

BLOCKCHAIN APPLICATIONS FOR COVID-19—A SURVEY

Kanwal Zahoor^{1,*}, Narmeen Zakaria Bawany² and Anum Hameed³

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Abstract

The COVID-19 has changed the way technology has been perceived and adapted. It has revealed the potential of technology in overcoming the challenges caused by this pandemic. COVID-19 has disturbed all essential activities especially education, business, healthcare, etc. People were forced to employ technology to carry out their day-to-day tasks like grocery shopping, education, business, healthcare etc. Various computing technologies such as Internet of Things (IoT), big data, Artificial Intelligence (AI) and Blockchain are being widely adopted to help track the outbreak of pandemic, enforce restrictive measures, ensure availability of medical equipments, develop, and test vaccine. Blockchain is among these technologies that can be used as a potential problem solver to overcome numerous challenges. It has various key features, such as immutability, decentralization, and transparency, that can be utilized to benefit different sectors affected by the COVID-19 pandemic. This research aims to present COVID-19 applications that are based on blockchain technology. Further, we have illustrated the applicability of blockchain technology in various fields like healthcare, education, government, finance, etc. We have also discussed a comparison of blockchain-based applications. Features and benefits of these applications are discussed along with the challenges associated with the adoption of blockchain-based COVID-19 applications.

Keywords: Blockchain, COVID-19, ethereum, hyperledger, social distancing, healthcare

Introduction

In the year 2020, people all across the world witnessed a deadly and transmittable respiratory disease caused by a virus called Coronavirus or COVID-19. This novel virus was initially reported in Wuhan, China in December 2019. However, the actual outbreak of this virus in the entire world occurred in the year 2020. World Health Organization (WHO) declared the virus as a world pandemic in a short time of this outbreak (WHO, 2020). This virus spreaded rapidly and affected almost everyone across the world. As of March

2021, worldwide 119 million cases were reported, as shown in Figure 1.

The coronavirus is a severe virus that targets the respiratory systems of the patient and is transmitted rapidly. As there is no cure and vaccine is also in the initial stage for this particular virus, hence only social distancing can prevent this virus from further spreading. With the initial outbreak, countries immediately imposed lockdowns, travel bans, international restrictions in trade, and border crossings. Strict measures for imposing social

Center for Computing Research, Department of Computer Science and Software Engineering, Jinnah University for Women, 5-C Nazimabad, Karachi, Pakistan. E-mail: kanwal.zahoor@juw.edu.pk

* Corresponding author

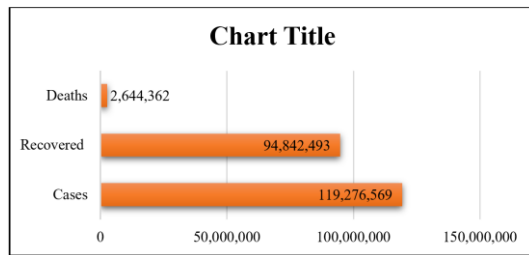


Figure 1. Number of Total COVID-19 Cases

distancing were taken. Due to lockdowns and social distancing, many major activities were called off worldwide to reduce the spread of this aerosol transmitted virus. However, these sudden actions were unanticipated for the general public which resulted in social anxiety leading to depression and emotional breakdown among people. Moreover, the maintenance of social distancing among people has become a major challenge for governments. For social distancing, the first measure taken was imposing lockdowns in many countries. Due to these lockdowns, businesses, charity processes, food supplies, education, medical supplies, and tourism were immensely affected and had directly imposed a negative impact on the economy of almost every country in the world (Qamar and Zakaria Bawany, 2021). With the help of state-of-the-art technologies, new ways are opening up to cope up with difficulties caused due to this pandemic and bring human lives back again to normal.

Hence, technology advancements can be considered as one of the key strengths of this era to overcome the challenges raised due to the COVID-19 pandemic. In this regard, many researches have been utilizing innovative technologies such as Cloud Computing, blockchain, Machine learning, Internet of Things, 5G Technology etc. In order to reduce the severity of the challenges faced by the world.

Among these new innovative technologies, in the past decade, blockchain technology has emerged as a powerful technology that has helped to revolutionize various industries. The industries including finance, supply chain, education, e-government, and the healthcare sectors were greatly affected by this pandemic. Therefore, blockchain technology can be a great help in resolving the problems caused by COVID 19 in these fields.

Blockchain technology provides a decentralized architecture with different built-in features such as transparency, tamperproof transactions, automation, etc. Once data is validated and verified on the block, tampering or modifying the record becomes

impossible. In tackling the ongoing pandemic crisis blockchain technology has various use cases that if used could be a great help. Blockchain can be useful in simplifying the clinical trial process of drugs and vaccines that are being conducted in many countries, for raising awareness in public, providing transparency in fund-raising and donation processes, providing a contactless delivery mechanism, and acting as an authentic way of tracking data.

In this COVID 19 pandemic scenario, this is essential to build the above-mentioned use cases using the blockchain platform, because many of the traditionally implemented solutions are prone to cybercriminal activities especially hacking. It must be noted that the implementation of a blockchain network to monitor COVID-19 transmission is necessary, as many of the solutions currently being built are vulnerable to hacking and cyber-criminals. Table 1 illustrates the advantages of adopting a blockchain-based system over a conventional centralized solution in a number of ways, including data handling, quality assurance, fault tolerance, etc.

Table 1. Features of blockchain

S. No.	Features	Description
1	Time Stamped	With each block in a blockchain, the time and date are attached.
2	Decentralized	Blocks are distributed, decentralized, and each block has multiple copies placed in several locations.
3	Transparency	Every transaction on the blockchain is visible.
4	Security	Blockchain offers advanced security features such as authentication, confidentiality and integrity.
5	Consensus Mechanism	Achieving agreement on the state of a distributed system (de Oliveira <i>et al.</i> , 2020).
6	Security	Every transaction is highly secured.
7	Immutable	Data, once stored, cannot be update or delete.

For example, according to the World Economic Forum, coronavirus maps are being used by cybercriminals for spreading malwares (Tangermann, 2020). The criminals do this by impersonating interactive maps that are used for tracking virus spread. This is done for tricking users to give their confidential information such as usernames, passwords, and credit card details. This data is then sold on the deep web by these cybercriminals. They use this data to exploit people financially. Also, some cybercriminals use fake mobile apps to gather personal data and then use this

data for trapping people into paying ransoms for not leaking their social-media details (Villas-Boas, 2020). Moreover, much chaos and fear have been created among people by spreading misleading and fake information. Therefore, the blockchain platform can be used for eliminating these issues. The main objective of this research is to review existing proposed solutions that use blockchain technology for COVID-19.

The paper is structured as follows. Section 2 discusses blockchain and its applications. Section 3 highlights the COVID-19 and its challenges. Section 4 discusses the blockchain-based applications in combating the COVID-19 outbreak and the use cases and requirements of those applications. Section 5 discusses the challenges of blockchain, limitation and future scope and Section 6 concludes the paper.

Fundamentals of Blockchain Technology

Blockchain is a decentralized and distributed public digital ledger. It does not have any central authority, and transactions are recorded and spread out on a peer-to-peer network of computers referred to as nodes, thus creating a distributed environment with no central point of failure. The nodes in the blockchain network work together to record new transactions in it. These transactions are added in bundles known as blocks. Whenever a new block is added, it is linked with the previous block sequentially, resulting in a blockchain. Each block contains its own transaction data and cryptographic hash function of its predecessor block. Blockchain enables every user to access the complete history of transactions ever made on the open ledger. In a nutshell, blockchain is nothing more than a merely distributed database that provides an unalterable public record of digital transactions (Nofer *et al.*, 2017). Key features of blockchain and its applications are summarized in Tables 1 and 2 respectively.

Covid-19

The COVID-19 has spread like wildfire throughout the world, marking its presence in 213 countries (Sharma and Bahl, 2020). This illness has mild symptoms for most of the people who are affected by this virus however, it can be fatal for people with old age and also for people with underlying medical complications. Below, we have discussed briefly the major challenges caused by COVID-19 and safety precautions that can slow down the transmission intensity of this virus.

As discussed earlier, the outbreak of this virus has resulted in medical and economical challenges worldwide. Some of the most prominent challenges are listed in Table 3.

Blockchain-Based Applications for Covid-19

This section provides a comprehensive survey of blockchain applications that can support many use cases for COVID-19. Blockchain technology can facilitate to overcome the above-mentioned challenges, such as Contact Tracing, Contactless delivery, Online Education, Donation Tracking, Supply Chain, Telehealth, Food and Agriculture, and E-government as shown in Table 4. Afterward, this section provides a comparison of blockchain applications developed for the listed sectors. A number of applications have been developed using blockchain technology.

Table 2. Blockchain applications

S. No.	Sector	Applications
1	Healthcare	MedRec (Azaria <i>et al.</i> , 2016), Healthbank blockchain (Mettler and Hsg, 2016), DApps, HIPAA (Zhang <i>et al.</i> , 2017), Electronic Medical Records (EMR) (Zhang and Poslad, 2018)
2	Finance	Value Added Tax (Alkhodre <i>et al.</i> , 2019), FinTech (Lee, 2017), Corda (Khan <i>et al.</i> , 2017)
3	Education	Examination Review (Mitchell <i>et al.</i> , 2019), MOOC (Chen <i>et al.</i> , 2018), Trusted certification of learning results (Sun <i>et al.</i> , 2018)
4	Supply chain	Agri-food supply chain (Tian, 2016), Echchain, ElectricChain, and Suncontract (Futurethinkers, 2017)
5	Government	E-voting (Koç <i>et al.</i> , 2018), Value Registry (Alketbi <i>et al.</i> , 2018)
6	Agriculture and Food	E-agriculture (Li <i>et al.</i> , 2020), Agricultural Insurance, Smart Agriculture, Food Supply chain (Xiong <i>et al.</i> , 2020), Food Tracking (Galvez <i>et al.</i> , 2018)

Table 3. COVID-19 Challenges

S. No.	Challenges
1	Maintaining social distancing
2	Financial and economical challenges
3	Shortage of food and basic necessities
4	Continuing of education
5	Conducting governmental activities
6	Remote Patient Monitoring
7	Operations and supply chain disruption

Table 4. Blockchain applications

S. No.	Use Case	Applications
1	Contact Tracing	Public Health blockchain Consortium (Marbough <i>et al.</i> , 2020; Sharma and Bahl, 2020), Blockchain Network (Valente Klaine <i>et al.</i> , 2020), Beep Trace (Xu <i>et al.</i> , 2020), Mass surveillance system (Torky and Hassanien, 2020)
2	Contactless Delivery	Blockchain-powered UAVs and robots, Aerial Vehicles (Jayaraman <i>et al.</i> , 2020; Kalla <i>et al.</i> , 2020; Sharma and Bahl, 2020), End to End delivery (Alsamhi <i>et al.</i> , 2020)
3	Education	E-learning (Humayun, 2020), BDoTs (Shukla <i>et al.</i> , 2020)
4	Donation Tracking	Binance charity (Nguyen <i>et al.</i> , 2021), Give Track, Givecrypto.org (Wu and Zhu, 2020)
5	Supply Chain	Rapid Supplier Connect (Khurshid, 2020), Value Chain (Nandi <i>et al.</i> , 2021)
6	Telehealth	mHealth (Mashamba-Thompson and Crayton, 2020), Trace Together, LetsBeat (Mobile Apps) (Alam and Benaïda, 2022), Hashlog (Rimsan <i>et al.</i> , 2020), Med Credits, Medical chain (Ahmad <i>et al.</i> , 2021), Civitas, Mipasa (Chamola <i>et al.</i> , 2020)
7	Food and Agriculture	Traceability and food authentication, Smart Farming (Lin <i>et al.</i> , 2020), Robotic Agriculture (Di Vaio <i>et al.</i> , 2020)
8	E-government	Digital voting, Digital identity, E-Pass (Gupta and Kumar, 2018), Digital Passports and immunity certificates (Kalla <i>et al.</i> , 2020)

Table 5. Comparisons of contact tracing applications

Authors	Contact Tracing Applications	Blockchain Type	Features						
			Systematic tracking	Continuous and adequate monitoring	Pseudo identity sharing	Contact list sharing	Immediate notification	Proposed	Implemented
Marbough <i>et al.</i> (2020); Sharma and Bahl (2020)	Public Health blockchain Consortium (PHBC)	✓	✓	✓	-	-	-	-	✓
Valente Klaine <i>et al.</i> (2020)	Blockchain Network	-	✓	✓	✓	✓	✓	✓	-
Xu <i>et al.</i> (2020)	Beep Trace	✓	✓	-	✓	-	✓	✓	-
Torky and Hassanien (2020)	Mass-Surveillance System	✓	✓	✓	-	-	✓	✓	-

Blockchain Solution for Contact Tracing

The major problem faced in this pandemic is tracing people who came into contact with a COVID-19 infected person. Contact Tracing helps to avoid the spread of a virus by pro-actively detecting and quarantine people who came into contact with an infected person. Using contact tracing applications different governments are launching smartphone apps to monitor COVID-19 patients. However, contact tracing methods are never completed without taking personal data device protection and privacy measures into account. Since the application of the users communicates information from and to the control server, the privacy and security of collected data become a major concern. Therefore, providing data security and a trustable mode of data transfer, the blockchain platform can be used instead of a traditional

approach. In this section, we have explained some of the leading contact tracing applications developed by using blockchain technology. Table 5 shows the comparisons of different contact tracing proposed or implemented applications for COVID-19.

Public Health Blockchain Consortium (PHBC)

The Public Health blockchain Consortium (PHBC) is a blockchain-based framework developed on Ethereum (Putzger, 2020). This solution provides systematic and continuous monitoring of virus-free areas and communities. It provides continuous and effective monitoring of an uninfected person to ensure that the unaffected person does not leave the safe zones and if the person returns from a virus-affected area, it helps to restrict their return to the safe zones by generating alerts (Joshi, 2020).

Blockchain Network (BCN)

Blockchain Network is a proposed mechanism developed on Ethereum. The purpose of this mechanism is to identify and verify that a person has come in contact with a COVID infected patient or not using data available on BCN. In BCN any infected person can share his/her contact details by initiating a transaction and then the transaction is broadcast and validated all over the network. Other users can simply check their coronavirus statuses by querying the blockchain via a query transaction after publishing the contact details in the BCN successfully. It uses any existing blockchain tracing mechanism to preserve the privacy of the contacts (Valente Klaine *et al.*, 2020).

Beep Trace

It is a mobile application that provides a pseudo-identity for Covid infected users. In this solution, Healthcare professionals note the information of a COVID infected person on the blockchain using an anonymous ID, and that user is traced for last 14 days of the entry in the blockchain i.e. this framework only records tracing information for 14 days. Any other user who has been contacted during this period will receive a notification. This app uses GPS to track users' movement and upload their data on the blockchain (Xu *et al.*, 2020).

Mass Surveillance System

Mass-Surveillance System is a proposed framework developed on Ethereum for detection and tracking of possibly unidentified infected individuals and places. This framework utilizes time stamping, decentralized storage, and peer-to-peer benefits of blockchain for developing a novel system for verification and detection of unidentified COVID 19 infected individuals. Furthermore, it will enable people for predicting the infection risk within communities or public areas by sending notifications immediately through a mobile app (Torky and Hassanien, 2020).

Blockchain Solution for Contactless Delivery

Contactless delivery is a type way of delivery without any personal interaction. In contactless delivery, the product is simply delivered at people's doorstep without personal contact. To stop the spread of coronavirus, contactless delivery is widely being used for delivering essentials, mostly foods and medicines, to the people in quarantine. However, there is no way to get any receiving's on the delivered goods (Jayaraman *et al.*, 2020). While this probably avoid the virus, it might increase the potential of frauds due to the suspension of receipt confirmation through signature and absence of personal data verification. In order to solve this issue, there are a few solutions proposed in which digital biometric verification through blockchain is used. Apart from this, systems using Blockchain-based robots and unmanned vehicles have also been proposed for providing contactless delivery. All these systems utilize data stored on the blockchain. Below we have discussed existing solutions that have been proposed and/or implemented for contactless delivery using blockchain for avoiding frauds. Table 6 shows that the comparisons of contact delivery applications.

Digital Biometric Verification using Blockchain

This framework works by utilizing the digital biometric information submitted by the customers upon order that is stored using blockchain technology. When the service provider personnel reaches the given destination, they ping the customer from a mobile identity verification and product acceptance (Putzger, 2020).

Unmanned Aerial Vehicles (UAV) and Robots

are implemented solutions that are used for automatic surveillance and contactless delivery. Without human interaction, Blockchain-powered UAVs and robots can be an effective way for

Table 6. Comparisons of contactless delivery applications

Author	Contactless delivery Applications	Blockchain type	Features				
			Automated surveillance	Foods and medicine delivery	Delivery status	Proposed	Implemented
Putzger (2020)	Digital Biometric Verification using Blockchain	✓	✓	✓	✓	-	✓
Kalla <i>et al.</i> (2020)	UAVs and robots	✓	✓	-	✓	-	✓
Jayaraman <i>et al.</i> (2020)	Aerial vehicles	✓	-	✓	-	-	✓
Alsamhi <i>et al.</i> (2020)	E2E delivery system	✓	-	✓	✓	✓	-

supplying goods to the infected areas (Xiong *et al.*, 2020). Blockchain technology in these systems is used to trace and track the aerial vehicles and robot's location. Also, it includes consumer verification which makes the performance of these systems trustable, transparent, and accountable (Xu *et al.*, 2020).

End to End Delivery (E2E)

End to End delivery (E2E) is a two-fold proposed system; 1) Quarantine E2E delivery system and Hospital E2E delivery system. In these systems, goods are delivered to customers using robots based on blockchain encrypt data (including robot IDs, locations, path-details, receivers' information) (Torky and Hassanien, 2020).

Blockchain Solution for Online Education

Many countries closed their schools, colleges, and universities due to pandemic for an extended period. In this ongoing situation, the loss of education is the worst loss for a nation. So, online education is one of the best solutions. However, online education is not well established and faces several challenges. Tradition online learning management systems and online classrooms are being used worldwide for this purpose. But these systems are highly prone to cyber-attacks and cybercriminal activities. For instance, a popular cloud platform, Zoom (Communications, 2016) that has widely been used for online classes has been targeted by hackers, due to lack of security. According to a cyber intelligence firm, hundreds of zoom verified account were hacked by cybercriminals stealing users' login information and other important data. Therefore in order to avoid these cyber-criminal activities, different approaches have been proposed using blockchain technology to provide a secure and trustworthy environment to the users. Table 7 shows the comparison of online education applications.

E-Learning (EL)

This framework is a proposed mechanism that is developed using Ethereum. It provides a secure and transparent solution for EL-environment by securing the learning environment through cryptography. In this regard, proof of identity is used for user authentication. This framework provides an interactive environment for students as well as instructors. It is a five-layer framework. The first layer is the cloud layer that works as a hosting layer. The second layer is the most important; it is a blockchain layer that serves as a secure platform between EL application and the cloud. The third layer is the EL framework that acts as a portal from which users and administrators access the course data. The fourth layer contains primary users of the system, which is comprised of teachers, students, and educational institutions. And the fifth layer is education milestones where students are provided certification and/or points upon completion (Humayun, 2020).

BDoTs: BC-based Online Teaching

This application is the second online proposed solution which is also based on Ethereum. This system also has three layers. First is the instructor layer, the second layer is the middle layer, and the third layer is the student layer. On the first step, instructor needs to register by providing their details; after that, they have to upload their course information. It should be well structured and easy to understand for every student. The middle layer is the vital layer that is based on blockchain technology. In this layer, the data is stored using blockchain technology. Blockchain provides a decentralized way without any bottleneck, and peers can fetch the data with the help of a distributed hash table. The third and the last layer is the student layer, in which students initially perform registration by providing the necessary details. It also uses smart contracts for necessary payments (Shukla *et al.*, 2020).

Table 7. Comparisons of online education applications

Authors	Online Education Applications	Blockchain type Ethereum	Features						
			Online interactive learning Environment	Student registration	Instructor registration	Peer evaluation	Certificate of completion	Proposed	Implemented
Humayun (2020)	E-learning	✓	✓	✓	-	-	✓	✓	-
Shukla <i>et al.</i> (2020)	BDoTs	✓	✓	✓	✓	✓	-	✓	-

Blockchain Solution for Donation Tracking

Due to lockdowns, resulted by this pandemic many people lost their jobs and faced major losses in their businesses. Therefore, the financial crisis faced by people required the best of humanity to overcome. In this regard, many individuals, as well as local and government organizations, played an important role in providing financial assistance to people who were in immense need. However, many charitable organizations lacked transparency and security which resulted in frauds and misuse of the donated fund that cause a negative impact on the willingness of the people to donate. Therefore, in order to resolve the fraud issues that occurred during donation distributions, blockchain-based systems were introduced. By using these systems several donors have contributed goods and financial help to ease the difficulties of people in need. In these systems, the data involved in the entire donation process which consists of warehousing, logistics, and delivery data has been stored using blockchain. It allows the donors to transparently check the distribution process and transactions of their donated funds. This will remove the intermediaries, save costs, eliminate the misuse of contributions, and improve social stability (Chang and Park, 2020). Table 8 shows that the comparison of donation tracking applications

Binance Charity

It is a Blockchain-based application. It is an implemented Ethereum solution to seek a donation. With this application, people have donated multiple different gears in hospitals and monetary donations during this pandemic to needy people. This application allows people to track their donations in order to determine whether their donations have reached the targeted audience or not.

Give Crypto

Give Crypto is a mobile application which implemented on Ethereum. This is a non-profit application for charities with real-time security and financial transparency. In this application, blockchain allows donors to trace the transaction publicly in real-time and donors can also ensure that their charity has reached the final destination (Shin *et al.*, 2020). Moreover, Give Track is a non-profit website for accepting donations and sharing those donations to people who are in need.

Blockchain Solutions for Supply Chain

The COVID-19 epidemic has affected major distractions across supply chains worldwide. Various factories are closed due to safety precautions and there is an unprecedented demand for various goods, especially PPE and medical supplies. However, Traditional supply chain systems, due

Table 8. Comparison of donation tracking applications

Authors	Donation Tracking Applications	Blockchain type		Features				
		Ethereum	Crypto currency BTC	Monetary donation	Donation of protective gear	Monitor progress donation	Proposed	Implemented
Nguyen <i>et al.</i> (2020)	Binance charity	✓	✓	✓	✓	✓	-	✓
Wu and Zhu (2020)	Give Track	✓	✓	✓	-	✓	-	✓
Wu and Zhu (2020)	GiveCrypto.org	✓	✓	✓	-	✓	-	✓

Table 9. Comparison of supply chain applications

Authors	Supply chain Applications	Blockchain type	Features				
			Tracking medical supplies	Help to find vendors	End-to-End digital supply chains	Proposed	Implemented
Khurshid (2020)	Rapid Supplier Connect	✓	✓	✓	✓	-	✓
Nandi <i>et al.</i> (2021)	Vechain	✓	✓	-	✓	-	✓

to conflicting records, extensive paperwork, and delays that resulted from manual settlement procedures that involved various documents exchanges between various parties, have become data-intensive, inefficient, and costly. In the past few years blockchain has played a vital role in revolutionizing traditional supply chain management systems. This technology provides substantial advantages in this situation, that include auditable and secure transaction validations, document automation for supporting legal and customs agreements improved end-to-end transparency. Comparisons of blockchain applications for the supply chain are shown in Table 9.

Rapid Supplier Connect

Rapid Supplier Connect is a proposed mechanism that is developed on Ethereum. This application helps medical supply chains during the COVID-19 pandemic and offered it to health systems and government agencies to help find suppliers for medical supplies and PPE. Blockchain provides authentic information about the supplier and reduces the risk of fake information while facilitating and connecting the suppliers between the buyers or distributors. Through this application, the tracking of medical supplies is easily managed.

Vechain Platform

This application ensures and tracks protective gears like KN95 or N95 mask is authentic and reliable. Vechain saves all information about masks on the Vechain blockchain. It traces all information like product ownership and production place to ensure the mask are legal and as well as logistics points along the supply chain.

Blockchain Solutions for Telehealth

The restriction of social distancing and the shortage of effective treatments have made Telehealth solutions the safest interactive system between patients (uninfected/infected) and doctors. However, Telehealth systems are centralized and do not provide privacy and security to the important information, operational health records, transparency, traceability, and immutability, in order to identify frauds associated to patients' insurance rights and physician credentials. However, Blockchain technology can play an important role and securely provide the necessary information. It stores time-stamped data on the ledger and provides secure patient history, moreover, the data cannot be available without permission. Through Telehealth applications, Blockchain minimizes the effort of the middleman and plays its role during COVID-19 (Bahl *et al.*, 2020). Comparisons of Telehealth applications are shown in Table 10.

Mobile Health (mHealth)

It is a proposed mobile application solution that provides a self-testing and tracking system. However, Trace Together and CovidWatch is implemented Ethereum based mobile applications. The purpose of these applications is to track an infected person, so this app can secretly send a notification to a non-infected person when an infected one comes closer. Moreover, the hash log application monitors viruses in real-time by tracking the movement of infected people.

Table 10. Comparison of telehealth applications

Authors	Telehealth Applications	Blockchain type		Features				
		Ethereum	Hyper ledger	Patient Consent Management	Track and traceability of remote treatment	Secure access to Personal health Record	Proposed	Implemented
Mashamba-Thompson and Crayton (2020)	mHealth	✓	-	✓	✓	✓	✓	-
Alam and Benaïda (2022)	Trace Together	✓	-	✓	✓	✓	-	✓
Alam and Benaïda (2022)	CovidWatch	✓	-	✓	✓	✓	-	✓
Rimsan <i>et al.</i> (2020)	Hashlog	✓	-	✓	✓	✓	-	✓
Ahmad <i>et al.</i> (2021)	Med Credits	✓	-	✓	✓	✓	✓	-
Ahmad <i>et al.</i> (2021)	Medical chain	✓	✓	✓	✓	✓	✓	-
Chamola <i>et al.</i> (2020)	Civitas	✓	✓	✓	✓	✓	-	✓
Chamola <i>et al.</i> (2020)	Mipasa	✓	✓	✓	✓	✓	-	✓

Med Credits

Med Credits is Ethereum based system that assists patients using Telehealth service, and the Medical chain has support Ethereum and Hyper ledger fabric for implementing Telehealth service where a patient can directly contact the doctor.

Civitas and Mipasa

It is an implemented blockchain solution that can support local authorities in different ways to control the impact of COVID-19. This application track and traces a person's health using their official IDs whether they leave home or not. This application also has telemedicine functionality if the person is not feeling well and if they have any COVID-19 symptoms; Apps allow the doctor to track their patients and send them important instructions and medicine prescription.

Blockchain Solutions for Food Distribution and Agriculture

COVID-19 virus has not only affected humans' health but also all industries. Food distribution and agriculture is a basic need for every individual. But, the restrictions imposed by this pandemic, like social distancing implement many control measures such as export restrictions, travel bans, closure of factories, organization, markets have caused various challenges for distributors, consumers, and sellers. Farmers are facing difficulties in selling their yields at a good price. Moreover, distributors were also facing difficulties due to travel bans. Many other organizations who serve food is free to the needy people were also facing difficulties. However, blockchain technology can provide a solution in the form of applications or systems. Through these systems blockchain provides a platform where two parties manage directly, manufacturers can procure raw material directly from farmers. This will allow producers to achieve better prices for their goods and reduce the average price of foodstuffs. Many organizations can remotely and safely help poor

people purchase free or discounted food from local farmers by utilizing blockchain technology. In this context, blockchain provides numerous solutions for food distribution and agriculture. Some solutions are compared in Table 11.

Traceability and Food Authentication

Traceability and Food Authentication is a most common mechanism in the blockchain. It is an implemented hyper ledger solution that provides a very efficient way to trace the food and its supply and decrease fraud and food scandal issues. Meanwhile, all relevant data related to the product origin activities can be stored with minimal tampering risk. Moreover, Agri-food is also an implemented Ethereum based solution. This system is a traceability system where you can trace the food quality and productions to ensure the food safety and security (Di Vaio *et al.*, 2020).

Blockchain Solutions for E-government

E-government refers to the use of digital communication technology to provide government services to citizens. Blockchain technology ensures security and data consistency between organizations. Moreover, it reduces the processing delays and extra operational costs. The main features of blockchain authentication, shared database, and workflow automation are important when implementing different features in e-government systems. These systems can automatically detect possible errors and different counterfeiting issues. During COVID-19 some researchers also proposed and implement blockchain E-government services. These services include digital voting, paying taxes, digital identity, E-pass, and Digital health passport and immunity certificate. A comparison of different e-government applications is shown in Table 12.

Digital Voting and Digital Identity

These systems are implemented on the hyper ledger and they have almost the same feature except

Table 11. Comparison of food distribution and agriculture applications

Authors	Food and Agriculture Applications	Blockchain type		Features					
		Ethereum	Hyper ledger	Trace the food	Irrigation System	Distribute foods/Deliver the food	Harvesting or cropping	Proposed	Implemented
Lin <i>et al.</i> (2020)	Traceability and food authentication	-	✓	✓	-	-	-	-	✓
Lin <i>et al.</i> (2020)	Agri-food	✓	-	✓	-	-	-	-	✓
Di Vaio <i>et al.</i> (2020)	Agri-Digital	✓	-	-	✓	✓	✓	✓	-

electronic voting. Through electronically voting, corruption chances are less because a unique user ID provided to the vote caster, and his/her vote will be stored in a block that contains the user name and ID.

Electronic Pass (E-Pass)

It is a proposed Ethereum based application. In this application simply user register their selves by providing necessary information, and once the authorities verify the information, a user gets registered on the app. This app has multiple features like self-assessment, COVID-19 updates, and E-pass. User can use this pass when they want to travel out of country in emergency condition.

Digital Health Passports and Immunity Certificates

It is a proposed framework. It will be implemented on Ethereum and hyper ledger. This system issued digital health passport to that person by the government after testing process government-issued immunity certificate, who has been cured with coronavirus and their antibodies is already developed.

Blockchain Based Application Requirements

In this section the main focus is to highlight the requirements needed while implementing and proposing a blockchain based applications for COVID-19 as shown in Table 13. Blockchain applications has great potential in various fields which are contact tracing, contactless delivery, online education, supply chain, telehealth, donation tracking, food and agriculture and E-government. Blockchain allows applications to provide private and secure platform to control the data privacy. In Contact tracing and contactless delivery applications blockchain can also offer a decentralized solution that allows users to retain full control of their data. Moreover, Blockchain-based online education and supply chain management platforms can offer a wide range of possibilities to mitigate the security issues. For instance, such systems enable secure cross-platform sharing of online content and encourage automatic standardization across educational establishments also donation tracking, food and

Table 12. Comparison of e-government applications

Authors	E-government Applications	Blockchain type		Features				
		Ethereum	Hyper ledger	Registration and notification	Digitally verification	Electronic voting	Proposed	Implemented
Gupta and Kumar (2018)	Digital voting	-	✓	✓	✓	✓	-	✓
Gupta and Kumar (2018)	Digital Identity	-	✓	✓	-	-	-	✓
Gupta and Kumar (2018)	E-Pass	✓	-	✓	-	-	✓	-
Kalla <i>et al.</i> (2020)	Digital Health Passports and immunity certificates	✓	✓	✓	✓	-	✓	-

Table 13. Requirements in blockchain based COVID-19 applications

Use Case	Traceability	Anonymity	Data Security	Decentralized	Authority	Transparency	Privacy
Contact Tracing	✓	✓	✓	✓	✓	✓	✓
Contactless Delivery	✓	-	✓	✓	-	✓	✓
Online Education	✓	-	✓	✓	-	✓	✓
Supply chain	✓	-	✓	✓	-	✓	✓
Telehealth	✓	✓	✓	✓	-	✓	✓
Donation Tracking	✓	✓	✓	✓	-	✓	✓
Food and Agriculture	✓	✓	✓	✓	-	✓	✓
E-government	✓	-	✓	✓	✓	✓	✓

agriculture blockchain based solutions can provide transparency and Anonymity. In donation tracking apps through blockchain third parties can ensure transparency over the donation network. Blockchain technology can improve telehealth and telemedicine services by offering remote healthcare services in a manner that is decentralized, tamper-proof, transparent, traceable, reliable, trustful, and secure. It enables health professionals to accurately identify frauds related to physician educational credentials and medical testing kits commonly used for home-based diagnosis.

The use of blockchain for e-government can ensure security by enhancing traceability, and transparency, between organisations. Moreover, its use improves efficiency by reducing processing delays and lowering operational costs.

Open Challenges of Blockchain

As discussed above, in this global pandemic blockchain technology has a potential to develop numerous applications that could help in overcoming many challenges. However, there exist several limitations and challenges that hinder the successful implementation of the above-mentioned proposed blockchain-based systems. Some of these challenges are discussed below.

Security of the Private Key

In blockchain technology, a special and secret key that is known as the private key is assigned to each node or user in the system. Here, if the randomness of the private key is low, an attacker will get an authenticated user's private key. If a user's private key is hacked, hackers and malicious users are likely to target all of the user's data. In addition, because of the decentralization blockchain network, it is difficult to identify and define the attacker's actions (Namasudra *et al.*, 2021).

Environmental Cost

Although, blockchain technology has long-term advantages like productivity, efficiency, security but the implementation cost of blockchain-based systems is very high. To implement blockchain applications in any company, there are various requirements such as few specific software that is very expensive to purchase and maintain. It gradually makes the cost of the systems being developed high. Moreover, Blockchain technology is a rapidly growing new advancement, it requires a different skillset and trained individuals to operate and maintain blockchain-based systems. The hiring of these skilled individuals would be a new

challenge due to their shortage and can also increase the system's cost (Namasudra *et al.*, 2021).

Public Perception

Mostly people are still unaware of blockchain technology and they don't have much knowledge regarding the potentials of the technology. At present, a huge number of people even in the field of technology still think that blockchain is a synonym of Bitcoin and that blockchain is just a cryptocurrency that is involved in black market frauds and other illegal Monterrey frauds. Therefore, this negative impression needs to be eliminated for supporting blockchain to stand on its own.

Consumption of Energy

Energy consumption is also an important concern because while exchanging cryptocurrencies blockchain consumes high-level energy. Whether it is a Hyper ledger or Ethereum network, to update the transactions' Proof-of-work mechanism, complex mathematical problems need to be solved. These calculations require massive energy to power a system or computer. Although many techniques are being introduced to lower this energy consumption but a standard solution is still required.

Limitations and Future Scope

Blockchain is an emerging technology that has been adopted in various domains effectively. However, as the technology is still evolving there are certain limitations that need further research. Energy consumption and scalability are among the most critical challenges. Due to these limitations blockchain based applications are not being widely adopted on large scale. It consumes a lot of energy because each transaction requires a lot of processing power. Similarly, scalability and complexity is also a major limitation because the majority of nodes must approve transactions before they can be validated. In future combining blockchain technology with other developing technologies like artificial intelligence (AI), big data, and cloud computing could give a highly effective solution to deal with devastating pandemics like the coronavirus.

Conclusions

The COVID 19 pandemic has affected everyone in almost every field of life, including finance, economics, medical and educational sectors, etc. Technology has played a leading role in facilitating people during this period. Blockchain, in particular,

has been a key in addressing the various issues such as privacy, security and transparency. For the appropriate implementation of many use cases, i.e. Contact Tracing, Contactless delivery, Online Education, Donation Tracking, Supply Chain, Telehealth, Food and Agriculture, and E-government, the key characteristics of this technology can be very helpful. This study presents a review and comparison of more than 30 blockchain-based COVID-19 applications in various sectors. Benefits of using blockchain in these applications is highlighted in this research. Ethereum is found to be the most used platform for implementation of blockchain applications. Blockchain technology has the potential to overcome various problems such as transparency, trust, security but there exists many challenges before the this technology is fully adapted. These challenges include energy consumption, throughput, people perception, and resource utilization problems. More research is required to address these critical challenges so that the Blockchain technology can be fully utilized in all major computing areas.

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