A Survey on MCT vs. DCT: Who is the Winner in COVID-19

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Abstract—Coronavirus disease (COVID-19) is a contagious disease appeared in late 2019 and caused by a virus called SARS-CoV-2. It is a pandemic spreading across the whole world and impacts millions of people and sadly causes death. There are two main Contact Tracing Methods (CTMs) to limit and slow down any chance of transmission of it: Manual Contact Tracing (MCT) and Digital Contact Tracing (DCT). The MCT abides by the guide to World Health Organization’s guidance (WHO) on COVID-19 in terms of properly applying social distancing, wearing masks, washing hands, using sanitizers, etc. while the DCT abides by the digital contact tracing applications developed by several countries. This survey is mainly focused on these CTMs and the recent proposed solutions in this field, in order to highlight their drawbacks that negatively impact on both of satisfaction and feasibility in using them. The findings in the survey will be beneficial to understand the effectiveness of CTMs and current proposed solutions, in order to develop a comprehensive smart tracking system able to cooperatively contribute with both of MCT and DCT in extremely detecting, preventing, and slowing down the spread of COVID-19 or even any other similar pandemics in the future.

Keywords—COVID-19; coronavirus disease; manual contact tracing; digital contact tracing

I. INTRODUCTION

Coronavirus disease (COVID-19) has been emerged for the first time in Wuhan [1-9], where the first reported cases were found in Huanan seafood market [10-12]. It has been reported by the World Health Organization (WHO) that there are 318,648,834 confirmed cases of COVID-19, including 5,518,343 deaths [13]. To slowing the spread of COVID-19 and protect family and community, Contact Tracing Methods (CTMs): Manual Contact Tracing (MCT) and Digital Contact Tracing (DCT) play a vital role in this respect, The MCT is a manual method [14-20] strives to [21]:

1) Support COVID-19 patients to stay home and self-isolate.
2) Alert and help people who have been in close contact with COVID-19 patients.
3) Follow-up them in testing, quarantine, and wearing a mask properly.

The DCT is a dynamic method [22-34] based on smartphones' applications which strives in tracking people diagnosed with COVID-19 to notify mobile users whether they have been exposed to the virus or not. The DCT utilize several technologies to collect data [35]: cell tower location data, Quick Response (QR) code, credit card/public transit card, videos surveillance, Global Positioning System (GPS), and Bluetooth.

There are three main approaches to store users' sensitive data [36]: Centralized Approach (CA) where the data is stored on centralized servers, Decentralized Approach (DA) where the data is stored on individual mobiles, and Hybrid Approach (HA) which is combination between CA and DA. The DA aims to protect users' sensitive data where a central server plays a small role in this respect by keeping very little data [37]. The CA is more efficient [37] and more secure compared with the DA, while it is considered a single point of failure [38].

To the best of our knowledge, existing related works have not fully considered CTMs and recent proposed solutions. Therefore, this paper thoroughly surveys both of CTMs and recent proposed solutions to highlight their drawbacks that negatively impact on both of satisfaction and feasibility in using them. The rest of the paper is organized as follows: In Section II, an overview of CTMs and proposed solutions is presented: DCT and MCT. In Section III, a comprehensive comparison of CTMs and proposed solutions is presented: MCT vs. DCT, DCT approaches, and DCT proposed solutions. In Section IV, a discussion is presented. Finally, a conclusion is given in Section V.

II. OVERVIEW OF CTMS AND PROPOSED SOLUTIONS

To provide a comprehensive comparison of CTMs, this section presents lots of vital recent related works either theoretical or practical: surveys, overviews, and proposed solutions for DCT and MCT.

A. DCT

In [22], the authors have introduced a Self-Sovereign Identity (SSI) model based blockchain to address the following issues in DCT applications: privacy leakage, efficiency, and energy consumption. The effectiveness of the proposed solution has been validated by theoretical analysis.

In [27], the authors have proposed a blockchain enabled privacy preserving contact tracing scheme: BeepTrace. Numerical analysis has shown higher security and privacy, battery friendly, and globally accessible.
In [34], a framework of a blockchain, Artificial Intelligence (AI) and Internet of Things (IoT) based system for the detection of COVID-19 and distancing has been proposed. It has aimed to offer real time data sharing, security, and transparency. However, no implementation or testing provided about the framework.

In [35], an overview of several DCT applications has been conducted. It has been concluded that the DCT have had the following issues: limited Internet access in poor countries, people without smartphones, lack of signal, transparency, privacy and security.

In [39], a cross national online survey has been conducted in the UK, Republic of Ireland, and the US, in order to discover public attitudes and the acceptability of DCT. It has been concluded that that trust and privacy have been the main concerns for the adoption of DCT.

In [40], 41 countries and 23 US states have developed a total of 64 DCT applications, where they have sampled eight applications in European countries between British Isles, and mainland Europe equitably. Using various analysis (e.g., quantitative analysis and qualitative coding), it has been concluded that the DCT has required updating regularly due to governmental policies and guidelines, there have been issues in the devices, applications and their features, high battery consumption, usability should be enhanced, and users have been generally unhappy with the applications.

In [41], a detailed analysis of DCT applications for 32 countries has been presented. The proposed architecture using blockchain Hyperledger Fabric (HF) has addressed the following inherent issues related to contact tracing: security, privacy, authentication, access control, flexibility, scalability, interoperability, and efficiency.

In [42], the authors have proposed COVERT blockchain HF for COVID-19 contact tracing with keeping user’s privacy. The results have proved its scalability, robustness, and efficiency in protecting privacy leakage.

In [43], the authors have proposed a blockchain platform for contact tracing with keeping user’s privacy, using a Generative Adversarial Network (GAN) application. It has shown that the privacy has been addressed by iterative deleting older data from the database.

In [44], the authors have proposed a prototype of blockchain and SSI-based digital contact tracing platform, using Mystiko blockchain cluster. A performance evaluation of the platform has been conducted, where it has shown addressing issues in security, privacy, scalability, and transaction throughput features.

In [45], the authors have proposed a framework used off-chain scaling mechanism of Interplanetary File System (IPFS) for contact tracing. There a performance evaluation using Ethereum application has been conducted of the framework in terms of security, privacy, and scalability.

In [46], the authors have proposed and implemented a blockchain based system called COVID-19 Contact Tracing System (CCTS), to verify, track and detect new cases of COVID-19, using Ethereum application. However, user's privacy and accuracy in detecting contacts of COVID-19 have not been investigated.

The DCT provides several features: accurate, fast, and low cost [47].

B. MCT

It is a traditional contact tracing method manually managed by health care providers to identify the contacts of infected individuals, interview, alert them to quarantine, and to seek a test [47]. However, the MCT has become difficult to be used due to rapid spread of COVID-19 [48], as it has been some drawbacks: relying on human memory, taking time [49], requiring trained human resources [47], [50], inefficient [51], costly, highly error prone, and not scalable [14].

The recent studies in [52] and [53] shows that the combination of MCT and DCT is more efficient for contact tracing.

III. COMPARISON OF CTMS AND PROPOSED SOLUTIONS

In Section II, plenty of recent related works have been considered: surveys, overviews, and proposed solutions of CTMs. To provide a comprehensive comparison of CTMs, in this Section, three types of comparisons are presented: MCT vs. DCT, DCT approaches, and DCT proposed solutions.

A. MCT vs. DCT

Ten factors are considered to distinguish between CTMs (MCT and DCT): time, efficiency, accuracy, cost, diagnosis, failure, scalability, reliability, dependency, and investigation. This is shown in Table I. In this competition, the DCT obviously has a full advantage over the MCT.

B. DCT Approaches

Five factors are considered to distinguish between the DCT approaches (CA, DA, and HA): data storage location, efficiency, privacy, security, and point of failure. This is shown in Table II. In this competition, the HA obviously has dominant features over the CA and DA.

| Comparison | DCT | MCT |
|------------|-----|-----|
| Time       | Less | More |
| Efficiency | More | Less |
| Accuracy   | More | Less |
| Cost       | Less | More |
| Diagnosis  | Fast | Slow |
| Failure    | Low  | High |
| Scalability| High | Low |
| Reliability| High | Low |
| Dependency | Technology | Human memory |
| Investigation | GPS, QR code, Bluetooth cell tower location data, credit card/public transit card, videos surveillance | Self-assessment survey |

TABLE I. MCT vs. DCT
TABLE II. DCT APPROACHES

| Comparison       | CA | DA | HA |
|------------------|----|----|----|
| Data storage location | Server (S) | Mobile (M) | S & M |
| Efficiency       | High | Low | Average |
| Privacy          | Low | High | Average |
| Security         | High | Low | Average |
| Point of failure | High | Low | Average |

TABLE III. DCT PROPOSED SOLUTIONS

| Paper | Year | Type of Research | Implementation | Concern                                                                 | Addressing                                      | Solution |
|-------|------|------------------|----------------|--------------------------------------------------------------------------|-------------------------------------------------|----------|
| [22]  | 2021 | Theoretical      | Analysis       | n/a                                                                      | Privacy, efficiency, energy consumption          | SSI model based blockchain                       |
| [27]  | 2021 | Theoretical      | Analysis       | n/a                                                                      | Security, privacy, battery friendly, globally    | BeepTrace based blockchain                       |
| [34]  | 2021 | Theoretical      | n/a            | Not developed                                                            | Real time data sharing, security, transparency   | Framework based blockchain, AI and IoT           |
| [35]  | 2020 | Theoretical      | Overview       | Limited Internet access, people without smartphones, lack of signal,     | n/a                                             | n/a                                               |
|       |      |                  |                | transparency, privacy, security                                          |                                                 |                                                   |
| [39]  | 2021 | Theoretical      | Survey         | Trust and privacy                                                        | n/a                                             | n/a                                               |
| [40]  | 2021 | Theoretical      | Analysis       | Updating DCT regularly, issues in the devices, applications and their    | n/a                                             | n/a                                               |
|       |      |                  |                | features, battery consumption, usability, user satisfaction              |                                                 |                                                   |
| [41]  | 2021 | Practical        | HF             | -                                                                        | Security, privacy, authentication, access control, | Architecture based blockchain                   |
|       |      |                  |                |                                                                          | flexibility, scalability, interoperability,      |                                                   |
|       |      |                  |                |                                                                          | efficiency                                     |                                                   |
| [42]  | 2021 | Practical        | HF             | -                                                                        | Scalability, robustness, privacy                | COVERT based blockchain                          |
| [43]  | 2021 | Practical        | GAN            | -                                                                        | Privacy                                        | Platform based blockchain                        |
| [44]  | 2021 | Practical        | Mystiko        | -                                                                        | Security, privacy, scalability, transaction      | SSI model based blockchain                       |
|       |      |                  |                |                                                                          | throughput features                            |                                                   |
| [45]  | 2021 | Practical        | Ethereum       | -                                                                        | Security, privacy, scalability                  | Framework based blockchain and IPFS              |
| [46]  | 2021 | Practical        | Ethereum       | Privacy, accuracy                                                       | Verify, track, detect new cases of COVID-19      | CCTS based blockchain                            |

C. DCT Proposed Solutions

Five factors are considered to distinguish between the DCT proposed solutions [22, 27, 34, 35, 39-46]: type of research, implementation, concern, addressing, and solution. This is shown in Table III.

As for the type of research, it can be seen that the related works have been equitably conducted between theoretical and practical research works. This is shown in Fig. 1.
For the implementation, three related works are used analysis, followed by HF and Ethereum with two research works each; lastly, overview, survey, GAN, and Mystiko. This is shown in Fig. 2.

In terms of the concern, fifteen common issues are arisen and divided into two main categories: IT’s issues and user’s issues. This is shown in Fig. 3.

In the addressing, eighteen common issues are arisen. It has been noticed that all the addressed issues are related to IT issues. This is shown in Fig. 4.

Finally, the most DCT proposed solutions based on the blockchain, as shown in Fig. 5.

In Section III, a comparison of CTMs has been conducted, where three types of comparisons have been presented: MCT vs. DCT, DCT approaches, and DCT proposed solutions.

For MCT vs. DCT, the DCT has shown a full advantage over the MCT in terms of time, efficiency, accuracy, cost, diagnosis, failure, scalability, reliability, dependency, and investigation, as shown in Table I.

For DCT approaches, the HA has shown dominant features over the CA and DA in terms of data storage location, efficiency, privacy, security, and point of failure, as shown in Table II.

For DCT proposed solutions, twelve research works have been conducted [22, 27, 34, 35, 39-46]. It has been noticed that all these works have been confined in introducing, enhancing or proposing DCT applications related to IT issues and user issues, as shown in Table III.

Therefore, in addition to the combination between DCT (HA approach) and MCT, it would be more effective to propose, implement and, distribute a comprehensive smart tracking system located in public places, universities, schools, hospitals, banks, airports etc. This obviously will extremely limit and slow down any chance of transmission of COVID-19 or even any other similar pandemics in the future. This is shown in Fig. 6.
V. CONCLUSION

In this paper, the CTMs and the recent proposed solutions for COVID-19 have been surveyed thoroughly, where a fair comparison has been presented: MCT vs. DCT, DCT approaches, and DCT proposed solutions. For DCT proposed solutions, twelve research works have been conducted. It has been concluded that all these works have been confined in introducing, enhancing or proposing DCT applications related to IT issues and user issues.

Therefore, the competition in this paper has shown the importance of using both of MCT and DCT (HA approach), and come up with a comprehensive smart tracking system able to cooperatively contribute with them in extremely detecting, preventing, and slowing down the spread of COVID-19 or any other similar pandemics in the future.

REFERENCES

[1] M. Fradi and M. Machhout, “Real-time application for Covid-19 class detection based CNN architecture,” IEEE International Conference on Design & Test of Integrated Micro & Nano-Systems (DTS), Sfax, Tunisia, pp. 1-6, 2021.

[2] Y. Jiang, H. Chen, M. Loew and H. Ko, “Covid-19 CT image synthesis with a conditional generative adversarial network,” IEEE Journal of Biomedical and Health Informatics, vol. 25, no. 2, pp. 441-452, 2021.

[3] W. Haochen, “Western perspectives of the Covid-19 in China,” International Conference on Public Health and Data Science (ICPHDS), Guangzhou, China, pp. 116-119, 2020.

[4] M. Wang, W. Kong, J. Xie and S. Xu, “Modeling the Covid-19 epidemic in PR China,” 7th International Conference on Big Data and Information Analytics (BigDDIA), Chongqing, China, pp. 324-333, 2021.

[5] S. Vishnu and S. Jino Ramson, “An internet of things paradigm: pandemic management (incl. Covid-19),” International Conference on Artificial Intelligence and Smart Systems (ICAIS), Coimbatore, India, pp. 1371-1375, 2021.

[6] P. Porwal, K. Thirunavukkarasu, A. Sinha and A. Singh, “Data analysis and detection of coronavirus disease using convolution neural network,” 2nd International Conference on Advances in Computing, Communication Control and Networking (ICACCCN), Greater Noida, India, pp. 786-790, 2020.

[7] H. Turabieh and W. Ben Abdessalem, “Predicting the existence of Covid-19 using machine learning based on laboratory findings,” International Conference of Women in Data Science at Taif University (WIDSTaif ), Taif, Saudi Arabia, pp. 1-7, 2021.

[8] L. Zhu, W. Dong, Q. Sun, E. Vargas and X. Du, “Estimation of the unreported infections of Covid-19 based on an extended stochastic susceptible-exposed-infective-recovered model,” IEEE 10th Data Driven Control and Learning Systems Conference (DDCLS), Suzhou, China, pp. 953-958, 2021.

[9] T. Karakose, T. Ozdemir, S. Papadakis, R. Yirci, S. Ozkayran and H. Polat, “Investigating the Relationships between COVID-19 Quality of Life, Loneliness, Happiness, and Internet Addiction among K-12 Teachers and School Administrators—A Structural Equation Modeling Approach,” International Journal of Environmental Research and Public Health, vol. 19, no. 3, pp. 1-20, 2022.

[10] W. Yang, Q. Cao, L. Qin, X. Wang, Z. Cheng, A. Pan, J. Dai, Q. Sun, F. Zhao, J. Qu and F. Yan, “Clinical characteristics and imaging manifestations of the 2019 novel coronavirus disease (Covid-19): A
multi-center study in Wenzhou city, Zhejiang, China,” J Infect, vol. 80, no. 4, pp. 388-393, 2020.

[11] L. Graiinski and V. Menachery, “Return of the coronavirus: 2019-nCoV;” Viruses, vol. 12, no. 2, pp. 1-8, 2020.

[12] D. Kuldeep, K. Sharun, T. Ruchi, S. Subhankar, B. Sudipta, M. Yashpal, S. Karam, C. Wanpen, A. Katterine and M. Alfonso, “Coronavirus disease 2019 – Covid-19,” Clinical Microbiology Reviews, vol. 33, no. 4, pp. 1-48, 2020.

[13] World Health Organization. (Jan, 2022). WHO coronavirus (Covid-19) Dashboard. Available: https://covid19.who.int/

[14] M. Chowdhury, M. Ferdous, K. Biswas, N. Chowdhury and V. Muthukkumaramas, “Covid-19 contact tracing: challenges and future directions,” IEEE Access, vol. 8, pp. 225703-225729, 2020.

[15] P. Ng, P. Spachos, S. Gregori and K. Plataniotis, “Personal devices for contact tracing: smartphones and wearables to fight Covid-19,” IEEE Communications Magazine, vol. 59, no. 9, pp. 24-29, 2021.

[16] M. Bano, C. Arora, D. Zowghi and A. Ferrari, “The rise and fall of Covid-19 contact-tracing apps: when NFRs collide with pandemic,” IEEE 29th International Requirements Engineering Conference (RE), Notre Dame, IN, USA, pp. 106-116, 2021.

[17] P. Ng, P. Spachos and K. Plataniotis, “Covid-19 and your smartphone: BLE-based smart contact tracing,” IEEE Systems Journal, vol. 15, no. 4, pp. 5367-5378, 2021.

[18] B. Patel, N. Jain, R. Menon and S. Kodeboyina, “Comparative study of privacy preserving-contact tracing on digital platforms,” International Conference on Computational Intelligence (ICCI), Bandar Seri Iskandar, Malaysia, pp. 137-141, 2020.

[19] A. Khandelwal, A. Kotwal, P. Sutone and V. Wagi, “Automated contact tracing using person tracking and re-identification,” 2nd International Conference on Secure Cyber Computing and Communications (ICSCCC), Jalandhar, India, pp. 102-107, 2021.

[20] D. Yazti and C. Claramunt, “Covid-19 mobile contact tracing apps (MCTA): a digital vaccine or a privacy demolition?,” 21st IEEE International Conference on Mobile Data Management (MDM), Versailles, France, pp. 1-4, 2020.

[21] Centers for Disease Control and Prevention. (Feb, 2022). Contact tracing. Available: https://www.cdc.gov/coronavirus/2019-ncov/daily-life-coping/contact-tracing.html#

[22] D. Wang, X. Chen, L. Zhang, Y. Fang and C. Huang, “A blockchain based human-to-infrastructure contact tracing approach for Covid-19,” IEEE Internet of Things Journal (Early Access), pp.1-1, 2021.

[23] H. Faria, S. Paiva and P. Pinto, “An advertising overflow attack against android exposure notification system impacting Covid-19 contact tracing applications,” IEEE Access, vol. 9, pp. 103365-103375, 2021.

[24] G. Betarte, J. Campo, A. Delgado, P. Ezzatti, L. González, Á. Martín, R. Martinez and B. Muracciole, “Proximity tracing applications for Covid-19: data privacy and security,” XLVII Latin American Computing Conference (CLEI), Cartago, Costa Rica, pp. 1-10, 2021.

[25] A. Lubis and B. Basari, “Proximity-based Covid-19 contact tracing system devices for locally problems solution,” 3rd International Seminar on Research of Information Technology and Intelligent Systems (ISRITI), Yogyakarta, Indonesia, pp. 363-370, 2020

[26] I. Ozelcik, “CAPEN: cryptographic accumulator based privacy preserving exposure notification,” 9th International Symposium on Digital Forensics and Security (ISDFS), Elazig, Turkey, pp. 1-6, 2021.

[27] H. Xu, L. Zhang, O. Onireti, Y. Fang, W. Buchanan and M. Imran, “BeepTrace: blockchain-enabled privacy-preserving contact tracing for Covid-19 pandemic and beyond,” IEEE Internet of Things Journal, vol. 8, no. 5, pp. 3915-3929, 2021.

[28] L. Garg, E. Chukwu, N. Nasser, C. Chakraborthy and G. Garg, “Anonymity preserving IoT-based Covid-19 and other infectious disease contact tracing model,” IEEE Access, vol. 8, pp. 159402-159414, 2020.

[29] S. Sharma, G. Singh, R. Sharma, P. Jones, S. Kraus and Y. Dwivedi, “Digital health innovation: exploring adoption of Covid-19 digital contact tracing apps,” IEEE Transactions on Engineering Management (Early Access), pp.1-17, 2020.

[30] V. Shubina, A. Ometov and E. Lohan, “Technical perspectives of contact-tracing applications on wearables for Covid-19 control,” 12th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), Brno, Czech Republic, pp. 229-235, 2020.

[31] A. Sarkar and S. Ray, “A data driven decision making and contract tracing app for organizations to combat Covid-19,” International Conference on Computing, Networking, Telecommunications & Engineering Sciences Applications (CoNTESA), Tirana, Albania, pp. 88-93, 2020.

[32] A. de Araujo, I. Garcia, N. Cacho, L. Nascimento, D. Rolim, J. Medeiros, S. Santana, A. Paiva, M. Lima, T. Ramos, K. Macedo, J. Pereira, J. Nascimento, L. Monteiro, M. Ferna. N. Fernandes and F. Lopes, “A platform for citizen cooperation during the Covid-19 pandemic in RN, Brazil,” IEEE International Smart Cities Conference (ISC2), Piscataway, NJ, USA, pp. 1-8, 2020

[33] M. Winter, H. Baumeister, U. Frick, M. Tallon, M. Reichert and R. Pryss, “Exploring the usability of the German Covid 19 contact tracing app in a combined eye tracking and retrospective think aloud study,” 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), Mexico, pp. 2215-2221, 2021.

[34] M. Sheeraz, A. Athar, A. Hussain, S. Aich, M. Joo and H. Kim, “Blockchain, AI & IoT based Covid-19 contact tracing and distancing framework,” International Conference on Robotics and Automation in Industry (ICRAI), Rawalpindi, Pakistan, pp. 1-4, 2021.

[35] S. Hsaini, H. Bibri, S. Azzouzi and M. Charaf, “Contact-tracing approaches to fight Covid-19 pandemic: limits and ethical challenges,” IEEE 2nd International Conference on Electronics, Control, Optimization and Computer Science (ICEECOS), Kenitra, Morocco, pp. 1-5, 2020.

[36] S. Alanoca, N. Jeanrenaud, I. Ferrari, N. Weinberg, R. Cetin, and N. Miallhe, “Digital contact tracing against Covid-19: a governance framework to build trust,” International Data Privacy Law, vol. 11, no. 1, pp. 3-17, 2021.

[37] L. White and P. Basshuysen, “Privacy versus public health? a reassessment of centralised and decentralised digital contact tracing,” Science and Engineering Ethics, vol. 27, no. 2, pp. 1-13, 2021.

[38] S. Vaudenay. (May, 2020). Centralized or decentralized? the contact tracing dilemma. Available: https://eprint.iacr.org/2020/531

[39] L. Nurgalieva, S. Ryan and G. Doherty, “Attitudes towards Covid-19 contact tracing apps: a cross-national survey,” IEEE Access (Early Access), pp.1-29, 2021.

[40] V. Garousi, D. Cutting and M. Felderer, “What do users think of Covid-19 contact-tracing apps? an analysis of eight European apps,” IEEE Software (Early Access), pp. 1-9, 2021.

[41] S. Tahir, H. Tahir, A. Sajjad, M. Rajarajan and F. Khan, “Privacy-preserving Covid-19 contact tracing using blockchain,” Journal of Communications and Networks, vol. 23, no. 5, pp. 360-373, 2021.

[42] J. Khan, K. Bangalore and K. Ozbay, “COVERT-blockchain: privacy-aware contact tracing for Covid-19 on a distributed ledger,” 3rd Conference on Blockchain Research & Applications for Innovative Networks and Services (BRAINIS), Paris, France, pp. 31-32, 2021.

[43] M. Ružička, M. Volosin, J. Gažda and T. Maksymyuk, “Deep learning-based blockchain framework for the Covid-19 spread monitoring,” International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECME), Mauritius, Mauritius, pp. 1-6, 2021.

[44] A. Bandura, X. Li, P. Fischik, S. Shetty, C. Hall, D. Bowden, N. Ranasinghe and K. De Zoya, “A blockchain empowered and privacy preserving digital contact tracing platform,” Information Processing & Management, vol. 58, no. 4, pp. 1-17, 2021.

[45] N. Bar, U. Qamar and A. Khalid, “Efficient contact tracing for pandemics using blockchain,” Informatics in Medicine Unlocked, vol. 26, pp. 1-12, 2021.

[46] T. Mohamed, E. Goda, V. Snaesel and A. Hassani, “Covid-19 contact tracing and detection-based on blockchain technology,” Informatics, vol. 8, no. 4, pp. 1-24, 2021.

[47] D. Siddharth, B. Cantrell, L. Trettik, P. Eckerles, J. Langford, S. Leibrand, S. Kakade, S. Latta, D. Lewis, S. Tessel and G. Weyl, “Outpacing the virus: digital response to containing the spread of Covid-19,” JACSA International Journal of Advanced Computer Science and Applications, Vol. 13, No. 5, 2022
while mitigating privacy risks,” Edmond J. Safra Center for Ethics, White Paper 5, pp. 1-38, 2020.

[48] R. Sun, W. Wang, M. Xue, G. Tyson, S. Camtepe and D. Ranasinghe, “An empirical assessment of global Covid-19 contact tracing applications,” IEEE/ACM 43rd International Conference on Software Engineering (ICSE), Madrid, ES, pp. 1085-1097, 2021.

[49] A. Chen and K. Thio, “Exploring the drivers and barriers to uptake for digital contact tracing,” Social Sciences & Humanities Open, vol. 4, no. 1, pp. 1-13, 2021.

[50] M. Shahroz, F. Ahmad, M. Younis, N. Ahmad, M. Boulos, R. Vinuesa and J. Qadir, “Covid-19 digital contact tracing applications and techniques: A review post initial deployments,” Transportation Engineering, vol. 5, pp. 1-9, 2021.

[51] P. Ng, P. Spachos and K. Plataniotis, “Covid-19 and your smartphone: BLE-based smart contact tracing,” IEEE Systems Journal, vol. 15, no. 4, pp. 5367-5378, 2021.

[52] M. Mancastrroppa, C. Castellano, A. Vezzani and R. Burioni, “Stochastic sampling effects favor manual over digital contact tracing,” Nature Communications, vol. 12, no. 1, pp. 1-9, 2021.

[53] A. Barrat, C. Cattuto, M. Kivelä, S. Lehmann and J. Saramäki, “Effect of manual and digital contact tracing on Covid-19 outbreaks: a study on empirical contact data,” Journal of the Royal Society Interface, vol. 18, no. 178, pp. 20201000, 2020.