT.

Step 2: Every hospital's DT records information about the available resources such as beds, medical staff, and medical equipment. These data are sent to the Global Blockchain for better resource management between deferent hospitals (i.e.: patients, based on the gravity of their symptoms, are assigned automatically to the right hospital that can respond to their needs or the hospital with enough medical resources.) thus reducing the time and cost.

Step 3: If two users or more stayed at one place for over 5 min, their DTs exchange the public keys and save them.

Step 4: The DT keeps the record of each public key for 15 days and then deletes it.

Step 5: In the case of a user being tested, and the test is positive (Test_Result == 1), the user has to type his test identification (Giving by the hospital). The DT by it turns to send the frequently visited locations' data, symptoms data, and test identification to the consortium Blockchain.

Step 6: Consortium Blockchain participants check if the test results are accurate.

Step 7: After confirming the results, the information is sent to the Global Blockchain.

Step 8: The location of the user anonymously is added as a red spot in the map, and the respective symptoms are being shared anonymously as well for the globally shared real-time database. And based on the patient underlying health conditions and current symptoms, personalized treatment is offered. Moreover, using the stored Public Key, an alert is sent to all the DTs with the respective Public Keys so they can be aware of the situation and undertake the test as well before they spread the virus more.

Step 9: The user with a previous positive test has to undertake the test again. If the result is negative, the information is sent with the test identification again to the consortium Blockchain.

Step 10: The consortium Blockchain participants check if the test results are accurate.

Step 11: After confirming the results, the information is sent to the Global Blockchain.

Step 12: The map is updated.

These steps are continuously repeated, the user must update the data based on his current symptoms and the hospital must update the data based on its current situation as well. The data shared in the Blockchain can be used for future predictions and reduce the number of future cases by showing a real-time map to avoid infected places and sending a personalized notification to the protentional patient to decrease the possibility of spreading the virus. It can be used as well as a collaborative researches platform between hospitals and healthcare providers all over the world and to create a personalized treatment for the user based on his health condition. This framework is not only designed for the COVID-19 pandemic but can also be used for future virus crises.

4 Conclusion

In this paper, we proposed a Blockchain-based Digital Twin framework for a smart healthy city. We discussed the application of this framework for the current COVID-19 pandemic and explained its sequence diagram based on a methodology flow. Digital Twins can remarkably benefit and improve smart healthcare systems by digitally modeling objects, systems as well as humans, testing all the possible scenarios, and orchestrating medical resources. In the case of the COVID-19 scenario, a DT is capable of creating personalized treatment, managing medical resources, and providing a secure shared database for healthcare providers and professionals to anonymously use the data to improve the treatment and prevent futures virus-waves from occurring.

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