Available online at www.qu.edu.iq/journalcm
JOURNAL OF AL-QADISIYAH FOR COMPUTER SCIENCE AND MATHEMATICS
ISSN:2521-3504(online) ISSN:2074-0204(print)

# SMARTPHONE APPLICATIONS FOR CONTACT TRACING IN COVID-19 EPIDEMIC: A SYSTEMATIC REVIEW

***Fouad Salim Saleem*** [a], ***Intisar Al-Mejibli*** [b]

[a] *Informatics Institute for Postgraduate Studies (IIPS), Iraqi Commission for Computers and Informatics (ICCI), Iraq ,Baghdad, email: Ms201910536@iips.icci.edu.iq*

[b] *Biomedical Informatics College, University of Information Technology and Communications, Baghdad, Iraq, email: dr.intisar.almejibli@gmail.com*

**ARTICLE INFO**

*Article history:*
Received: 29 /05/2021
Rrevised form: 15 /06/2021
Accepted : 07 /07/2021
Available online: 09 /07/2021

***Keywords:***

***Smartphone applications, Mobile apps, COVID-19, Epidemic, Contact tracing.***

**ABSTRACT**

The great spread of the COVID-19 Pandemic and its effect on lifestyle around the world has led countries and organizations to accelerate the design or use of mobile health systems and applications to tackle and monitor the outbreak. Digital contact tracing applications have been proposed to automatically warning individuals at risk of infection and exposure. This systematic analysis discusses the various types of mechanisms and systems used in applications for digital contact tracing including Centralized, Decentralized, or Hybrid, in addition to, the used communication technologies such as Bluetooth, GPS, WiFi, and others, with a focus on user privacy and the efficiency of dealing with the extracted data. Four databases were scanned (IEEE Xplore, ScienceDirect, Web of Science, and PubMed) between 2015 and 2020. To review the collected 636 papers, precise exclusion criteria and selection strategies were applied. Only seven papers have been thoroughly analyzed and included in this study. The results in all papers have been presented to identify gaps and issues to supply an overview of the main aspects that need to be included and resolved in mobile applications that will be built to effectively restrict the spread of this pandemic and preserve full user privacy.

MSC. 41A25; 41A35; 41A36

**DOI : https://doi.org/10.29304/jqcm.2021.13.2.818**

## 1. Introduction

Controlling epidemics, infectious diseases, and limiting their spread are among the real challenges facing the international community. In 2016, infectious diseases accounted for 29% of all global deaths and resulted in 4.3 million deaths (1.7 million women and 2.7 million men) according to the 2019 World Health Statistics report from WHO [1]. Since December 2019, the world has been living in the nightmare of the new strain of Coronavirus, COVID-19. The accelerated dissemination of the virus led the World Health Organization on 11 March 2020 to pronounce COVID-19, the respiratory disease caused by the current Covid, SARS-CoV-2, as a pandemic [2]. In response, governments have taken a large range of

∗Corresponding author: Fouad Salim Saleem

Email addresses: Ms201910536@iips.icci.edu.iq

Communicated by*: Dr. Rana Jumaa Surayh aljanabi.*

procedures and measures trying to curb an outbreak of COVID-19 [3]. There is no doubt that this pandemic has caused many consequences in all aspects of life, especially the health aspect [4]. The danger of the virus lies in the possibility of its transmission from the infected person to others even before the symptoms of infection appear, as it behaves like a 'hit and runs' killer [5]. Therefore, Public health officials have followed a set of measures to reduce the effects of the virus and relieve closures, such as social distancing, community education, contact tracing for infected, and self-quarantine for a specified time [6]. In this respect, the World Health Organization (WHO) describes surveillance of public health as "An ongoing, systematic collection, analysis and interpretation of health-related data essential to the planning, implementation, and evaluation of public health practice" [7]. Contact tracing can smash the transmission series of infectious diseases when routinely implemented and thus it is effective health of public method to control infectious disease outbreaks [8]. Contact tracing has been described by the WHO as intently tracking these contacts when exposed to an infected person, helping contacts get care and treatment, and avoid further the virus spread [9]. Timely contact tracing, testing, and adequate quarantine/isolation will go a long way in curbing the rapid spread of this disease [10]. Recent studies show that COVID-19 can be contained using reliable and fast technology for contact tracing, considering that a significant population proportion is utilizing the application of contact tracing in their smartphone [11]. The World Health Organization has identified 3 basic steps for the contact tracing process:

A. Contact identification: Contact identification: contacts are determined through ask about the activities of infected individuals and the behaviors and functions of the persons surrounding them since the beginning of the ailment.
B. Contact listing: All people deemed to have touch with the contaminated individual ought to be recorded as contacts, and the provision of information on disease prevention.
C. Contact follow-up: An orderly follow-up of all contracts should be carried out to observe for symptoms and check for infection signs [9].

Contact tracing, quarantine, and isolation measures were of great importance during the outbreak of SARS in 2003 [12], Ebola in Africa in 2014 [13], and so is now in the fight against Covid-19. Here, technology has become an urgent necessity to find solutions that help develop smartphone applications to track virus-infected people and notify contacts after assessing the possibility of their infection. The use of digital contact tracing tools will speed up the identification of probable cases in a given population on time. For contact tracing apps to be acceptable and useful, they must be freely downloaded and used by the majority of people. This can only happen if people make sure that these apps are transparent and do not violate their privacy. Therefore, the main objectives of this systematic review are to explore the methods and techniques used in digital contact tracing applications and to assess their effectiveness in identifying contacts at risk of contracting the Covid-19 virus. In addition to, reviewing articles on proposed strategies and mechanisms, and gathering various information to gain a clear understanding of the available studies, their development, improvement, and employment. Further, examine the challenges faced with this approach, and provide recommendations for enhancing its efficiency.

## 2. Method

Our systematic review was prepared in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA statement [14]. Four digital databases were selected, namely IEEE Xplore, ScienceDirect (SD), Web of Science (WoS), and PubMed. IEEE Xplore contains the highest quality technical literature in engineering and information technology. SD provides access for science, technological, and medical research to a highly reliable journal. WoS is a highly trusted resource in engineering, social sciences, humanities, and interdisciplinary studies. PubMed is the essential database for biomedical, life science, and biomedical engineering studies. The four databases provide an overview of smartphone applications designed to track contacts through literature search. The results of this literature review can assist in developing future applications and making them more appropriate and acceptable for beneficiaries to avoid infection and limit the spread of epidemics and infectious diseases.

## 3. Search Strategy

Based on the four aforementioned listed databases, which are in the English language, published from 2015 to 2021, a systematic literature search was performed. The criteria of selecting the investigated research indices their adequate inclusion of the literature identified to our study as newly discovered novel coronavirus need greater

interest than another infectious disease. This study presented and carried out a Boolean search technique for different keywords (e.g. Pandemic, Epidemic, COVID-19, SARS-CoV-2, coronavirus, smartphone, mobile, tracing, and tracking). To improve our search in various studies of smartphone systems and contact tracing applications, we used these query techniques. Inclusion criteria are:

1. The article is a journal or conference paper in English.

2. The major focus is on the development of various smartphone applications, systems, and techniques.

3. The development focuses only on tracking persons those close contacts or at risk of the epidemic.

## 4. Study Selection

This process began with eliminating duplicated papers and screening titles and abstracts for non-duplicated articles to verify their conformity with our requirements for inclusion and exclusion. To collect and extract data from research and create the article of review, the related papers were exposed to a full process of reading. For all research papers, they have been read and analyzed in-depth to guarantee the development of a very accurate and useful systematic review in this paper of research.

## 5. Data Extraction and Selection

Extraction of data and classification chosen studies, including data relating to Covid-19 for Smartphone apps (especially Contact Tracing techniques), To assess the usefulness of these applications in terms of detecting, tracking, and notifying people close to or in contact with affected. The elements of the data were taken from scholarly literature and contained the contributors' nationalities, the date of publishing, the publications number per year, and the articles number per database. To give an overall viewpoint of contact tracing apps, this study discussed those applications and analyzed their worldwide growth scale using different frameworks and techniques in tracking, communication, and security data. This analysis collected the significant feature names and characteristics of each technique for each research in the literature. Brief challenges, limitations, and recommendations were taken from the reviewed papers to develop more flexible, reliable, and transparent contact tracking applications.

## 6. Results

Figure 1 presented the outcomes of the proposed query performed in this study. The first result consisted of 636 papers from all 4 databases. The number of duplicated articles in all databases was 31, and the results were 605. The next approach was to screen papers based on the title and abstract, followed by mapping the requirements for inclusion and exclusion, resulting in 73 articles. A full reading of all articles was the final step and the result was only 7 articles that met the requirements of inclusion and exclusion. Our interpretation of the purpose/target of these studies motivated us to examine each analysis in the search question that was carried out in this systematic review based on two linked conditions. The first is the article should provide an overview of the application, and the second is the use of contact tracing techniques and frameworks.

## 7. Discussion

Contact tracing is an important control strategy to overcome epidemics and infectious diseases [15]. The traditional methods of contact tracing require a lot of human effort and material resources, which is inconvenient, given that a rapid response is necessary to deal with these dangerous diseases. The methods of tracking digital contacts are much more efficient as they helped reduce human effort, material resources, speed, and accuracy of implementation. Therefore, many contact tracing apps have been implemented in many countries as an effective way to discourage COVID-19 [16]. The mobile app allows us to receive a notification immediately after confirming a positive case of Covid-19, by recording potential convergence events between users. If a person gets a positive result, then everyone who coincides with him/her in a specific time and distance is vulnerable to contracting the disease [17]. We identified seven studies to digital contact tracing with a summary of the characteristics, as shown in (Table1). These studies were based on different system architectures (centralized, decentralized, and hybrid) [18]. Where four studies depended on the central architecture [17] [19] [20] [21], one study on decentralized architecture [22], and

two studies on hybrid architecture [23] [24]. Three studies relied on the principle of proximity using Bluetooth Low Energy (BLE) technology [17] [19] [20], one of which used GPS optionally to determine the location [20]. While the other three studies relied on the principle of location using GPS technology [21] [23] [24], one of them used BLE to improve location accuracy only [21], and another study used a QR code in tracking [22]. One study developed the application in a joint response interface for both smartphone and PC users utilizing the classic web stack: PHP and MySQL [23]. While two studies developed their applications based on Android phones [19] [20].

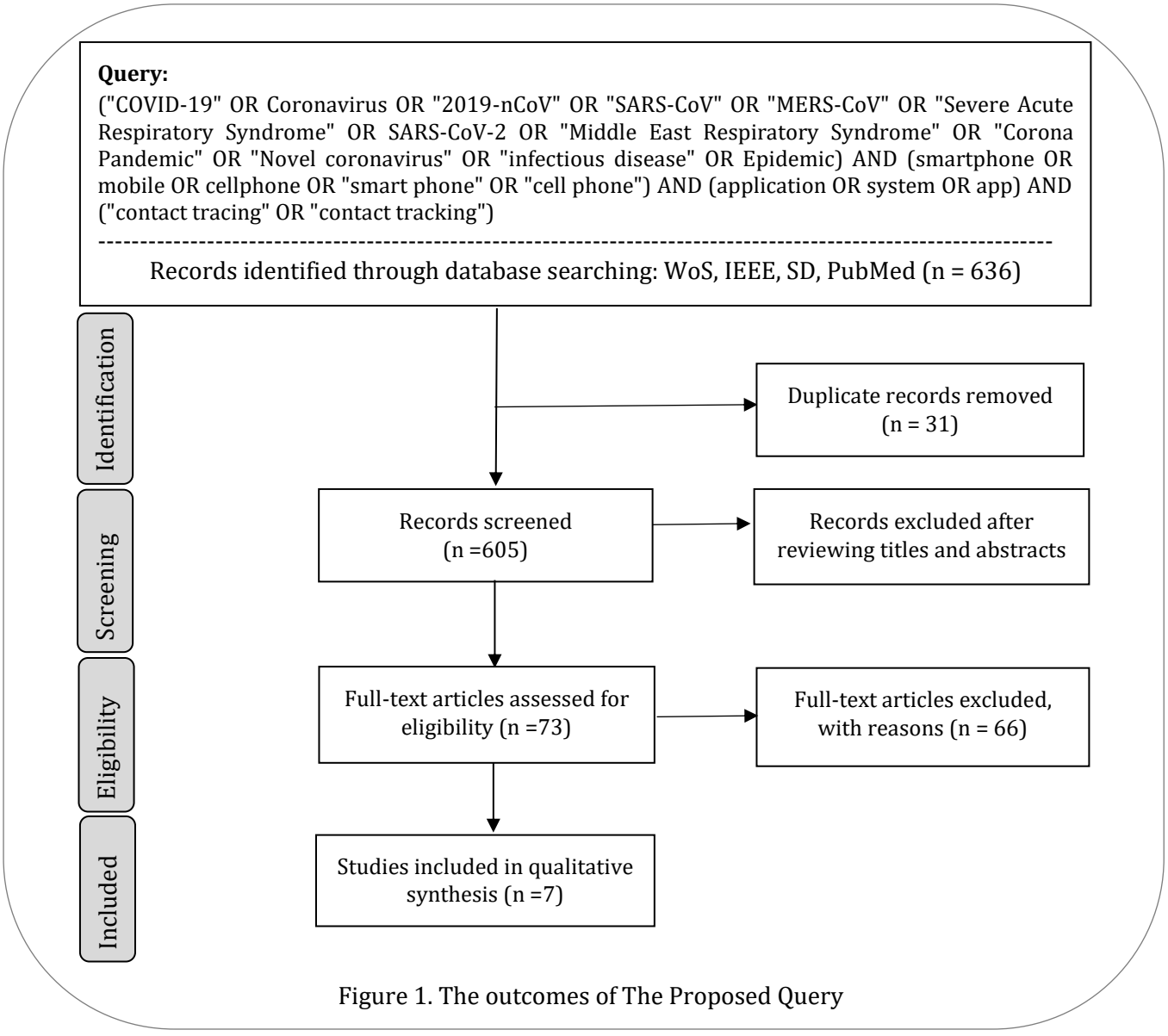


Figure 1. The outcomes of The Proposed Query

The research of [17], identifies of the main parameters needed to reduce the reproductive number R0 to less than 1: the ratio of cases that require to be isolated and the ratio of contacts that require to be quarantined. For every one of the 40 transmission pairs, this study provided an estimate of the proportion of pre-symptomatic transmission, asymptomatic, symptomatic persons, the environment, and quantified the impact of the intervention (case isolation, contact tracing, and quarantine) at various delay periods. The research of [19], based on using a fog-based IoT-healthcare that provides optimization to improve communication of data, low power usage, improves efficiency in cost terms, delay of network, and energy consumption [26] [27]. It presented that another new unique reference code RUERC every two hours drove from primary UERC is created in the application, which is shared based on user consent with neighboring devices. It guarantees that the information from the broadcast can't be used to track a person. Both [17] and [19] are centralized application and offer a service of immediate contact tracing between phones by Proximity-based. Only [19] used mechanism for privacy preserving that included in e-government

Privacy-Preserving Mobile and Fog computing framework to trace transmission. In [20], the authors developed and improved Infection Probability Prediction Algorithm, in addition to distance and contact period. To evaluate the correlated Risk Factors (RF), three essential characteristics were known to be age, comorbidity, and gender. It presented simulations that were compared together with a real data set from Hainan province in China from 22nd January to 7th May 2020 (168 confirmed cases), when the edges maximum number is reduced. The iterations number made is increased, which takes all nodes to infect. Thus, this outcome is verifying that self-isolation is necessary to avert or slow down the progression of the disease. This research registered the user's contact information such as phone number, address, and e-mail, as well as the users' health-related data (e.g. chronic conditions), which are optionally provided to improve the associated Risk Factors (RF) and receive more accurate. This research based on social interaction tracking app to gather information about the closely phones and interaction duration so this application cannot be used without existing the social interaction. In [21]. The authors implemented ZE2-PT3 which is relied on active cryptographic hashes and blind RSA signatures of 1024 bits [25] to avoid fake positive reports. The implemented ZE2-PT3 used a position negotiation protocol (PNP) that involved users' pairs to improve the precision of GPS captured coordinates. This research-based on dividing a large geographical area into several microcells, every microcell ci associated with a point Ci known as centroid corresponding to the square center. This solution requires the cooperation of a telephone service provider (TSP) to send a random RP to all users in a fixed area P called a cell (a set of microcells) periodically, depending on the antenna coverage range. Therefore, the two users obtain always the same RP at the same time in the same microcell. The proposal in [22] aimed to limit the abuse of the application by false reporting. The authors also implemented a centralized framework for managing confirmation codes for users with a confirmed diagnosis, as the data on the server is anonymized because no registration is mandatory for users, and no personal data are collected. In addition, smartphone app users can access their checkpoint points only. This research presented a development of a low-fidelity computer simulation model that allows disease propagation at contact points over time through interaction between individuals. No need to worry about the lifespan of QR codes, because they are unlimited[28]. The results indicate that usage and acceptance rates are critical to the effect of such application on disease outbreaks. Thus, in comparison with no adoption, even a 25% adoption will suppress the infection curve. It allows the users to create "checkpoints" or joining those already established for contact tracing by QR code, check their level of risk based on their previous interactions (standard or elevated), and their peer network anonymously self-report a positive status.

The proposal of [23], kept all websites that the user has been in in the last 14 days in a JSON file inside the phone, and the file automatically sent from the patient's device to the server. Nevertheless, if it is not used the application, the sites are added manually to the server via the "Report Case" window. In [24], the authors developed two algorithms. The first is used to extract the efficient points of the path of the person, utilizing the K-means algorithm to find the effective location by the data processing platform then send the results to all system-registered smartphones. The second is used to self-investigation contacts with infected users within the user's device by comparing the efficient points, which is obtained from the person tracking data of the infected individual with active points for the mobile owner, and an alert will be automatically by the Application when there is a match between them. This algorithm was implemented on the user's phone or data processing platform if the user can choose to periodically send the tracing information file to the platform. The data is saved to the phone's memory in an encrypted file, and used data processing platform to extracts the efficient points of the path of the individual and categorizes them into two classes. The first is for the location coordinates that can be advertised to the public. The second is sent only to specific entities to take precautionary measures and used a website to display the active points of the path of the infected person on a map or by text messages, to warn people who may have been to these locations and neither to have smartphones nor use the application on their phones. (Table 2) show the reviewed objective of the Intervention or exposure and the main outcomes. Both [23] and [24] are based on GPS only and it's hard to maintain user privacy when deploying the GPS.

**Table 1. Summary of the Literature Researches Characteristics**

| Authors | Study design | Country | App Name | Architecture | Device Type | Tech. | Type of tracking |
|---|---|---|---|---|---|---|---|
| Ferretti et al (2020) [[2]] | Modeling study | China | Not specified | Centralized | Smartphone app | BLE | proximity-based |
| Whaiduzzaman et al (2020) [19] | Modeling study | Australia | PPMF | Centralized | Smartphone app | BLE | Proximity-based |
| Sandeepa et al (2020) [20] | Modelling study | China | Not specified | Centralized | Smart phone app | BLE & GPS | proximity based and location (optional) |
| Buccafurri et al (2020) [21] | Modeling study | N/A | ZE2-P3T | Centralized | Smartphone app | GPS & BLE | Location and Use BLE to improve accuracy |
| Yasaka et al (2020) [22] | Modeling study | USA | TrackCOVID | Decentralized | Smartphone app | QR code | face-to-face with manual code checking |
| Hang et al (2020) [23] | Modelling study | Romania | Covid-19 Contacts Tracker App | Hybrid | Smart phone app / PC | GPS | Location |
| Elmesalawy et al (2020) [24] | Modelling study | Egypt | Tracy | Hybrid | Smart phone app | GPS | Location |

**Table 2. A Summary of Intervention Target and Main Outcomes**

| Authors | Intervention or exposure | Main outcomes |
|---|---|---|
| Ferretti et al (2020) [[2]] | A mathematical model for infectiousness to assessment the basic reproductive number R0 and measure the contribution of various transmission routes. | Developed an application to allow immediate contact tracing between phones by Proximity-based and automatically notifies contacts are instantly. |
| Whaiduzzaman et al (2020) [19] | The system contains of two kinds of fog nodes: ARCs to identify if there are positive or suspected cases close by and broadcast pre-cautionary alerts to closely individuals without uncovering the identity of the infected person, and SUDUNs to send the test results of the report to the central cloud app. | Developed an e-government Privacy-Preserving Mobile and Fog computing framework to trace transmission of community as well maintaining the privacy of user data. |
| Sandeepa et al (2020) [20] | Formulated an infection prediction algorithm based on social interaction to calculate infection probability by analyzing data in the cloud. | Designed social interaction tracking app that can gather information about the closely phones and interaction duration. |

| | | |
|---|---|---|
| Buccafurri et al (2020) [21] | Divide a large geographical area into several microcells, and send RP to all users by TSP. | Described a solution called (ZE2-P3T), based on GPS to sense proximity, and just on BLE to increase accuracy without exchange of identifiers. |
| Yasaka et al (2020) [22] | Structure of transmission graph data to appear the interactions between people. | Designed a smartphone application that protects consumer privacy by not collecting location data or other sensitive data. |
| Hang et al (2020) [23] | Google Maps JS API to represent the marked locations on the map. | Developed an app displayed all the locations visited by the confirmed patients on the map, detect the user's location, and the distance to each place is computed. |
| Elmesalawy et al (2020) [24] | Identify user points with a timestamp and compare them with hotspots received for the affected person to determine if there is any potential match. | Developed privacy-preserving contact tracing solution that supports self-investigation, and website. |

## 8. Challenges and Limitation

Smartphone-based contact tracing offers an applicable solution to reduce the transmission of diseases, but many research challenges and constraints have been mentioned in the literature academic and need to be processed. One of these main challenges is what is related to the privacy issues of users. Another challenge is the effective and reasonable use of the app, based on its well-founded public confidence and trust in the data gathered [17]. Some of these challenges are related to infected individuals who can carry the disease for 14-21 days without any symptoms. As a result, the virus is transmitted to other people they have come into contact with and making it highly contagious [24]. In addition, the challenge of there is no means of ensuring that users report confirmed diagnoses through the app [22]. Further, Other challenges related to critical user data (location history) need to be ensured that nobody can access this for illicit purposes [23]. Moreover, the inability to predict the possibility of infection with the virus [20]. Battery power consumption is another challenge because the user is unable to turn off the app background service, and these apps don't have the option to shut down [19]. Finally, finding solutions to address transmission across environments and surfaces (indirect contacts) [21].

## 9. Recommendation

This study aimed to highlight the academic literature's proposals for recommended solutions to address some of the challenges. Studies, such as [17], proposed an app that allows immediate contact tracing by proximity-based interactions between phones these are registered in the app, contacts are recorded, anonymously notified of their risk automatically and instantly, and asked for self-isolating. The study of [19] proposed Privacy-Preserving Mobile Framework (PPMF) consists of four essential components: A smartphone of the user that contains BLE technique, the dashboard of privacy, the algorithm of filter, storage file, and service of communication, two kinds of fog nodes: Automatic Risk Checkers (ARC) and Suspected User Data Uploader Node (SUDUN), and a central cloud app that integrates these nodes. in [20], the authors proposed monitoring user social interaction and predict the risk of infection based on social interactions. The study in [21], proposed a solution (ZE2-P3T) Using GPS to detect proximity, and BLE only to boost accuracy without identifier sharing, while ensuring that nothing is known about user positions by the server. In [22], the authors proposed an effective mechanism for contact tracing without compromising user privacy named TrackCOVID based on using an anonymized graph of interpersonal interactions (transmission graph) contains on nodes. These nodes represent points of contact between people and guided edges, which are transmission vectors between points of contact. In [23], A cross-platform app has been proposed called

(Covid-19 Contacts Tracker App) to trace the infected individuals by their location history depend on each person social responsibility. in [24], The authors proposed an innovative contact tracing solution while preserving privacy called "Tracy", which is designed and built based on a hybrid architecture, facilitating self-investigation and protecting confidentiality.

## 10. Conclusion

In light of the significant impact of the COVID-19 pandemic on the world, it has become necessary to find several technical solutions to fight this epidemic and other infectious diseases. One such solution is the development and deployment of digital contact tracing tools to manage the epidemic, forecast infections, and reduce lockdowns. This systematic review provided an overview of the available contact tracing systems and applications with their effective role in detecting infected persons as well as those who had been in close contact with them. Distinctive information was indicated, such as the nature of the application, working principle, techniques used to detect convergence and contact, algorithms for extraction of effective contact points, injury prediction algorithms, and improvement of communication accuracy. One of the main challenges in contact tracing methods is maintain the contact privacy. This research analysis the investigated studies in terms of architecture, device type, used technique, and tracking type. It explain the intervention or exposure and main outcomes of each study with its advantages and disadvantages. In addition to, discuss set of proposals that have been developed to address many challenges where most prominent of which are preserving privacy and restricting access to data and ensuring that these tools are scientifically sound and ethically to ensure the confidence of the public and use widely. The aim is to behavior new studies that can help governments and health institutions fight and control this epidemic by making use of the characteristics and features gathered in the literature.

## References


[1] WHO. World Health Statistics. https://www.who.int/data/gho/publications/world-health-statistics (2020).

[2] WHO. WHO Director-General's opening remarks at the media briefing on COVID-19 - 11 March 2020. https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020 (2020).

[3] Emily Cameron-Blake, Helen Tatlow, Laura Hallas, S. M. Coronavirus Government Response Tracker | Blavatnik School of Government,Oxford COVID-19 Government. https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker (2020).

[4] Douglas, M., Katikireddi, S. V., Taulbut, M., McKee, M. & McCartney, G. Mitigating the wider health effects of covid-19 pandemic response. BMJ 369, (2020).

[5] Gallagher, J. Covid: Why is coronavirus such a threat? - BBC News. https://www.bbc.com/news/health-54648684 (2020).

[6] European Centre for Disease Prevention and Control. Contact tracing: public health management of persons, including healthcare workers, who have had contact with COVID-19 cases in the European Union – third update. https://www.ecdc.europa.eu/en/covid-19-contact-tracing-public-health-management (2020).

[7] WHO. WHO | Public health surveillance, Immunization, Vaccines and Biologicals. https://www.who.int/immunization/monitoring_surveillance/burden/vpd/en/ (2020).

[8] WHO. Contact tracing in the context of COVID-19: interim guidance, 10 May 2020. https://apps.who.int/iris/handle/10665/332049 (2020).

[9] WHO. Contact tracing. https://www.who.int/news-room/q-a-detail/contact-tracing (2020).

[10] Ish, P., Agrawal, S., Goel, A. D. & Gupta, N. Contact tracing: Unearthing key epidemiological features of COVID-19. SAGE Open Med. Case Reports 8, 2050313X2093348 (2020).

[11] Hernández-Orallo, E., Manzoni, P., Calafate, C. T. & Cano, J. Evaluating How Smartphone Contact Tracing Technology Can Reduce the Spread of Infectious Diseases: The Case of COVID-19. IEEE Access 8, 99083–99097 (2020).

[12] Riley, S. et al. Transmission dynamics of the etiological agent of SARS in Hong Kong: Impact of public health interventions. Science (80-. ). 300, 1961–1966 (2003).

[13] Saurabh, S. & Prateek, S. Role of contact tracing in containing the 2014 Ebola outbreak: A review. Afr. Health Sci. 17, 225–236 (2017).

[14] Moher, D., Liberati, A., Tetzlaff, J. & Altman, D. G. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 6, e1000097 (2009).

[15] Brown, J., Chapman, S. & Lupton, D. Infinitesimal risk as public health crisis: News media coverage of a doctor-patient HIV contact tracing investigation. Soc. Sci. Med. 43, 1685–1695 (1996).

[16] WHO. Digital tools for COVID-19 contact tracing. https://www.who.int/publications/i/item/WHO-2019-nCoV-Contact_Tracing-Tools_Annex-2020.1 (2020).

[17] Ferretti, L. et al. Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing. Science 368, (2020).

[18] Vaudenay, S. Centralized or Decentralized? The Contact Tracing Dilemma. https://www.golem.de/news/pepp-pt-streit-beim-corona-app-projekt-2004-147925.html (2020).

[19] Whaiduzzaman, M. et al. A Privacy-preserving Mobile and Fog Computing Framework to Trace and Prevent COVID-19 Community Transmission. IEEE J. Biomed. Heal. Informatics 1 (2020) doi:10.1109/JBHI.2020.3026060.

[20] Sandeepa, C., Moremada, C., Dissanayaka, N., Gamage, T. & Liyanage, M. Social Interaction Tracking and Patient Prediction System for Potential COVID-19 Patients. in 2020 IEEE 3rd 5G World Forum (5GWF) 13–18 (2020). doi:10.1109/5GWF49715.2020.9221268.

[21] Buccafurri, F., Angelis, V. De & Labrini, C. A Privacy-Preserving Solution for Proximity Tracing Avoiding Identifier Exchanging. in 2020 International Conference on Cyberworlds (CW) 235–242 (2020). doi:10.1109/CW49994.2020.00045.

[22] Yasaka, T. M., Lehrich, B. M. & Sahyouni, R. Peer-to-peer contact tracing: Development of a privacy-preserving smartphone app. JMIR mHealth uHealth 8, (2020).

[23] Hang, A., Dascalu, M.-I. & Stanica, I. Contact Tracing App for Containing Diseases Spread. in 2020 Zooming Innovation in Consumer Technologies Conference (ZINC) 216–217 (2020). doi:10.1109/ZINC50678.2020.9161820.

[24] Elmesalawy, M. M., Salama, A. I. & Anany, M. G. Tracy: Smartphone-based Contact Tracing Solution that Supports Self-investigation to Limit the Spread of COVID-19. in 2020 2nd Novel Intelligent and Leading Emerging Sciences Conference (NILES) 623–628 (2020). doi:10.1109/NILES50944.2020.9257915.

[25] Goldwasser, S. & Bellare, M. Lecture Notes on Cryptography. (2008).

[26] Mahmud, R., Koch, F. L. & Buyya, R. Cloud-fog interoperability in IoT-enabled healthcare solutions. in ACM International Conference Proceeding Series 1–10 (Association for Computing Machinery, 2018). doi:10.1145/3154273.3154347.

[27] Yang, G. et al. IoT-Based Remote Pain Monitoring System: From Device to Cloud Platform. IEEE J. Biomed. Heal. Informatics 22, 1711–1719 (2018).

[28] H. K. Selman and A. E. Ali, "Quick Response Code for Controlling Web of Things," *J. Al-Qadisiyah Comput. Sci. Math.*, vol. 12, no. 1, p. Page 1 – 9-Page 1 – 9, Feb. 2020, doi: 10.29304/JQCM.2020.12.1.657.