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IOT AND CLOUD BASED BLOCKCHAIN MODEL FOR COVID-19 INFECTION SPREAD CONTROL

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ABSTRACT

Due to the increasing number of infected people and the number of deaths from COVID-19 over the world, there is a big challenge towards finding a radical solution to reduce the spread of disease and infection. The early detection, isolating the infected persons and tracing possible contacts are very critical. This paper presents an integrated approach that connects hospitals/laboratories, COVID-19 negative persons, positive persons, and contact persons to a cloud-based consortium blockchain system to guarantee reliable secured COVID-19 spread control. The proposed model guarantees a real time monitoring, tracking, and updating to persons status whether normal, contact, or positive COVID-19 case, and the related updates are done in the blockchain based on the results of execution of the blockchain smart contract rules. Tracking infected persons and their contacts is implemented using IoT sensors to determine contact time and spatial distances between them. The GPS/Bluetooth/UWB was used as IoT sensors technologies to determine the distances between the infected people and those in contact. The proposed blockchain Ethereum system smart contract was implemented by solidity programming language through the Remix IDE. The proposed approach was tested and successfully detected the contact cases and managed the different persons states on the cloud based blockchain system applying the smart contract rules accurately. As the calculated distances using the proposed model in the distance of one meter do not exceed the error rate of 11 cm.

Keywords: *IoT, Cloud Computing, Blockchain, Smart Contracts, COVID-19.*

1. INTRODUCTION

At the end of 2019, Wuhan in China experienced an outbreak of a novel coronavirus that killed more than eighteen hundred and infected over seventy thousand individuals within the first fifty days of the epidemic. This virus was reported to be a member of the β group of coronaviruses. The novel virus was named as 2019 novel coronavirus (2019-nCov) by the Chinese researchers. The International Committee on Taxonomy of Viruses (ICTV) named the virus as SARS-CoV-2 and the disease as COVID-19 [1]. The human to the human spreading of the virus occurs due to close contact with an infected person, exposed to coughing, sneezing, respiratory droplets or aerosols. These aerosols can penetrate the human body (lungs) via inhalation through the nose or mouth. Droplets can land on surfaces that others come into contact with and are then infected when they touch their nose, mouth or eyes. The virus can survive on surfaces from anything between a few hours (copper, cardboard) to a few days (plastic and stainless steel). However, the amount of viable virus declines over time, and it may not always be present in a sufficient quantity to cause infection [2].

The incubation period for COVID-19 (i.e., the time between exposure to the virus and the onset of symptoms) is currently estimated to be between one and 14 days [3].

IoT currently plays an important role the health sector, IoT has drastically changed the lives of both the young and elderly, as it can constantly track their health [4]. The role of the IoT landscape has been significantly changed due to the COVID-19 pandemic. It can be used directly to manage the spread of the virus (e.g., contact tracing, temperature screening, etc.). It is important to be able to detect early cases, trace, and isolate infected people during pandemics. IoT technologies with RFID, Near Field Communication (NFC), Wi-Fi, Bluetooth Low Energy (BLE), and GPS help provide better solutions for the previously mentioned cases. During the COVID-19 pandemic, the use of contact tracing has proved to be an appropriate solution to manage COVID-19 virus spread [5]. Integration of cloud computing into IoT-based healthcare applications gives a facility of accessing the shared resources globally. Blockchain integration with cloud computing brings us into the next era of data security and service availability. Blockchain overcomes most of the research issues of the cloud with its characteristics. (i) Interoperability: When cloud integrated with blockchain, consider the different clouds as nodes. Inter-node communication is possible in the blockchain. (ii) Data encryption: the data is decrypted before storing it in the cloud, which questions the data integrity. In the blockchain network, all the block data is turned into a hash code using cryptographic algorithms, and it generates a hash key for each block. (iii) Service level agreements: A smart contract in blockchain helps to build trust between the parties who do not know each other. (iv) Cloud data management: The data stored in the cloud is in a very unstructured manner. The data stored in the blockchain is in a very structured manner. The data can be traced using the hash key generated for every block. Each block contains the previous block's hash key, and its key to keep track of the network [6].

Identifying the exact location of infected people, tracking their movements, and isolating them to minimize spreading infection. Internet of things (IoT) technology is one of the most important tools that can be used to meet the needs imposed by facing Covid-19 spreading exponentially all over the world.

IoT technology offers positioning solutions for the object position which can be derived from many sensors such as GPS/Bluetooth/UWB.

These sensors can be divided into two types, indoor sensors such as UWB and outdoor sensors such as GPS. Therefore, this paper aims to integrate indoor and outdoor sensors to achieve meter level position accuracy in outdoor environment and centimeter level position accuracy in indoor environment. According on the previously identified position points, we can accurately calculate the distance between the infected person and the contact person.

In this paper, we propose a new approach that integrates the IoT outdoor and indoor tracking technologies, and cloud computing based blockchain system to control and minimize COVID-19 spread. The used IoT outdoor GPS based sensors, and indoor UWB/Bluetooth based sensors technologies are used to detect the COVID-19 patients and determine contact persons and provide their readings to the cloud computing based on consortium blockchain system that executes a built in programmed smart contract that evaluates each person’s status whether it is a normal, contact, or patient case and broadcast a location based warning with the a COVID-19 infected case or contact case and add a new block to the blockchain with new detected contact cases according to the way enforced by the consensus mechanism. The proposed blockchain type for this model is permissioned consortium blockchain (i.e., only accounts that are allowed can participate). This restricted access to the network in consortium blockchains ensures data privacy.

The paper is organized as follows: related studies and work are presented in Section 2. In section 3, motivation and the challenges facing the proposed model are presented in two subsections. In section 4, the proposed IoT and Cloud Blockchain Model for COVID-19 Infection Spread Control model is introduced in 4 subsections: 4.1 the proposed model architecture. 4.2 Blockchain Smart Contract Rules. 4.3 blockchain block structure. 4.4 The Proposed IoT and Cloud based Blockchain Model Architecture for COVID-19 Infection Spread Control Activity Diagrams. Section 5 presents proposed model implementation and results discussion. In section 6, conclusions and future work are presented.

2. RELATED WORK

In the medical field, many papers covered in general the importance of the IoT in the face of COVID-19 pandemic and early detection of zoonotic infectious [7-9]. However, many of them lacked clear technical details on how to adapt the IoT to confront COVID-19.

On the other hand, many researchers contributed deeply in different ways in using IoT, in facing COVID-19 and it will be discussed in five main directions which are:

- The survey papers that cover IoT technology to confront COVID-19.
- The IoT models, frameworks, structures, approaches, systems, and applications to confront COVID-19.
- Integrating IoT and artificial intelligence to confront COVID-19.
- Integrating IoT and blockchain to confront COVID-19.
- Analyzing the generated data from the IoT environments.

In the following, we will discuss in detail each of these directions.

On the first direction, some researchers reviewed the available literature on the use of IoT in COVID-19. K. Kumar et al. [10] reviewed the tracking techniques, and presented an architecture based on IoT that can be used to minimize the spread of Covid-19. Musa Ndiaye et al. [11] provided a survey about the IoT technology and how to benefit from it in the COVID-19. Also, the paper reviewed the challenges facing the sensor deployment process and the impact of the COVID-19 pandemic on the future of IoT networks. Ravi Pratap Singh et al. [12] discussed and explored and explored twelve applications which are working based on IoT and their importance in facing the COVID-19 pandemic. Awishkar Ghimire et al. [13] reviewed and discussed many models based on the Internet of Things and artificial intelligence and evaluate the results of these models. Mohammad Nasajpour et al. [14] reviewed the applications and systems that based on the IoT to face COVID-19, and the review was based on three phases: early diagnosis, quarantine time, and after recovery.

On the second direction, some researchers presented IoT models, frameworks, structures, approaches, systems, and applications to confront COVID-19. Gupta, D. et al. [15] presented a number of synergistic applications and systems to build resilient communities against future pandemics using multiple smart infrastructures components, such as e-health, smart home, supply chain management, transport, and city, which can work together, and the researcher has suggested and implemented a framework named as a generalized cloud-enabled IoT. The framework can be adapted and expanded to deploy smart connected ecosystem scenarios using commonly used cloud infrastructures from Amazon Web Services (AWS). In addition, to illustrate the need and practicality for smart connected populations, the researcher implemented an E-Health RPM use case scenario. Kumar K.R. et al. [16] developed a model to predict infected and suspected cases by tracking the relevant symptoms and predicting and analyzing the peak rate of the disease. Many IoT sensors are used and placed in some selected points by government agencies. The research provided a set of models to analyze the collected data to reach more accurate prediction results. Kaaviya Baskaran et al. [17] proposed a model to track the body temperature through infrared sensors at regular time intervals and inform the higher authorities in case the temperature rises above normal rates. M. Ennafiri et al. [18] presented a system to monitor the temperature and the percentage of oxygen through a bracelet. In addition, the bracelet contains a GPS tracker to ensure that the patient is obligated to isolation and social distancing. The proposed study was applied to 50 medical stuffs. Peng Hu [19] provided a framework to assist with future designs and evaluation of IoT based contact tracing solutions and enable data-based collective efforts to combat current and future infectious diseases. Sarah Jaafari et al. [20] presented an approach based on the IoT technology by monitoring a large number of patients at the same time through GPS sensors and ECG sensors and collecting the generated data to analyze each case separately. Younchan Jung et al. [21] provided a general application that can be used all over the world to provide real-time updated information about infected cases to world-wide Centers for Disease Control and Prevention (CDCs) and regular users. Also, the proposed application guarantees the privacy, confidential and secure transfer of data. Vibhutesh Kumar Singh et al. [22] designed an IoT based wearable quarantine band to detect those who are not obligated to isolate and with inexpensive cost. Aya Hossam et al. [23] presented a system for tracking COVID-19 in Egypt using Micro-Electro-Mechanical System (MEMS) IR sensors and display results in a dashboard include interactive map. The proposed system consists of three subsystems, which are: Embedded Microcontroller (EM), Internet of Things (IoT) and Artificial Intelligent (AI) subsystems.

On the third direction, some researchers linked the IoT with artificial intelligence to confront COVID-19. Sagar Kumar [24] covered three main points his research.1) In vitro diagnostic tests (IVDs), i.e., tests using biological samples such as blood, consisting of two types: nucleic acid tests for detecting RNA of the virus, and tests of antibodies which are developed by the body in response to the virus. 2) Chest X-Ray and CT scan machines, related methods of detection based on Deep Learning, and portable devices. 3) Wearable sensors, IoT and telemedicine for remote monitoring of patients with COVID-19 for evaluation of their condition, as well as those with non-COVID-19 for risk reduction of cross-infection. In order to identify the infected (suspicious) person using wearable smart gadgets, Muhammad U. Ashraf et al. [25] proposed an intelligent system for remote monitoring, advance warning and identification of a person's fever, heartbeat rate, cardiac conditions and some of the other radiological features. Fadi Al-Turjman et al. [26] presented in the sixth chapter detailed information on coronaviruses and the use of AI tools and IoT for detection, prediction, and determine vaccines and drugs. Also, this chapter highlighted the transmission, strains, and symptoms of coronaviruses. Manjur Kolhar et al. [27] provided a prototype for a decentralized IoT based biometric face detection framework for cities that are hat are under lockdown during COVID-19 outbreaks. Analyzing face detection depending on utilized a CNN based multi task cascaded framework. Swapnili Karmore et al. [28] designed and developed a smart system called a medical diagnosis humanoid (MTH) to diagnose people with Covid-19 using real time data sensing and processing through machine learning produced by various sensors used in the context. Sharnil Pandya et al.[29] presented an IoT based sensor-fusion assistive technology for COVID-19 disinfection called as "Smart epidemic tunnel" was implemented to protect an individual using an automatic sanitizer spray system equipped with a sanitizer sensing unit based on individual using an automatic sanitizer spray system equipped with a sanitizer sensing unit based on human motion detection.

On the fourth direction, some researchers linked the IoT with blockchain to confront COVID-19. Nada et al. [30] proposed a new distributed multi-layer IoT/blockchain based architecture model to meet the design principles required to efficiently manage the raw data streams produced by numerous IoT devices. The proposed architecture was designed to support high availability, real-time data delivery, high scalability, security, resiliency, and low latency. The goal is to solve the problem of scalability and performance.

Dwivedi et al. [31] proposed a new framework of adjusted blockchain models appropriate for IoT devices that depend on their dispersed nature and other additional privacy and security features of the network. The suggestions given here make IoT application data and transactions more secure and anonymous over a blockchain-based network. The introduced hybrid approach combined the advantages of the private key, public key, blockchain and many other cryptographic primitives to create a patient-centric access control for electronic medical records, capable of giving security and privacy.

Tiago et al. [32] presented a new IoT system its main goal was estimating occupancy levels in public spaces during the current COVID-19 pandemic. The introduced system is based on the use of IoT devices that interact with identification and monitoring devices used in the monitored areas. The system has a decentralized traceable subsystem based on blockchain, which guarantees the availability, security, and immutability of the collected information in order to make it available among smart city stakeholders (e.g., health authorities, insurance companies) to secure public safety and then deliver transparent decision-making based on data-driven analysis and planning. Tanweer Alam [33] presented a four-layer architecture to assist infected people by using the IoT and Blockchain technologies. Where the IoT can be utilized to gather information, give extra understanding through symptoms and behaviors, allows remote monitoring, and simply gives people self-determination and better health care. On the other hand, the Blockchain handles the secure transfer and storage of patient health data. Lalit Garg et al.[34] designed an IoT model based on RFID technology and the blockchain was used to ensure the security and privacy of the transferred users data. Vinay Chamola et al. [35] reviewed the diagnosis, treatment and prevention of the COVID-19 and the effect on the economy. In addition to, the paper evaluated the use of varied technologies such as IoT, UAVs, AI, blockchain, and 5G to facing COVID-19 pandemic.

On the fifth direction, some researchers analyzed the generated data from the IoT environments. Bowen Wang et al. [36] studied how to exploit the social relationships between mobile devices in SIoT to reduce infection rates through early identification for COVID-19. The recursive autonomy identification (RAI) algorithm is used to solve the optimized problem which is transformed into the minimum weighted vertex cover (MWVC) problem. Karthickraja R. et al. [37] diagnosed symptoms and risk factors that influence by the coronavirus through recognizing the rate of respiration and saturation of oxygen (SpO2). the researcher studied all collected data (only 308 cases were studied out of a total of 238 cases) through wearable sensors. The collected data were analyzed statistically using chi-square distribution with t-test measure correlating the IoT factors.

According to the reviewed related work, there are a very few studies that employed the IoT, and cloud based blockchain architecture to control COVID-19 spread control. This study proposes a novel IoT and cloud-based consortium blockchain model that takes advantage of a set of integrated location tracking technologies based on the IoT mobile devices, the blockchain smart contracts algorithm to evaluate and approve adding a new COVID-19 suspected contact case to the blockchain. In addition, the proposed model broadcasts a warning to the surrounding of a detected COVID-19 patient or contact in a 50 m range.

3. MOTIVATION AND CHALLENGES FACING THE PROPOSED MODEL

In this section, motivation of the proposed model and the main challenges facing the proposed model are presented.

3.1 Motivation of The Proposed Model

According to WHO reports, the number of deaths and infected cases with COVID-19 is increasing daily. In 17 November 2021, the number of confirmed cases reached 254,256,432 and deaths cases reached 5,112,461 cases [38]. The daily increase in numbers was the main motivation for us, and the main reason for the increase in numbers was close contact with infected cases.

The WHO published an updated document in February 2021 for defining of "contact person" [39]. It was defined as a person who was exposed to a probable or confirmed by direct physical contact within 1 meter and for at least 15 minutes. This document showed that the contact person is the most dangerous element in the process of spreading Covid-19.

Internet of things technology with different tracking technologies that use IoT sensors such as GPS/Bluetooth/UWB plays a big role in tracking the distances between people [40]. Thus, we can track the infected people and those in contact.

3.2 Challenges Facing the Proposed Model

There are some challenges facing the proposed model, the most important of which are the following:

- The biggest technical challenge to tracking infected or contact cases is to determine the exact location of the person and thus the ability to determine distances between persons in distance less than one meter.
- Storing the infection history for each person as the system will deal with cases differently through an alerting module.
- Ensure the confidentiality and privacy for infected or contact cases.

4. THE PROPOSED IOT AND CLOUD BLOCKCHAIN MODEL FOR COVID-19 INFECTION SPREAD CONTROL

The proposed approach is based on three types of cases:

- Normal case: uninfected or non-contact case, as shown in figure 1 in green with the letter "A".
- Contact case: a case that contact with an infected case for a distance of less than one meter and for more than 15 minutes, as shown in figure 1 in orange with the letter "B".
- Infected case: a confirmed case in which it has been proven from chest CT or laboratory test (such as PCR and D-dimer [41]) as shown in figure 1 in red with the letter "C".

4.1 The Proposed IoT and Cloud based Blockchain Model Architecture for COVID-19 Infection Spread Control

The proposed model architecture consists of main four components, as shown in figure 1, which are IoT environment, alerting module, blockchain management system, and cloud-based consortium blockchain.

IoT environment contains multiple types of sensors which are GPS, Bluetooth and UWB for location tracking. it is difficult to rely on GPS sensors only in in locating positions, especially in indoor or closed places where error rate is more than 1 meter. On the other hand, the infection distance according to WHO report is less than or equal to 1 meter, the other two sensors have the ability to determine the location with greater accuracy in indoor or closed places where error rate is 10 cm. Therefore, all location data are collected and stored in the cloud-based location database in real time.

The alerting module sends the information about the contact persons (case B) to the blockchain management system and in parallel it broadcasts all the necessary procedures and information for each case according to its type in a way that helps to reduce the spread of infections, especially by focusing on contact cases (case B) and confirmed cases (case C).

The blockchain management system is responsible for managing entire data in the cloud-based consortium blockchain according to the received data from hospitals, laboratories, and the processed data from COVID-19 risk evaluator. The hospitals and laboratories send data about positive and negative cases which are proven through chest CT or laboratory tests (cases A or C). Also, the COVID-19 risk evaluator is responsible for calculating the contact time and the distance between persons according to stored data in the cloud-based location database and the received data from the blockchain about infected cases (case C). the blockchain management system sends data to

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the alerting module about contact cases (case B) and stores all cases information (whether A, B, and C) as transactions in the cloud-based consortium blockchain.

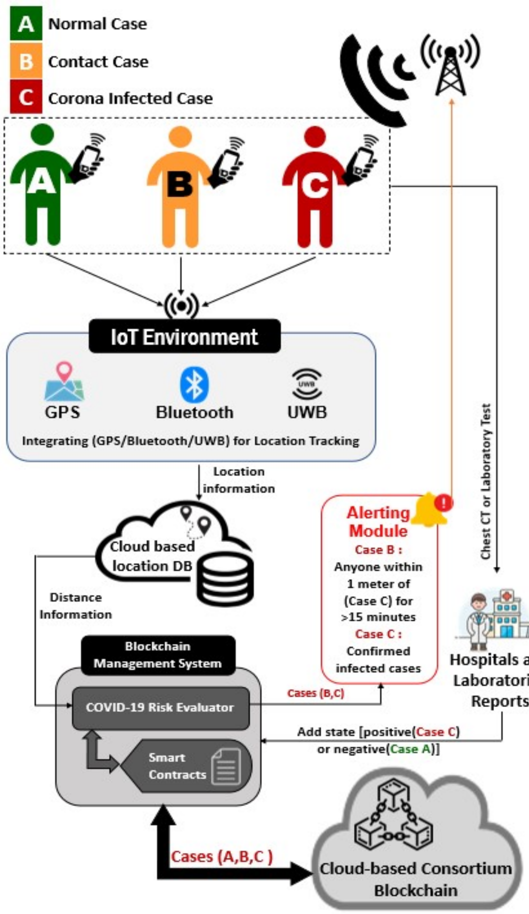

Figure 1: IoT and Cloud based Blockchain Model Architecture for COVID-19 Infection Spread Control

4.2 COVID-19 Infection Spread Control Blockchain Smart Contract Rules

The process of adding transactions is managed by blockchain management system through smart contracts component which are runed when predetermined conditions are met. The following table 1 shows how these rules were established, through which the smart contracts will verify the blocks that will be added.

4.3 Cloud Based Blockchain System Block Structure

The cloud-based consortium blockchain stores all information about all cases types (whether A, B, and C) into blocks. Each block composed of a header and a body, where a header contains the hash of previous block, the Merkle root and a timestamp, as shown in figure 2. The body of the block contains all stored transactions, and each transaction contains an information such as, person ID (e.g., SSN, National ID), Person name, person state (A,B,C) and COVID-19 vaccination state.

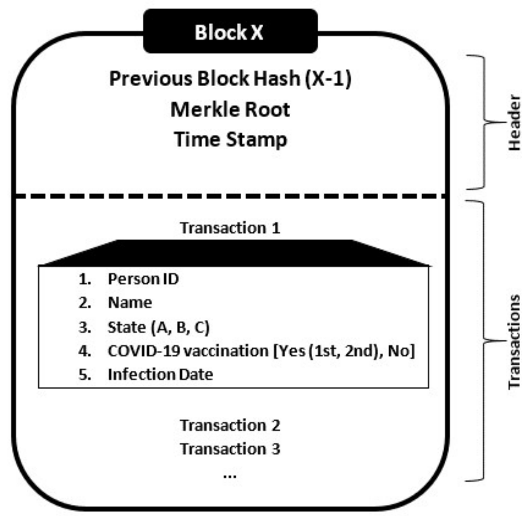

Figure 2: Cloud Based Blockchain System Block Structure

4.4 The Proposed IoT and Cloud based Blockchain Model Architecture for COVID-19 Infection Spread Control Activity Diagrams

The activity diagram in figure 3 explains the way to deal with all citizens whose infection states are positive or negative corona infection according to CT scan or laboratory analysis reports.

The activity diagram in figure 4 explains how the IOT and Cloud Based Blockchain model for COVID-19 Spread Control works and applies smart contracts rules to control and manage COVID-19 spread. Where:

X: Evaluated person for COVID-19 infection, carrying a smart phone equipped with the required technologies and Apps.

Yi: Detected person around, carrying a smart phone equipped with the required technologies and Apps. Where i = 1 -> n (n: no. of detected smart phones in range).

Table 1 SMART CONTRACTS RULES

Current Person Case	Condition	New Updated Person Case (New Transaction)
A	within 1 meter of (Case C) for >15 minutes	B
A	Positive reports (from hospitals and laboratories)	C
B	after 14 days quarantine without any symptoms	A
B	Positive reports (from hospitals and laboratories)	C
C	Negative reports (from hospitals and laboratories)	A

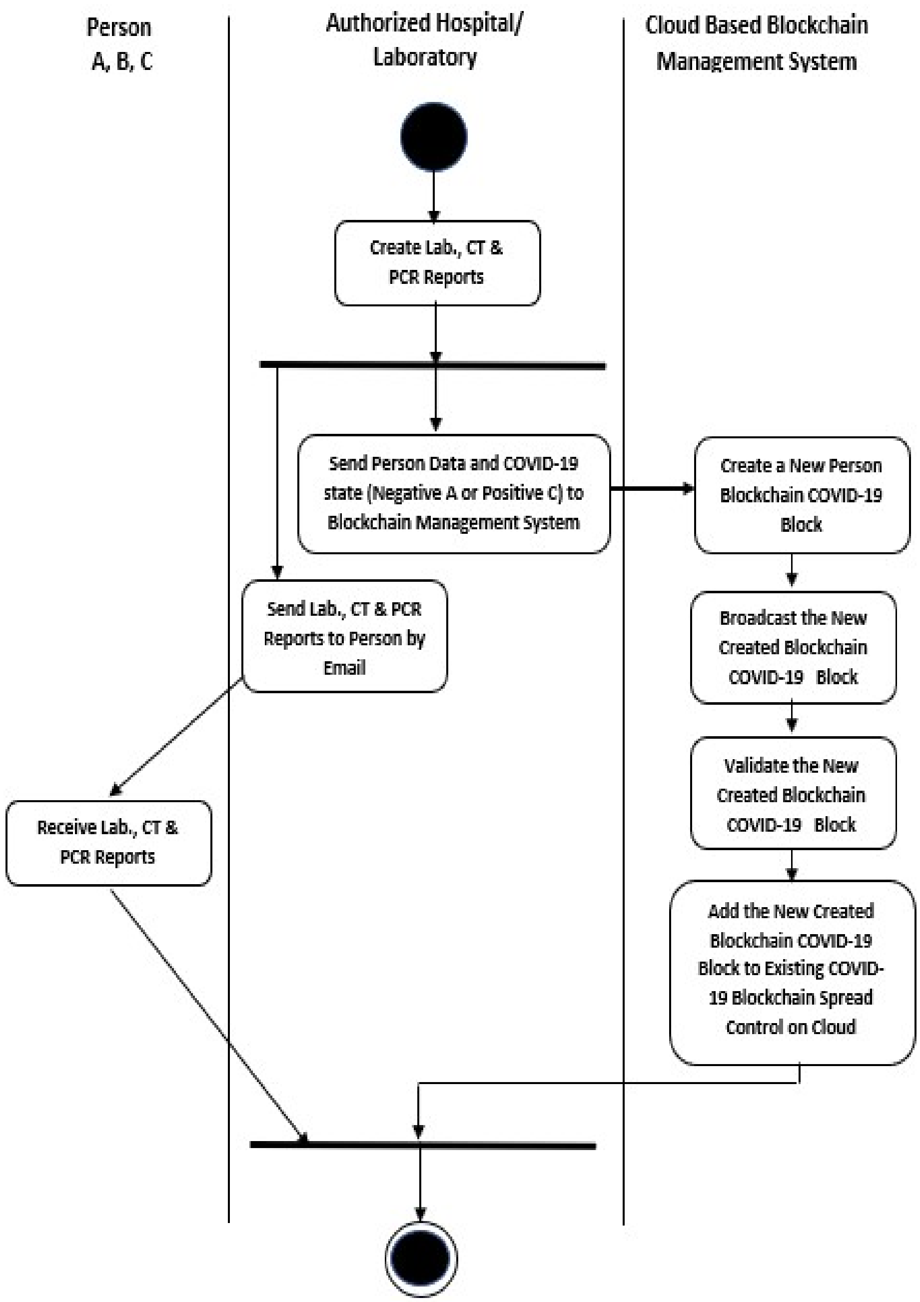

Figure 3: Regular Citizens COVID-19 Medical Records Addition to the Cloud Based Blockchain Activity Diagram

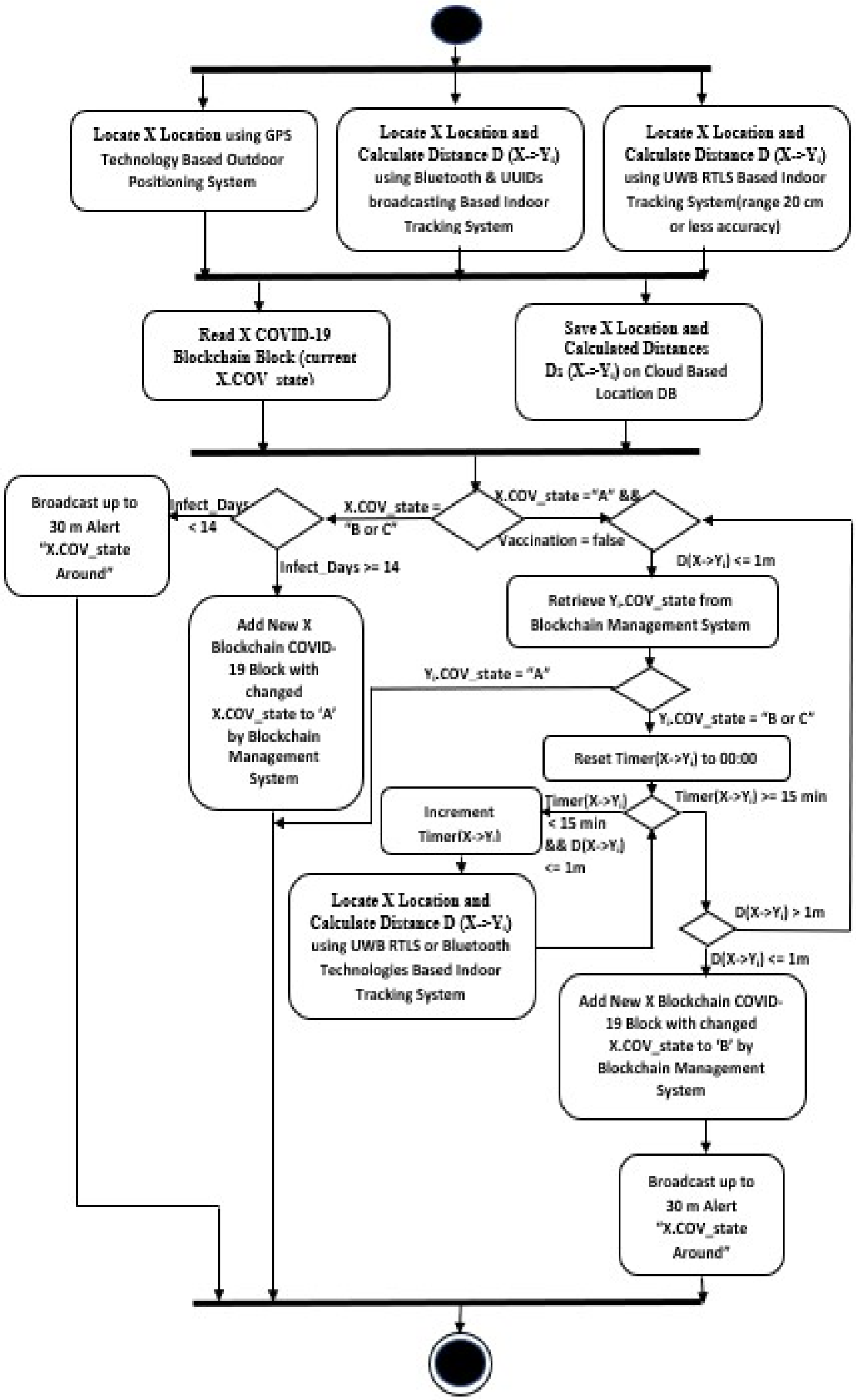

Figure 4: IOT and Cloud Based Blockchain model for COVID-19 Spread Control Activity Diagram

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5. MODEL IMPLEMENTATION AND RESULTS DISCUSSION

There are many details in the implementation process for the proposed model, but the focus will be on two main parts which are, smart contracts implementation and outdoor/indoor tracking.

5.1 Smart contracts implementation

Smart contract implemented by solidity programming language through one of the most common tools for implementing contracts to the Ethereum network which is the Remix IDE.

Figure 5 shows the implemented code to execute the rules of smart contracts. As shown in figure 5, there are five rules was tested to determine the type of case.

```
pragma solidity ^0.8.5;
contract Covid19_Infection_Spread_Control{
  uint256 public createTime= block.timestamp;
  enum Person1_Statelist{ A, B, C }
    Person1_Statelist Person1S_choice;
  enum Person2_Statelist{ A, B, C }
    Person2_Statelist Person2S_choice;
  enum MedicalReportlist{ P, N }
    MedicalReportlist MedicalReport_choice=MedicalReportlist.N;
  constructor() public {}
  function getCurrentState() public view returns(Person1_Statelist){
    return Person1S_choice; }
  function SetNewState(uint256 Distance,uint256 ContactTime,uint256
InfectionDate) public{
    //Distance in centimeter, Date and Time in seconds
    uint256 QuarantineDays=createTime-InfectionDate;
    if(Person1S_choice==Person1_Statelist.A && Distance < 100 &&
Person2S_choice == Person2_Statelist.C && ContactTime>900) {
      Person1S_choice=Person1_Statelist.B;
    } else if (Person1S_choice==Person1_Statelist.A &&
MedicalReport_choice==MedicalReportlist.P){
      Person1S_choice=Person1_Statelist.C;
    } else if (Person1S_choice==Person1_Statelist.B && QuarantineDays>1209600){
      Person1S_choice=Person1_Statelist.A;
      //14 days quarantine in seconds=1209600
    } else if (Person1S_choice==Person1_Statelist.B &&
MedicalReport_choice==MedicalReportlist.P){
      Person1S_choice=Person1_Statelist.C;
    } else if (Person1S_choice==Person1_Statelist.C &&
MedicalReport_choice==MedicalReportlist.N){
      Person1S_choice=Person1_Statelist.A; }}
  function getNewState() public view returns(Person1_Statelist){
    return Person1S_choice; }}
```

Figure 5: Smart contracts implemented code

A brief description of the smart contracts rules is as follows:

- Checking the contact case which is within 1 meter with (CASE C) for at least 15 minutes. Figure 6 shows the test results for a contact case that its type changed from A represented as zero to B represented as one. Note that the distance is measured in centimeters and time in seconds.

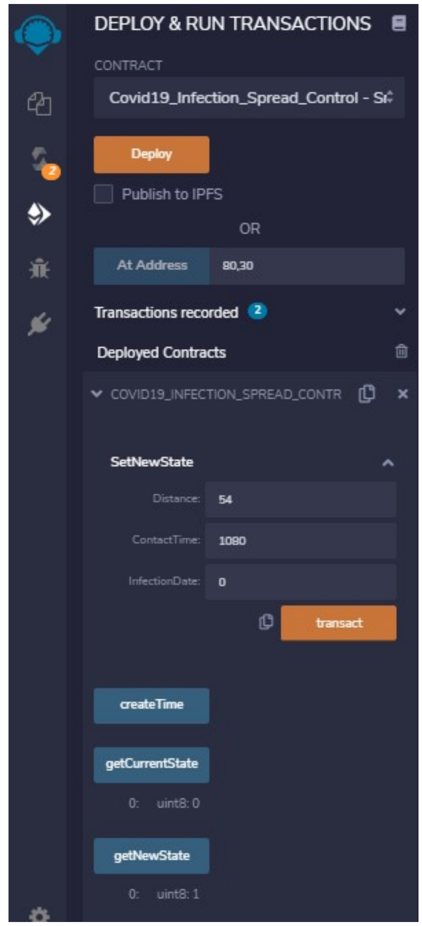

Figure 6: Rule 1 in the smart contracts

- Checking normal cases that are infected and confirmed according to positive reports from hospitals and laboratories. Figure 7 shows the test results for a case that its type changed from case A (0) to case C (2).

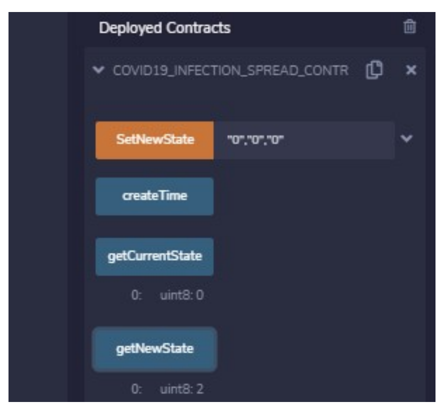

Figure 7: Rule 2 in the smart contracts

- Checking contact cases after 14 days quarantine without any symptoms. Figure 8 shows the test results for a case that its type changed from case B (1) to A (0). Note that the assumed current

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date/time (Unix epoch time): 1623584270 which is Sunday, June 13, 2021 11:37:50 AM and infection date/time (Unix epoch time): 1621398914 which is Wednesday, May 19, 2021 4:35:14 AM.

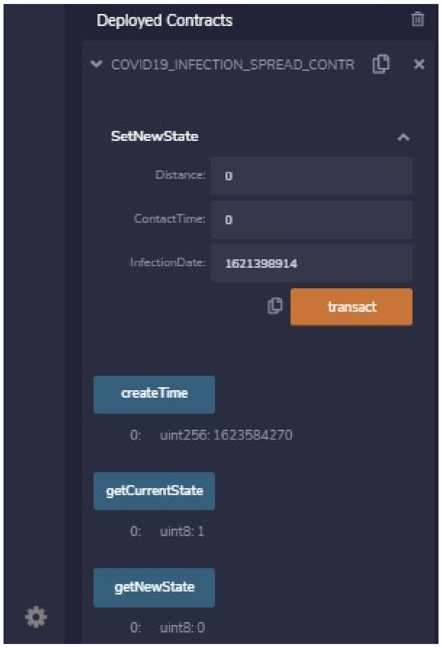

Figure 8: Rule 3 in the smart contracts

- Checking contact cases that were confirmed as infected cases according to positive reports from hospitals and laboratories. Figure 9 shows the test results for a case that its type changed from case B (1) to case C (2).

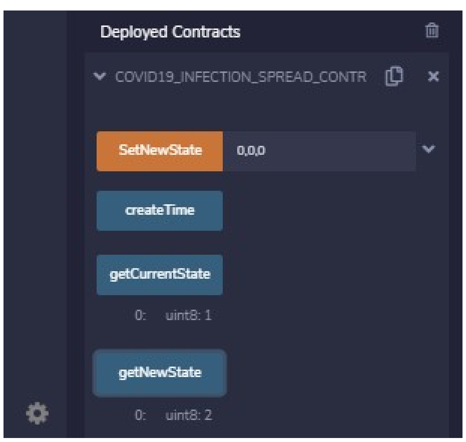

Figure 9: Rule 4 in the smart contracts

- Checking confirmed infected cases which are recovered according to negative reports from hospitals and laboratories. Figure 10 shows the test results for a case that its type changed from case C (2) to case A (0).

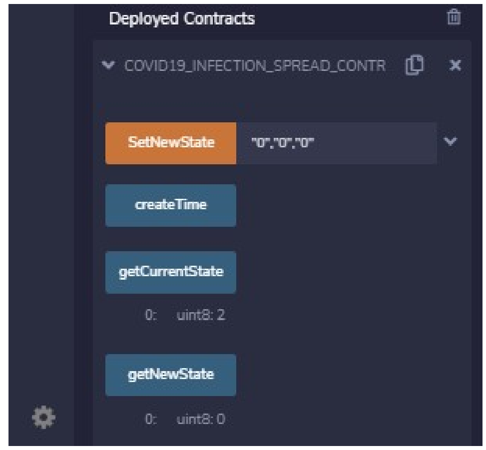

Figure 10: Rule 5 in the smart contracts

5.2 Outdoor/Indoor Tracking

To calculate accurate values of distances between people, cloud-based location DB is used to store locations every moment, and thus the ability to determine the distances between people. Figure 11 shows the database model of cloud-based location DB which shows the integration between indoor and outdoor technologies. GPS used for outdoor tracking, and on the other side Bluetooth and UWB used for indoor tracking.

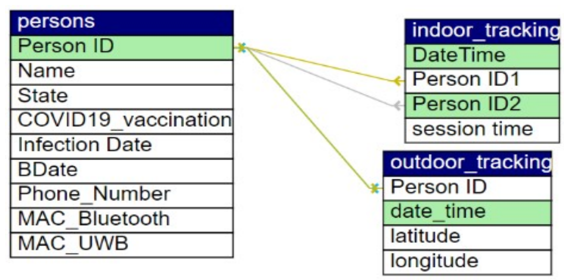

Figure 11: The database model of cloud-based location DB

Outdoor tracking in the proposed model is based on GPS technology, GPS location captured through IoT sensors and manipulated in model code by Geolocation.getCurrentPosition() function. Figure 12 shows a part of the code that explains how to determine the current position of the device.

```
var options = {
    enableHighAccuracy: true,
    timeout: 5000,
    maximumAge: 0
};
function position(pos) {
    var crd = pos.coords;
    console.log('current position:');
    console.log(`Latitude : ${crd.latitude}`);
    console.log(`Longitude: ${crd.longitude}`);
    console.log(`More or less ${crd.accuracy} meters.`);
}
function ErrorHandler(err) {
    console.warn(`ERROR(${err.code}): ${err.message}`);
}
navigator.geolocation.getCurrentPosition(position,
ErrorHandler, options);
```

Figure 12: Determining the current position

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Then the distances are calculated between two coordinates by latitude and longitude which are generated by GPS sensors. The distance is calculated based on the "haversine" function:

$$a = \sin^2(\Delta\varphi/2) + \cos\varphi_1 \cdot \cos\varphi_2 \cdot \sin^2(\Delta\lambda/2) \quad (1)$$

$$c = 2 \cdot \operatorname{atan2}(\sqrt{a}, \sqrt{1-a}) \quad (2)$$

$$d = R \cdot c \quad (3)$$

where φ is latitude, λ is longitude, R is earth's radius (mean radius = 6,371km). Figure 13 shows a part of the code that explains how to determine the distances based on GPS.

```
function distance(lat1, lon1, lat2, lon2) {
    var p = 0.017453292519943295;
    // Math.PI / 180 = 3.141592653589793 / 180
    var c = Math.cos;
    var a = 0.5 - c((lat2 - lat1) * p)/2 +
            c(lat1 * p) * c(lat2 * p) *
            (1 - c((lon2 - lon1) * p))/2;

    return 1274200000 * Math.asin(Math.sqrt(a));
     //  R = 6371 radius of earth in KM ;
    2*1000*100*6371 to convert it to centimeters
}
```

Figure 13: Determining the distances based on GPS

Indoor tracking in the proposed model is based on two technologies which are Bluetooth and UWB. The distance is calculated based on received signal strength indicator RSSI because the signal strength depends on distance and broadcasting power value. Figure 14 shows a part of the code that explains how to determine the distances based on Bluetooth and UWB.

```
protected static double calculateDistance
(int txCalibratedPower, double rssi) {
    if (rssi == 0) {
        return -1.0;
    }

    double ratio = rssi*1.0/
    txCalibratedPower;
    if (ratio < 1.0) {
        return Math.pow(ratio,10);
    }
    else {
        double distance =  (0.89976)*Math
        .pow(ratio,7.7095) + 0.111;
        return distance*100;
    }
}
```

Figure 14: Determining the distances based on RSSI

Figure 15 shows an example that applied in the real environment to verify that the calculated distances between two points are equal to the real distance in the real environment.

Figure 15: An example to determine the distance

In the applied example, Bluetooth and UWB can measure distances with a maximum coverage level of up to 50 meters and the GPS can measure distances with an unlimited maximum coverage. The results can be shown in figure 16.

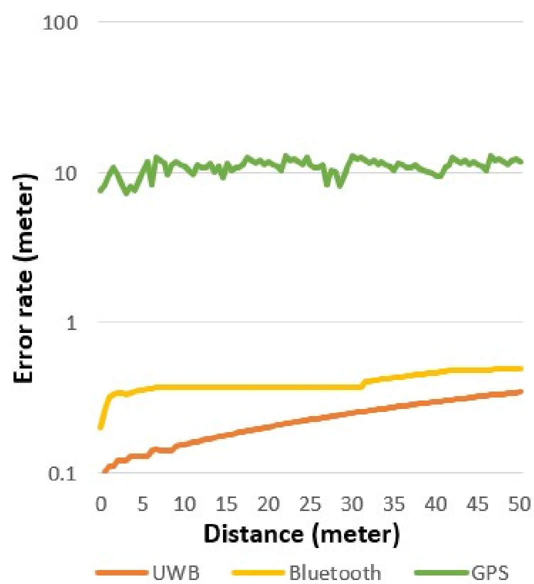

Figure 16: Distance error rate in GPS/Bluetooth/UWB

According to testing results as shown in figure 16, there are error rates in the calculated distances using the proposed model as following:

- In a distance of less than or equal 1 m (using Bluetooth and UWB only), the error rate does not exceed 11 cm.
- In a distance between 1 m to 50 m (using Bluetooth, UWB, GPS), the error rate does not exceed the values between 11 cm and 35 cm.

- In a distance of greater than 50 m (using GPS only), the error rate does not exceed 13 m.

6. CONCLUSIONS AND FUTURE WORK

In this study, a new IoT and Cloud based Blockchain Model for COVID-19 Infection Spread Control was presented by creating a reliable, secured, and effective collaborative and monitoring system connecting authorized hospitals/laboratories, COVID-19 patients, contacts, and normal cases. The new approach introduced by the model integrates the IoT outdoor and indoor tracking technologies, and cloud computing based blockchain system to control and minimize COVID-19 spread. The implemented model successfully used IoT outdoor GPS based sensors, and indoor UWB/Bluetooth based sensors technologies to detect the COVID-19 patients and determine contact persons with high accuracy for calculated distances, where the error rate does not exceed 11 cm in a distance of one meter. Distances are calculated by providing IoT sensors readings to the cloud computing based consortium blockchain system that executes a built in programmed smart contract that evaluates each person's status whether it is a normal, contact, or patient case and broadcast a location based warning with the a COVID-19 infected case or contact case. The system makes real time updates of the persons status in the cloud based blockchain according to results of smart contract rules execution and online provided updates for persons status coming from hospitals/laboratories. Smart contract was implemented by solidity programming language through one of the most common tools for implementing contracts to the Ethereum network which is the Remix IDE. The proposed approach was tested and successfully detected the contact cases and effectively managed the different persons states on the cloud based blockchain system applying the smart contract rules accurately.

In future work, it is recommended to integrate this proposed model with COVID-19 early diagnosis and treatment systems that customize the treatment protocol smartly according to each patient infection level.

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