CoviReader: Using IOTA and QR Code Technology to Control Epidemic Diseases across the US

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2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC) | 978-1-6654-1490-6/21/$31.00 ©2021 IEEE | DOI: 10.1109/CCWC51732.2021.9376093

***Abstract*— Despite all scientific advancements, the spread of infectious diseases continue to pose a significant challenge to the health and prosperity of our society. Therefore, the prevention and control of infectious diseases that have the potential of becoming global threats is a central priority of public health. However, the silent emergence and uncontrolled global spread of the novel virus called SARS-COV-2 has proven that neither governments nor healthcare systems are prepared to respond to a pandemic. As an example, the coming of the coronavirus (COVID-19) has not only disrupted economies and collapsed healthcare systems, but also filled hospitals and separated people from their families and work across the globe. While the outbreak originated in China, the pandemic's epicenter moved to the US, which has more cases than any country in the world (New York accounted for nearly more than one-third of the country's coronavirus infections). As the US continues to adapt its response to the evolving situation of the virus, the nation's coronavirus pandemic has highlighted many practical uses for blockchain-based applications. Motivated by this, we present a solution for fighting the coronavirus outbreak – and future pandemic outbreaks – in the US using IOTA and QR code technology. In this paper, we propose CoviReader: a decentralized healthcare management system that shares user's data anonymously. The system is built on the IOTA tangle platform and provides users detailed, unchangeable, and easy access to their personal information. CoviReader handles authentication, confidentiality, transparency and data sharing (with crucial considerations when revising confidential information). Users interact with IOTA's tangle via a mobile application which holds a FIREBASE database. The purpose of this short paper is to demonstrate a working prototype by which we assess and analyze strategies for mitigating the consequences of the COVID-19 health crisis in the US.**

***Keywords*— blockchain; iota; qr code; distributed information systems; SARS-COV-2; COVID-19; coronavirus; epidemic; pandemic.**

I. INTRODUCTION

A large-scale global pandemic as is the case of the novel coronavirus (COVID-19) was unavoidable. Over the past few years, a number of health experts have written books and articles warning countries of the possibility of future coronavirus-like epidemics and the complete lack of preparedness [1–7]. They warned that it is becoming increasingly difficult to contain epidemic-prone diseases such as Ebola, influenza, and Sars, and while governments and international organizations have taken measures to improve preparedness for future pandemics, we still do not have enough medical countermeasures for an outbreak control. What is more, even Bill Gates, the Co-founder of Microsoft, detailed plans on how the world can come through a pandemic, highlighting the weakness in the global response to Ebola and proposing ways to reform the pandemic preparedness, in his 2015 TED Talk [8] following the latest Ebola outbreak in 2014 [9].

In just recent months, the COVID-19 epidemic, which first appeared in China at the beginning of December 2019, has become a worldwide pandemic. What was initially perceived as a problem largely based on China is now recognized as a global health crisis, becoming a serious thread around the world [10]. The World Health Organization (WHO) [11] declared the COVID-19 outbreak a global pandemic within a month of its widely expansion on other continents, resulting in tens of thousands of cases in just a matter of months. The epidemic's epicenter has moved from China to Europe and then the US [12]. Since then, it has slowly spread to various nations, with authorities taking ever more stringent steps to control the virus as the number of infections rises. Although infections are mounting worldwide, the virus has spread more rapidly in the US than anywhere else in the world, with New York [13] accounting for a large shared of all confirmed cases – at the time of writing, according to the US Center for Disease Control and Prevention (CDC), the virus had spread to nearly 661,712 people, causing 33,049 death in the country [14]. Fig. 1 shows the geographical distribution of confirmed COVID-19 cases (red dots) in the US back in April 16th 2020.

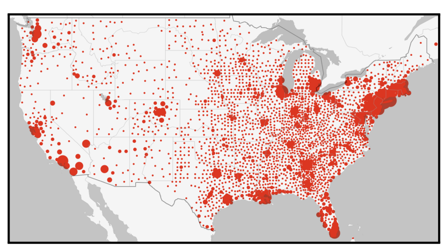

Fig. 1: Illustration of the geographical spread of confirmed COVID-19 cases in the US. Data from April 16th 2020 at 03:39 P.M. EST [15] (Source: Johns Hopkins University).

Across the US, in an attempt to prevent the viral infection from reaching other districts, around 316 million Americans were asked to "hunker down". The hunker down order went into effect in at least 42 states, some counties and cities, Washington, D.C. and Puerto Rico [16]. The nation, however, continues to show a rise in COVID-19 cases as travelers return from abroad in spite of rigorous containment and quarantine efforts. Alongside this, more than 312 thousand Americans have died from the virus, and more than 17 million cases have been reported, making the US the country with the largest number of cases reported in the world [17]. The US pandemic response continues to be a work underway despite the country's effort to halt the spread of the virus.

A. The Economic Impact of the Coronavirus

The COVID-19 outbreak has produced disruptions in both demand and supply, which has resonated across the globe. At the sectoral level, for example, tourism, travel-related industries, insurance, agriculture, and restaurants are among the hardest hit as authorities and owners were forced to stop operations worldwide [18, 19]. The impact of this viral infection on the global economy will largely depend on how rapidly the virus is contained, what measures the authorities take to contain it, and how much economic support governments are prepared to provide during and after the outbreak. However, according to the Organisation for Economic Cooperation and Development (OECD), the economic effect of this global pandemic will be felt for a long time now that COVID-19 has disrupted modern society on a scale never seen before [20].

Additionally, COVID-19 has forced countries to limit the movement of their citizens, sparking global protest movements [21–24]. As world leaders institute drastic and rigorous control measures required to halt the spread of coronavirus, these restrictions will affect not only a wide range of international economic activities, but also international commercial trades [25, 26]. The International Labour Organization (ILO), a United Nations' (UN) agency, has estimated that between 5.3 million and 24.7 million jobs could be lost due to the coronavirus [27]. In contrast, in the US, more than 22 million Americans have lost their jobs [28]. Together this could bring in an estimated 47 million jobs lost in the escalating coronavirus crisis.

In the US, increasing concerns about the economy have prompted Congress to decide on a massive stimulus package to support the stability of the current crisis [29]. However, long before the coronavirus, many hourly and self-employed Americans struggled to meet basic needs. Nowadays, they are struggling to cope with the economic fallout that COVID-19 has caused in the nation [30]. In response to the seriousness of the situation (and the lack of paid time off), President Donald Trump has offered governors guidelines for how Americans could return to work in hopes of reopening the US economy [31]. On that basis, there is no way to tell precisely what the economic damage caused by COVID-19 will be. A severe recession may be imminent.

B. Fighting an Invisible Enemy

With the large-scale global spread of COVID-19, every attempt has been made to respond to this deadly threat; examples include: providing assistance to the victims, reducing secondary infections between close contacts, keeping health care personnel risk-free, developing a vaccine, and reducing mortality and health care demands [32–35]. While it is virtually impossible to expect any country to be fully prepared for such an event, various bodies including businesses around the world are putting technology to work in order to mitigate the effects of the global health crisis. In the fight against COVID-19, a number of ongoing initiatives by universities, governments, non-profit organizations, and the private sector are leveraging the potential of distributed systems. Researchers are gradually turning to blockchain-based technology with the purpose of alleviating the effect of COVID-19 [36–39], which has thus far seen extreme lock-downs, curfews, stay-at-home and work-from-home orders, and called for social distancing all over the world. In light of this, blockchain has emerged as a promising solution to counter the coronavirus epidemic.

C. Blockchain Technology, a Borderless Solution to Humanitarian Concerns

One the one hand, blockchain technology has been proposed as an innovative means by which the US could improve taxation [40–42], with some considering using this technology to track the status of payments [43]. The CDC also emphasized the potential for digital technologies to help combat a disease outbreak [44]. On the other hand, with President Xi Jinping's backing blockchain, the Chinese government has deployed this technology in different applications designed to assist in the fighting of COVID-19 [45–48]. With the assistance of a Distributed Ledger Technology (DLT), the government has since been able to monitor the virus spread, patient records, medical supplies distribution, and charity donations. This current form of development made in the country is in line with President Xi's comments in October 2009, that China needs to take advantage of the opportunities provided by blockchain technology [49].

The WHO has also introduced a blockchain-based platform to support the COVID-19 epidemic response called MiPasa, a platform built on top of the Hyperledger Fabric aimed at promoting the exchanged of private information between individuals, state authorities, and health organizations [50, 51]. Moreover, several businesses have also initiated blockchain-based projects to help battle the coronavirus. Some of the technological initiatives taken at the start of the pandemic and the most popular use cases on blockchain to help combat the outbreak are listed below.

- Hyperchain, a Chinese blockchain start-up, developed a donation tracking platform called Shanzong [52] to assist governments and healthcare organizations in donating to the infected victims in China. This donation tracking platform helps donors monitor their donations, from medical supplies and money to the distribution and transfer of their donations to areas of need without being changed or modified.
- Acoer, a blockchain start-up in Atlanta, developed a data collection and visualization tool called HashLog [53]. This tool is designed to help the public and healthcare sector track, visualize, and control the outbreak of COVID-19 using the public data obtained from the CDC, WHO, Institute for

Health Metrics and Evaluation (IHME) and The New York Times. HashLog provides real-time coronavirus updates allowing health authorities to take decisions to prevent more infections.
- Spherity, a blockchain start-up in Berlin, developed a decentralized identity system for prescription pickup [54]. Patients can interact with healthcare providers and pharmacies while maintaining their social distance, thus reducing the risk of infection.
- Hashcash Consultants, a global blockchain software firm, has launched the Corona Fund Index Cryptocurrency (CFIX) [55] aimed at making profit even during the bear market caused by the coronavirus. The firm promised to redirect 90% of CFIX-derived trading fees to its Corona Relief fund, which will not only help the traders but also will allow them to collect more funds for those affected by the coronavirus.
- CoreWeave, presently the Euthereum blockchain's largest US miner, has agreed to dedicate thousands of its graphics processing units (GPUs) to coronavirus research [56]. The project leverages the computing capacity of organizations and individuals worldwide to study the role of viral proteins. Thereby, scientists are aiming to obtain a better understanding of how viruses replicate and affect the immune system.
- Xiang Hu Bao [57, 58], a Chinese Insurance Firm, uses blockchain to reduce the risk of infection from face-to-face contact when processing coronavirus claims. When participants make a claim, they provide supporting evidence via the Alipay app, which then passes through an approval review process. The firm incorporates Ant Blockchain, a platform developed by the blockchain team of Ant Financial.
- The Public Health Blockchain Consortium (PHBC) [59] has released a blockchain-based platform designed to track movement of individuals not infected with COVID-19, and VeChain [60] announced the development of a blockchain platform built for monitoring vaccine production in China.

More (COVID-19)-like pandemics are unavoidable. While advancing medical technology may provide weapons for governments to respond and protect their citizens against emerging diseases, they should invest time in seeking new opportunities where blockchain technology can make the most impact in the process. The best thing governments can do is to use this technology as a stepping-stone: *to learn something new and help the world cope with any epidemic positively and, if at all, reasonably fast*.

D. A Decentralized Information Platform Designed to Assist the US and CDC Against the Coronavirus

Currently, there is growing concern about the failure to identify and report COVID-19 cases owing to inadequate surveillance, lack of testing kits, and limited resources for public health [61]. To address these issues, this paper focuses on – a different kind of – blockchain technology, which, as illustrated in Sec. I-C, has demonstrated to be effective in mitigating the impact of the virus. We propose CoviReader as a decentralized healthcare database made to help the country monitor, control, and spread awareness by exchanging data in a fully autonomous manner.

CoviReader will not only allow sharing of information between state and healthcare authorities but will also enable the general public share their symptoms on a public transparent ledger, such as the **`IOTA`** tangle. Hence, sharing this information on a distributed ledger could have substantial benefits for the country. For example, whenever users makes their information accessible on the tangle, all kind of data are re-collected from administrative to medical insights, allowing physicians and medical personnel to focus on what matters most (i.e., providing effective, quality patient care), and states to focus on how the situation progresses.

The system architecture as shown in Fig. 2 integrates the **`IOTA`** tangle, a database, and a mobile application. The architecture is organized into 3 layers: *closed information*, *open information*, and *local/state information*. The initial step for this system is via a personal mobile Point-of-Care (PoC) application. The application will request logging information from users before uploading their data to the tangle, where it is checked and anonymized. The tangle uses an append-only, permanent data structure, as well as a protocol that defines how the members in the network decide to append new data. Copies of the data are then distributed anonymously among the members and only sensitive data is kept in a secure database. To securely store information within a transaction (the data send to the tangle), members need to confirm the transaction before the next transaction is appended to the network. This is done to prevent spam attacks. Finding a trusted transaction, therefore, will require members to solve a "puzzle", a hashing exercise but with considerably less difficulty. This will keep members up-to-date and committed to the increasingly changing information.

Our program implementation addresses two major issues: *contactless inspection* and *digital pass*. To overcome these drawbacks, the system employs **`QR`** code as personal identification cards for users. As such, data identification will no longer be a third party's operation. Instead, by putting a **`QR`** code on a mobile phone, authorities can instantly retrieve data, eliminating the need for pen and paper registrations. This simplifies time and attendance tracking, security access control, and data verification (i.e., **`QR`** code acts as a close contact detector). Without close examination, as long as the residents show their **`QR`** code, the risk of infection can be reduced. Moreover, the **`QR`** code program reads three colors: *green*, *yellow*, *red*, and *blue*. The color *green* is for the general public (i.e., those who have not been yet diagnosed); *yellow* is for individuals returning from infected areas, and who did not contracted the virus but may need to self-isolate; *red* is for patients or individuals under medical observation; and *blue* is for patients who have received a coronavirus drug or a kind of treatment tracker. With these colors, different groups of individuals can be identified to help authorities stay abreast of social activities and develop a full risk assessment model if appropriate.

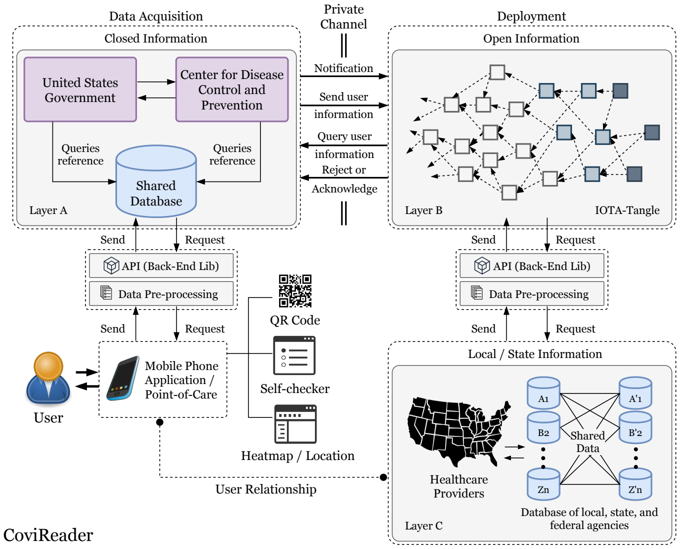

Fig. 2: Proposed decentralized healthcare management system and tracking system for emerging infectious diseases. Illustration of the architecture is organized into 3 layers: *closed information*, *open information*, and *local/state information*.

CoviReader has several goals:

- **User needs** – provide reliable information to the public sector, in real-time.
- **Connectivity** – develop a robust and high-quality online infrastructure for the country, the states, and its citizens.
- **Digital assistance** – demonstrate commitment to helping citizens gain access to trusted digital information.
- **Open standards** – engage in working together to help address, whenever possible, the re-emergence of infectious diseases.
- **Open government** – copies are stored in various locations, thereby avoiding the complete locked down and inaccessibility of any centralized system.
- **Share and learn** – maintain data available to healthcare providers to impede poor health outcomes and high mortality rates linked to the disease.

Ultimately, CoviReader should be ideal for situations where substantial prevention and control of epidemics, data query and analysis, and resources for tracking social activities in the country are critical.

To summarize, our contributions in this paper are as follows:

1. **A national healthcare database.** As a viral infection starts to spread, the country should quickly test people who might have it and quarantine the ones who do. With the strain of COVID-19, testing and contact tracing are crucial because people can transmit the disease before they begin to feel any symptoms. At present, there is no centralized health data in the country [44]. Health data is, instead, scattered across multiple local, state, and federal agencies with little to no integration. The country could improve its coronavirus response by making better use of every state's data. It could then quickly merge each data into a "national healthcare database", providing real-time reports on who was getting sick and where they had traveled to authorities across the nation. The goal is to prevent duplicated work by sharing data via a distributed ledger system. As such, we propose the use of **`IOTA`**. Since data can be collected and maintained in a shared, accessible decentralized database, the states can minimize work by simply sharing information (there will be seamless sharing of information and data). This should reduce or remove problems such as inaccuracy, burdens of data collection, and other challenges which are experienced when systems are fragmented.
2. **Data and surveillance (Not too big a brother).** Governments around the world are monitoring the locations of their resident's smartphones to help enforce mandatory quarantines [62]. In doing so, they know exactly who comes within a few feet of an infected (or potentially infected) individual, thus promoting fear of privacy invasion. On the other side, in the US the safest contingency plan is to stick with extreme social distancing while waiting for (COVID-19) testing capacity to improve [13, 63]. What is needed is to make better use of the data already in the country among its citizens, not just the states. We propose the use of a personal mobile PoC application, together with **`IOTA`**, that non-infected individuals can use to find out whether they have been in the proximity of infected people. Furthermore, when an individual becomes a newly-infected, the application immediately alerts all those who have been near the newly infected person. It is to be noted that sensitive information is stored ("off-chain") in a secured database owned by the US and CDC, and shared anonymously on the **`IOTA`** tangle to ensure privacy among users. To this end, we intent to raise awareness by sharing various advisories on preventive care and travel across the nation.
3. **Self-checker survey.** The mobile application provides citizen with two options. A "self-checker" option to check for symptoms as provided by the government and CDC, and another to learn about the advise subsequently given by the CDC. The first option is kind of a "logbook" with which individuals with suspected COVID-19 symptoms can register their symptoms, allowing the state to monitor the spread of the virus very closely. Note that the validity of this information will depend on physicians and medical personnel, as it is made available on the tangle. Healthcare providers can then query the tangle to gain access to a patient's logbook using the patient's colored **`QR`** code. A patient's **`QR`** code color may change depending on the severity of the case. The second option is for following recommendations on testing and when to contact a medical provider. Finally, the application will suggest nearby hospitals, and visual maps of locations where the number of known infected people is growing. Note that such data, the users' actual locations, are kept anonymous. Only their "approximate" locations are gathered and used to simulate heatmaps that represent the spread of the virus and areas of contagion.

II. Background and Related Work

A. Background

In this section, we briefly present then basic concepts on blockchain and **IOTA**.

Blockchain. A blockchain is database or distributed ledger that maintains an ever growing list of data records or transactions [64, 65]. The database is not centralized in a single location but instead scattered over a network of participants (i.e., computer). Each participant in the network thus stores a complete copy of the database. Hence, the name blockchain comes from the absence of a central authority required to validate a transaction and set rules. Therefore, there is no single point of failure because blockchain is architecturally decentralized. This decentralization is one of the most important principles of blockchain technology. Fig. 3 illustrate a blockchain transaction.

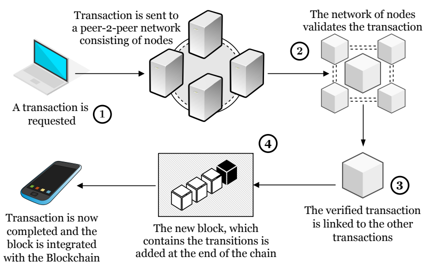

Fig. 3: Illustration of how a blockchain transaction works.

Blockchain can be generally categorized as either public (permissionless) or private (permissioned). For example, when a new block is added to a public blockchain, it is made publicly accessible to everyone. The best-known examples are Bitcoin and Ethereum [66]. Contrary, centralized organizations prefer private blockchains, using the power of the network for their own, and sharing information among themselves.

A blockchain network requires its participants to engage in a block verification process to create consensus. When someone tries to add a transaction to the chain, all participants in the network must validate it. This is conducted by applying an algorithm to the transaction to verify its validity. Here, the meaning of "validity" is determined by the blockchain system, which can vary between systems. Bitcoin, for example, uses Proof of Work (PoW) as its main consensus algorithm for transaction management [67]. It is therefore up to the majority of the participants to decided whether a transaction is legal or not. It is worth noting that – and only – a selected group of participants, called "miners", is responsible for identifying, validating, and adding transaction requests to the chain. These miners are paid with bitcoins and transaction fees as a reward for their work and efforts.

IOTA/IOTA–Tangle. Contrary to blockchain technology, the Internet of Things Application (**IOTA**) [68] is a distributed ledger designed to store and execute transactions between Internet of Things (IoT) devices in a lightweight manner. **IOTA** does not store transactions in blocks. Its structure is instead organized using a directed acyclic graph (DAG) called "tangle". The tangle is a directed graph consisting of transactions connected by edges, a model for storing all kinds of information. Fig. 4 illustrates an example of such graph.

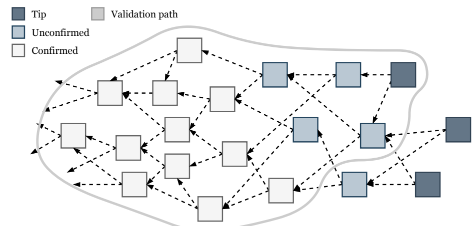

Fig. 4: Illustration of transactions that have been verified (light-gray), are being verified (gray), and are waiting for new transactions (dark-gray).

For every transaction that happens on the network, the transaction has to perform a small amount of computational work (i.e., Proof of Work – PoW) to verify two previous transactions. When a transaction is verified, it is transmitted to the entire network. Here, the verification process for a transaction is different from that of blockchain. The network does not have miners chosen to identify and validate transactions, but rather members operating on it are, in a sense, miners. As such, any member who makes a transaction actively participates in the consensus. No hierarchy of responsibility exists because all members have the same incentives and receive the same rewards, making **IOTA** more decentralized than blockchain.

At the same time, the consensus of valid transactions is not reached by any number of blocks, instead, by applying a weighted random walk [68]. Here, the number of approvers (whether direct or indirect) of the transactions is determined by a "cumulative weight". The higher the approvers number, the higher the cumulative weight. Furthermore, members follow a particular Markov Chain Monte Carlo (MCMC) algorithm [68] to choose the direction to follow in the network. Over time, and for as long as the majority of members follow the same path, by adding more PoW from added transactions, the path becomes secure. As a result, the network is more scalable as it becomes quicker and more stable with time.

B. Related Work

In this section, we briefly review prior work and address relevant techniques.

Alipay Health Code [69]**.** Alipay's system implements blockchain, big data, and **QR** code technology. The application assigns residents a color **QR** code on their phones, with the color correlating to what they can do, allowing them to move around after lock-down. For example, people need to show their **QR** code to get into places such as restaurants, hotels, shopping centers, etc., and only those with a *green* code can be granted access. Anyone with *yellow* or *red* code may be asked to self-isolate or go into state quarantine. This health code, therefore, provides users color-code designations based on their health status and travel history, as well as a **QR** code that authorities can use to identify them.

A person can register directly on the Alipay program to sign up for this system. Users put in their name, national identification number, phone number, and detailed answers to questions about travel history and health status. From there, the government works with a number of big data entities to rate each applicant's status. However, with millions of people emerging from weeks of lock-down in China, their freedom of movement depends largely on phone devices, raising concerns about people's private lives and data – this "health-code system" has become an integral part of the Chinese government.

Apple and Google [70, 71]**.** These companies have announced the introduction of a decentralized COVID-19 tracking application similar to Alipay's Health Code, which instead uses bluetooth signals on mobile devices to identify and alert users that they have been in close contact with an infected person. The mobile application uses short-range bluetooh communication to build a cooperative network of "contact tracing" phones that were at a short distance from each other. However, with user privacy and protection being the key to this application's design, both Apple and Google have refused to record location details or share information with health officials. As such, the main challenge here lies in the reliability of self-reporting and the information of people a person has been in close contact with. For example, individuals who have not been diagnosed may report that they are contagious and therefore set off false alarms. Additionally, the application does not reveal the location where the meeting of infected people took place, making the software of little use by contact-tracing teams due to the strict rules imposed by both companies.

We expand on these ideas and develop a decentralized healthcare management system to help formalize the process of exchanging information of users while given them greater control over their health indicators in the event of an epidemic. To the best of our knowledge, we were one of the first to introduce a scheme at the start of the outbreak in the country that the government, CDC, and states could benefit from, which uses the **`IOTA`** tangle (i) to monitor possible (COVID-19)-like outbreaks, and (ii) to be implemented as a shared healthcare database.

III. **`IOTA`**'s Tangle and **`QR`** Code Solution Against Coronavirus

As there is no suitable design for a healthcare data-exchange solution in the US, we propose a DLT-based healthcare management system that consists of a private shared database and the public **`IOTA`** tangle. The idea is to store significant amounts of medical data there, which can then be accessed from anywhere across the country via a mobile phone in real-time. The tangle is therefore used to record the data submitted to the central database along with the rights to read them and information about users.

Our healthcare network has three classes of groups, each of which belongs to a unique layer:

- **End-users.** Individuals and third parties (i.e., medical personnel) authorized to upload information to the system.
- **Verifiers.** An authorized group responsible for checking the quality and authenticity of data submitted to the tangle.
- **Publishers.** Government agencies responsible for publishing user data in their own "channels", where end-users can subscribe to the latest published data to access it.

A prototype application was introduced as a proof of concept to demonstrate the basic features and the effectiveness of the proposed model supporting different types of users. Both data publishing and data receiving were achieved through the Java-IOTA library using Android Studio on a MacBook Pro with a 8-core intel Core i9 2.6 GHz CPU, a 16 GB of RAM memory, and macOS Catalina 64-bit version operating system.

A. *Data Processing*

The first step is when users upload their data to the shared database, where it is checked and anonymized (i.e., the user's sensitive information is removed). The pseudonymization and anonymization techniques used to obscure data and to re-identify it later, such that is HIPAA[1] compliant, are referred to as "counter" and "triple-coded samples/data" [72]. Personal information is pseudonymized such that it can no longer be **attributed** to a single data user. For example, we replace the format of a variable by a number chosen by a monotonic function: a "seed" is set to some value and is incremented when a new entry is added to the database, making it efficient for extracting values at a record level while protecting users' privacy (i.e., by not directly identifying sensitive information). That is, for any occurrences of $x \in X$ within a database Y where X represents some group, x is replaced by a different pseudonym x'; therefore, $\rho : x \rightarrow x'$ where ρ is the monotonic function.

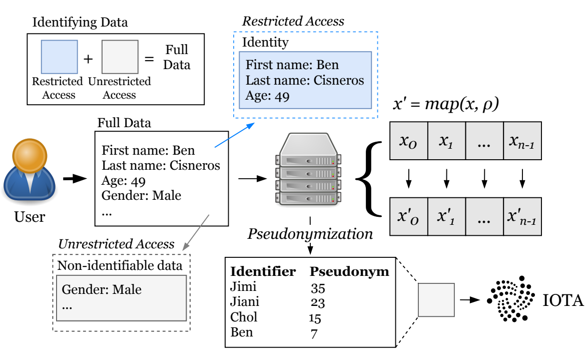

Fig. 5: Each time a user is added to the dabase, its `id` is replaced by the same pseudonym value, which is always mapped to the same collection of "$x' = map(x, \rho)$" in the database.

As illustrated in Fig. 5, the key to the first code (the pseudonym value) is always held by a central, secured protection database. Without knowledge of this key, it is not possible to map the identifiers (names) and pseudonyms. The triple-code samples/data method, on the other hand, requires a "random code" as identifier and a "random barcode". Here, the random code is a transaction (the **`QR`** code) that *uniquely* identifies a user. Then, a user-created `side_key` is used to generate the random barcode (a second **`QR`** code) before going to a medical check-up or treatment, and a restricted MAM

[1] The Health Insurance Portability and Accountability Act of 1996.

mode is used to identify additional information for the duration of a user visit. Therefore, only healthcare providers know the identity (the name) of the individual to whom the respective **QR** codes apply. Consequently, in a data breach scenario, if the data is compromised, the possibility of exposing the identity of the underlying individuals and thereby suffering privacy harm is considerably less.

B. Database Model

FIREBASE is an automatically indexed real-time database where data is stored as JSON objects (i.e., there are no tables or records but trees consisting of n number of nodes). Generally, our data is stored as "shallow" as possible to avoid sub-collections and nesting and is model as "streams" to provide great scalability and prevent large queries. Fig. 6 illustrates a top node named `form` as part of a user document that comprises user `ids` and can be used to query forms on users. Because of this versatility, we integrated an additional user interface for adding and managing content "on the fly" via a headless CMS. For example, if necessary, medical personnel can define multiple groups in the same model (e.g,. adding a group of patients who have been part of a treatment tracker), possibly with inter-group relationships.

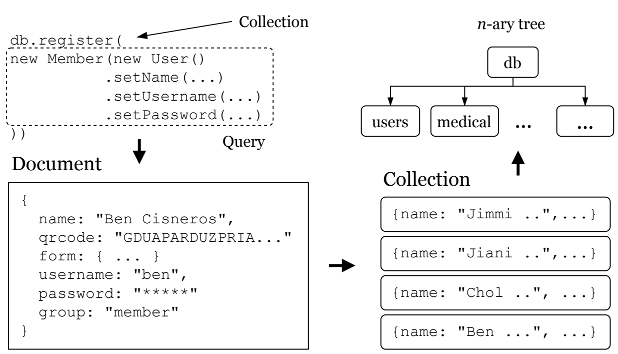

Fig. 6: A simple query and queue data structure used to register users. Users *transactions* are still accessible through their **QR** code, allowing us to loop through medical history without pulling down excess data.

Initially, a "random Unicode string" contains the number of code points specified in the **QR** code, but the code points do not change until after the "hash value of a transaction" is made available (i.e., after the user shares information on the tangle). Fig. 7 illustrates what information might be obtained, processed, and utilized with different functionalities via a personal mobile PoC. The listing, detail, and editing can be used to process data for display while adding or editing users' activities that are then saved into the database. It is worth noting the serialization and deserialization of data sent to and retrieved from the tangle, which might be further encrypted, authenticated, and compressed to support more security needs.

C. Data Transmission

As indicated, the "imaginary operator", the government and CDC, will act as the data controller and allow their users (i.e., individuals, local state, federal agencies, hospitals, etc.)

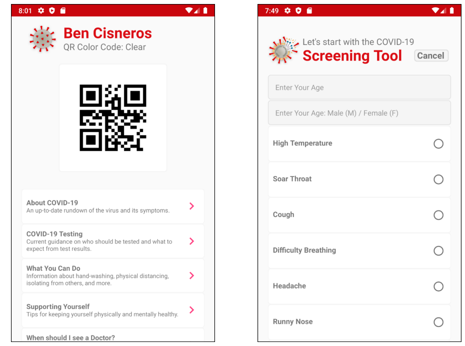

Fig. 7: This data is available in various formats, such as text, URLs, images, and PDFs. This demonstrates the database's ability to handle a range of data.

to register for an account that is stored in their shared database. With that account, users can make use of a set of functions, such as allow linking to other users and organizations, report their health and conditions, etc. The government and CDC can then create various communication links between parties by adding them as neighbors to the list of neighbors nodes before broadcasting a transaction.

In the event of a medical check-up, a physician might submit a request for a preliminary test for a particular patient using the **QR** code of the patient as per his/her diagnosis. If necessary, the patient might share his/her channel keys with the physician (as already mentioned in Sec. III-A) for him/her to request more associated data streams from the tangle. It should be noted that a physician's hospital must be subscribed to the government's and CDC's "private channel" – a *restricted channel* used to monitor the state and access of data – prior to fetching and sharing a patient's information (Fig. 2). Fig. 8 shows a screenshot of a live-demo demonstration of a **QR** code reading.

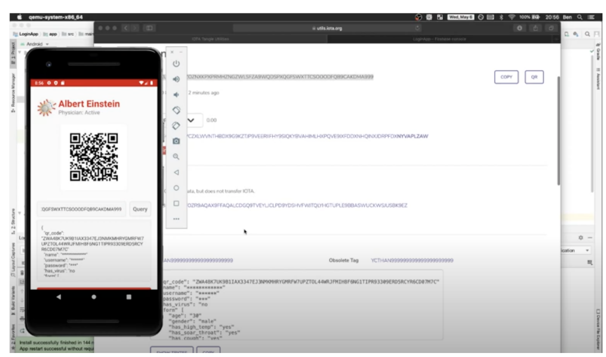

Fig. 8: Whenever a physician (e.g., Albert Einstein) accesses a patient's information, their interaction is logged and added to the user's profile, including timestamps.

Another possible scenario is the case where a user inputs his/her personal health information, including symptoms associated with COVID-19. Once the data is submitted to the tangle, a transaction is created. A node in the network validates the transaction by performing two tasks: (i) a user's authentication by decrypting the key using the **QR** code of the suggested user, and (ii) reliability of data by hashing the transaction data and comparing it with the descrypted message. For example, a valid transaction is broadcasted to (other) nodes in the network. A **verifier** (e.g., a physician) verifies the transaction during a medical treatment or at a testing site. Note that with regard to privacy and encryption, the patient report data and assessment are published in the restricted MAM mode. Therefore, to fetch the data from the tangle, subscribers need to know the address of the channel and an additional decryption key as introduced previously. The decryption key is the `side_key` provided by the government and CDC. Fig. 9 illustrates an example of a patient report data being published over the private channel.

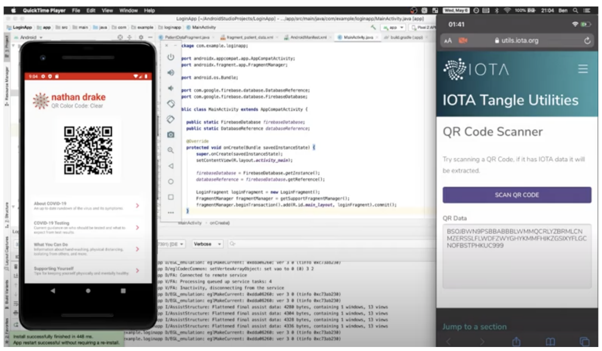

Fig. 9: Subcribers need to know the address and the `side_key` to fetch and decrypt the message.

IV. Conclusion

This paper reported on a healthcare management system that operates in a decentralized way relying on blockchain technology, allowing individuals to (i) share personal health information, and (ii) know when they have been in close contact with an infected person while restricting public access to sensitive information. Because of the ability to share information over the **IOTA** tangle seamlessly – at the push of a button via a personal mobile PoC, the complexity of coordinating a patient's treatment between a team of therapists, practitioners, and specialists can be minimized when the patient receives treatment from multiple healthcare providers. In addition, **IOTA**'s tangle, along with the MAM communication protocol, provides fee-less, stable, and highly scalable data sharing among users. Finally, our model and proposed solution (CoviReader) offers a mechanism for the government and CDC in collaboration with state, local health departments, public health, health care provides, etc., to monitor the development of Covid-19 disease in the US.

References

[1] G. J. Kotwal, "Genetic diversity-independent neutralization of pandemic viruses (eg hiv), potentially pandemic (eg h5n1 strain of influenza) and carcinogenic (eg hbv and hcv) viruses and possible agents of bioterrorism (variola) by enveloped virus neutralizing compounds (evncs)," *Vaccine*, vol. 26, no. 24, pp. 3055–3058, 2008.
[2] J. R. Schäffr, Y. Kawaoka, W. J. Bean, J. Süss, D. Senne, and R. G. Webster, "Origin of the pandemic 1957 h2 influenza a virus and the persistence of its possible progenitors in the avian reservoir," *Virology*, vol. 194, no. 2, pp. 781–788, 1993.
[3] S. Ludwig, L. Stitz, O. Planz, H. Van, W. Fitch, and C. Scholtissek, "European swine virus as a possible source for the next influenza pandemic?" *Virology*, vol. 212, no. 2, pp. 555–561, 1995.
[4] W. Laver and R. Webster, "Studies on the origin of pandemic influenza: Iii. evidence implicating duck and equine influenza viruses as possible progenitors of the hong kong strain of human influenza," *Virology*, vol. 51, no. 2, pp. 383–391, 1973.
[5] J. A. Belser, C. B. Bridges, J. M. Katz, and T. M. Tumpey, "Past, present, and possible future human infection with influenza virus a subtype h7," *Emerging infectious diseases*, vol. 15, no. 6, p. 859, 2009.
[6] Z. Meng, R. Han, Y. Hu, Z. Yuan, S. Jiang, X. Zhang, and J. Xu, "Possible pandemic threat from new reassortment of influenza a (h7n9) virus in china," *Eurosurveillance*, vol. 19, no. 6, p. 20699, 2014.
[7] F. G. Hayden, "Antiviral resistance in influenza viruses—implications for management and pandemic response," *New England Journal of Medicine*, vol. 354, no. 8, pp. 785–788, 2006.
[8] "Bill gates: The next outbreak? we're not ready — ted talk," https://www.ted.com/talks/bill_gates_the_next_outbreak_we_re_not_ready?language=en.
[9] M. F. Gomes, A. P. y Piontti, L. Rossi, D. Chao, I. Longini, M. E. Halloran, and A. Vespignani, "Assessing the international spreading risk associated with the 2014 west african ebola outbreak," *PLoS currents*, vol. 6, 2014.
[10] P. Zhou, X.-L. Yang, X.-G. Wang, B. Hu, L. Zhang, W. Zhang, H.-R. Si, Y. Zhu, B. Li, C.-L. Huang *et al.*, "A pneumonia outbreak associated with a new coronavirus of probable bat origin," *Nature*, vol. 579, no. 7798, pp. 270–273, 2020.
[11] "W.h.o. declares global emergency as wuhan coronavirus spreads - the new york times," https://www.nytimes.com/2020/01/30/health/coronavirus-world-health-organization.html.
[12] "Coronavirus cases top 300,000 worldwide as us becomes one of worst hit," https://www.cnbc.com/2020/03/21/coronavirus-cases-top-300000-worldwide-as-us-becomes-one-of-worst-hit.html.
[13] "New york city region is now an epicenter of the coronavirus pandemic - the new york times," https://www.nytimes.com/2020/03/22/nyregion/Coronavirus-new-York-epicenter.html.
[14] "Cases in u.s. — cdc," https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/cases-in-us.html.
[15] "Coronavirus covid-19 (2019-ncov)," https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6.
[16] "See which states and cities have told residents to stay at home - the new york times," https://www.nytimes.com/interactive/2020/us/coronavirus-stay-at-home-order.html.
[17] "U.s. coronavirus cases and state maps: Tracking cases, deaths - washington post," https://www.washingtonpost.com/graphics/2020/national/coronavirus-us-cases-deaths/.
[18] C.-C. Lai, T.-P. Shih, W.-C. Ko, H.-J. Tang, and P.-R. Hsueh, "Severe acute respiratory syndrome coronavirus 2 (sars-cov-2) and corona virus disease-2019 (covid-19): the epidemic and the challenges," *International journal of antimicrobial agents*, p. 105924, 2020.
[19] O. Coronavirus, "The world economy at risk," *OECD Economic Outlook, Interim Report March*, 2020.
[20] "Tackling the coronavirus (covid-19) crisis together: Oecd policy contributions for co-ordinated action," https://www.oecd.org/coronavirus/en/.
[21] "Coronavirus live updates: Protests to reopen states spread in the u.s., trump defends protesters - the washington post," https://www.washingtonpost.com/world/2020/04/20/coronavirus-latest-news/.
[22] "Coronavirus has crippled global protest movements — quartz," https://qz.com/1828468/coronavirus-has-crippled-global-protest-movements/.
[23] "Coronavirus: Ukraine protesters attack buses carrying china evacuees - bbc news," https://www.bbc.com/news/world-europe-51581805.
[24] "Coronavirus live updates: Updates from spain, italy, russia and around the world - cnn," https://www.cnn.com/world/live-news/coronavirus-pandemic-04-20-20-intl/index.html.
[25] "Global economic effects of covid-19," https://fas.org/sgp/crs/row/R46270.pdf.
[26] "ditcinf2020d1.pdf," https://unctad.org/en/PublicationsLibrary/ditcinf2020d1.pdf.
[27] "Nearly 25 million jobs could be lost globally due to the coronavirus," https://www.cnbc.com/2020/03/19/nearly-25-million-jobs-could-be-lost-globally-due-to-the-coronavirus.html.
[28] "U.s. now has 22 million unemployed as economy sinks toward depression-like scenario - the washington post," https://www.washingtonpost.com/business/2020/04/16/unemployment-claims-coronavirus/.

[29] "Senate approves $2 trillion stimulus after bipartisan deal - the new york times," https://www.nytimes.com/2020/03/25/us/politics/coronavirus-senate-deal.html.
[30] "Coronavirus crisis: Part-time workers struggle to get unemployment," https://www.usatoday.com/story/money/2020/04/17/coronavirus-crisis-part-time-workers-struggle-get-unemployment/2964894001/.
[31] "Trump gives governors options on how to reopen the economy - abc news," https://abcnews.go.com/Business/wireStory/trump-governors-options-reopen-economy-70202488.
[32] W. H. Organization *et al.*, "Coronavirus disease 2019 (covid-19): situation report, 72," 2020.
[33] N. Ferguson, D. Laydon, G. Nedjati Gilani, N. Imai, K. Ainslie, M. Baguelin, S. Bhatia, A. Boonyasiri, Z. Cucunuba Perez, G. Cuomo-Dannenburg *et al.*, "Report 9: Impact of non-pharmaceutical interventions (npis) to reduce covid19 mortality and healthcare demand," 2020.
[34] J. G. Adams and R. M. Walls, "Supporting the health care workforce during the covid-19 global epidemic," *JAMA*, 2020.
[35] Z. D. Berger, N. G. Evans, A. L. Phelan, and R. D. Silverman, "Covid-19: control measures must be equitable and inclusive," 2020.
[36] T. P. Mashamba-Thompson and E. D. Crayton, "Blockchain and artificial intelligence technology for novel coronavirus disease-19 self-testing," 2020.
[37] U. W. Chohan, "The coronavirus lesson: Do cryptocurrencies offer a counter-cyclical hedge?" 2020.
[38] Y. Huang, C. Lin, P. Wang, and Z. Xu, "Saving china from the coronavirus and economic meltdown: Experiences and lessons," *Available at SSRN 3570696*, 2020.
[39] M. Torky and A. E. Hassanien, "Covid-19 blockchain framework: Innovative approach," *arXiv preprint arXiv:2004.06081*, 2020.
[40] N. Webb, "A fork in the blockchain: Income tax and the bitcoin/bitcoin cash hard fork," *North Carolina Journal of Law & Technology*, vol. 19, no. 4, p. 283, 2018.
[41] N. Fulmer, "Exploring the legal issues of blockchain applications," *Akron L. Rev.*, vol. 52, p. 161, 2018.
[42] J. Michael, A. Cohn, and J. R. Butcher, "Blockchain technology," *The Journal*, vol. 1, no. 7, 2018.
[43] A. Ojo and S. Adebayo, "Blockchain as a next generation government information infrastructure: a review of initiatives in d5 countries," in *Government 3.0–Next Generation Government Technology Infrastructure and Services*. Springer, 2017, pp. 283–298.
[44] "Using digital technologies in precision public health: Covid-19 and beyond — — blogs — cdc," https://blogs.cdc.gov/genomics/2020/04/06/using-digital/.
[45] "China: Blockchain deployment rises amid coronavirus outbreak," https://cointelegraph.com/news/china-blockchain-deployment-rises-amid-coronavirus-outbreak.
[46] "China looks to become blockchain world leader with xi jinping backing," https://www.cnbc.com/2019/12/16/china-looks-to-become-blockchain-world-leader-with-xi-jinping-backing.html.
[47] "China start-up launches blockchain-based platform to improve donation efficiency amid virus crisis — south china morning post," https://www.scmp.com/tech/blockchain/article/3050461/china-start-launches-blockchain-based-platform-improve-donation.
[48] "Coronavirus: Ant financial funds financial aid via blockchain app, government promotes mobile payments - ledger insights - enterprise blockchain," https://www.ledgerinsights.com/coronavirus-blockchain-ant-financial-aid-xiang-hu-bao/.
[49] "President xi says china should 'seize opportunity' to adopt blockchain - coindesk," https://www.coindesk.com/president-xi-says-china-should-seize-opportunity-to-adopt-blockchain.
[50] "Mipasa project and ibm blockchain team on open data platform to support covid-19 response - blockchain pulse: Ibm blockchain blog," https://www.ibm.com/blogs/blockchain/2020/03/mipasa-project-and-ibm-blockchain-team-on-open-data-platform-to-support-covid-19-response/.
[51] "What is mipasa - mipasa," https://mipasa.org/about/.
[52] "China start-up launches blockchain-based platform to improve donation efficiency amid virus crisis — south china morning post," https://www.scmp.com/tech/blockchain/article/3050461/china-start-launches-blockchain-based-platform-improve-donation.
[53] "Acoer — coronavirus (covid-19) tracker," https://www.acoer.com/coronavirus.
[54] "German startup pitches decentralized id for prescription pickup during covid-19 - coindesk," https://www.coindesk.com/german-startup-pitches-decentralized-id-for-prescription-pickup-during-covid-19.
[55] "Hashcash consultants to launch 'corona fund index cryptocurrency'," https://cointelegraph.com/news/hashcash-consultants-to-launch-corona-fund-index-cryptocurrency.
[56] "Thousands of crypto miners now working on coronavirus research," https://www.coindesk.com/thousands-of-these-computers-were-mining-cryptocurrency-now-theyre-working-on-coronavirus-research.
[57] "Insurance service providers rely on blockchain to fast track claims payout amid coronavirus outbreak — south china morning post," https://www.scmp.com/business/companies/article/3049479/insurance-service-providers-rely-blockchain-fast-track-claims.
[58] "Ant financial," https://www.antfin.com/index.htm?locale=en_US.
[59] "Phbc - public health blockchain consortium," https://www.phbconsortium.org/.
[60] "Vechain announces blockchain vaccine tracing solution for china — nasdaq," https://www.nasdaq.com/articles/vechain-announces-blockchain-vaccine-tracing-solution-china-2018-08-16.
[61] "The lost month: How a failure to test blinded the u.s. to covid-19 - the new york times," https://www.nytimes.com/2020/03/28/us/testing-coronavirus-pandemic.html.
[62] "As coronavirus surveillance escalates, personal privacy plummets - the new york times," https://www.nytimes.com/2020/03/23/technology/coronavirus-surveillance-tracking-privacy.html.
[63] "Coronavirus: White house concedes us lacks enough test kits - bbc news," https://www.bbc.com/news/world-us-canada-51761435.
[64] M. Crosby, P. Pattanayak, S. Verma, V. Kalyanaraman *et al.*, "Blockchain technology: Beyond bitcoin," *Applied Innovation*, vol. 2, no. 6-10, p. 71, 2016.
[65] Z. Zheng, S. Xie, H.-N. Dai, X. Chen, and H. Wang, "Blockchain challenges and opportunities: A survey," *International Journal of Web and Grid Services*, vol. 14, no. 4, pp. 352–375, 2018.
[66] W. Chan and A. Olmsted, "Ethereum transaction graph analysis," in *2017 12th International Conference for Internet Technology and Secured Transactions (ICITST)*. IEEE, 2017, pp. 498–500.
[67] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," Manubot, Tech. Rep., 2019.
[68] S. Popov, "The tangle," *cit. on*, p. 131, 2016.
[69] "In coronavirus fight, china gives citizens a color code, with red flags - the new york times," https://www.nytimes.com/2020/03/01/business/china-coronavirus-surveillance.html.
[70] "Apple, google update coronavirus tracking tech to address privacy concerns - cnet," https://www.cnet.com/news/apple-google-update-coronavirus-tracking-tech-to-address-privacy-concerns/.
[71] "Privacy-preserving contact tracing - apple and google," https://www.apple.com/covid19/contacttracing.
[72] K.-H. Shriever and M. Schröder, *G3P - Good Privacy Protection Practice in Clinical Research : Principles of Pseudonymization and Anonymization*. Berlin/Boston: De Gruyter, 2014.