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Analysis of digital contact tracing technologies employed during the COVID-19 Pandemic

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ABSTRACT

Corona virus (COVID-19) is a worldwide pandemic that was first reported in Wuhan, China 2019.The virus claimed lives and negatively changed the mobility patterns of humans. As a measure to control the spread of the virus, Digital Contact Tracing Technologies (DCTT) were employed to contain the virus. The (DCTTs) are used to track and notify users digitally about their interactions with infected individuals and help strengthen health service systems. The most widely used Digital Contact Tracing Technologies include those that use Global Positioning, Bluetooth, Quick Response (QR) Codes and Wireless Fidelity (Wi-Fi). These technologies depend on monitoring symptoms, mobility of a person, location and proximity of individuals. This paper reviews literature by analyzing the Digital Contact Tracing Technologies (DCTTs) employed for COVID-19 through a desk study. The review highlights the advantages and disadvantages of using these technologies, with an aim of recommending ways in which the technologies can be used to attain maximum benefit.

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Introduction

World Health Organization (WHO, 2011) defines contact tracing as a process of monitoring individuals who may have been exposed to someone with an infectious disease and or are at risk of infecting others. The process of identifying contacts begins once an the tracking of an infected person has been done. Here, the individual who has contracted the infection recalls events and the responsibilities of others involved since the infection first manifested itself. Contact listing and contact follow-ups begins once the contact identification ends where contact listing helps in giving the names of likely affected contacts, and contact follow-up aids in keeping track of the manifestation of viral infection symptoms (Owusu, 2020).

In order to stop the spread of an infectious disease contact tracing is used (Trivedi et al., 2021).Traditionally contact tracing is done by officials in public health who interview infected individuals so as to identify their contacts and advice exposed contacts either to self-monitor for symptoms, self-quarantine or obtain medical evaluation and treatment(Kleinman & Merkel, 2020).

Contact tracing as an approach to manage infectious diseases has been adopted by public health organizations to control and monitor outbreaks of diseases like HIV, Ebola, measles (Shahroz, Ahmad, Younis, Ahmad, Boulos, et al., 2021), and through extensive contact tracing of infected people smallpox was controlled (Scutchfield & Keck, 1997). In order to suppress the transmission of any infectious disease it is important to identify cases and their close contacts early. The outbreak of the corona virus disease 2019 (COVID-19) led to the World Health Organization declaring COVID-19 a global pandemic, and strict regulations were imposed by nations as an infection control and preventative measures to combat the spread and impact of the virus(Shahroz, Ahmad, Younis, Ahmad, Kamel Boulos, et al., 2021).

Opportunities have been created for advancements in technology-based solutions as a result of COVID-19 and the provision of research and practice of technology in management of information, work practices, and design and use of technologies (He et al., 2021). Digital technology has several advantages and can play a crucial role in managing and lowering the risks associated with the lockdown during the pandemic and even after the pandemic, as evidenced by the rapid adoption of telemedicine, telework, and online education in response to the coronavirus threat (Richter, 2020). During COVID-19 pandemic, traditional contact tracing limitations have become apparent as it is intensive in terms of labor and time, making it challenging to scale with increasing numbers of people infected with COVID-19 (Kleinman & Merkel, 2020). Digital contact tracing uses electronic information for exposure infection identification addressing limitations of traditional contact tracing, such as scalability, delays in notification, errors in recalling and identification of contacts in public spaces (Kleinman & Merkel, 2020).

Digital contact tracing technologies (DCTTs) have been used to track and notify users digitally about their interactions with infected individuals thus breaking the chain of transmission and help strengthen health service systems. Digital contact tracing technologies can be categorized into those for response during outbreaks, proximity and contact tracing, and for monitoring symptoms (Anglemyer, 2020) (Gasser et al., 2020). Response tools for outbreaks are designed for public health response personnel involved in contact tracing activities and investigations during outbreaks. They encompass the management of complex relational data of cases and their contacts through electronic data entry of case and contact information.

Outbreak response tools can be used to facilitate all aspects of contact tracing, including case investigation, listing and monitoring of contacts, and automating analysis and performance monitoring (WHO, 2020). Proximity tracing (tracking) tools use location-based (GPS) or Bluetooth technology to find and trace the movements of individuals to identify people who may have had been exposed to an infected person. The risk of exposure to COVID-19 depends on the probability of coming into close (less than 1 metre) or frequent contact with people who may be infected. (WHO, 2020) defines tools for proximity tracing as either centralized or decentralized. Symptom tracking tools use applications designed to routinely collect self-reported signs and symptoms to assess disease severity or the probability of infection due to COVID-19.

When integrated into contact tracing these tools may also be helpful especially in settings where there are physical or security barriers to in-person visits by contact tracing teams. Additionally, symptom tracking tools could augment in-person visits by receiving reports from contacts of confirmed cases more than once a day (WHO, 2020). The merits of digital contact tracing solutions are (i) creation of logs of locations visited and time of visit (ii) doesn't require human intervention for passive logging (iii) scalability to a large audience, and (iv) provision of a notification interface that is easy and quick(Trivedi & Vasisht, 2020).

For every Digital contact tracing technology (DCTT) solution, the process can be manual, automated or a blend of both where for instance tools for proximity tracing that are manual rely on Quick Response codes scanned by users on entry into stores while tools that are automated use Global Positioning System or Bluetooth technology to register your visits. Thus complementing conventional contact tracing techniques with digital contact tracing techniques by employing

Digital Contact tracing technologies (DCTTs) like Global Positioning System, Bluetooth or Quick Response codes, to track and notify users digitally about their interactions with potentially infected individuals (Amann et al., 2021). Singapore, South Korea, Israel, Italy, Germany, and china implemented DCTTs and the platforms emerged as essential component of global response against COVID-19 (Anglemyer, 2020).

Objectives

The objective is to review literature by analyzing Global Positioning Systems (GPS), Bluetooth, Quick Response (QR) Codes and Wireless Fidelity (Wi-Fi) as Digital Contact Tracing Technologies (DCTTs) employed for COVID-19. Highlight use of DCTTs in contact tracing, their merits and demerits and look at specific solutions developed from these DCTTs.

Methods

The paper performs a literature review on COVID-19 contact tracing technologies, their application, benefits and challenges. The following search databases were used to search studies: Scopus, IEEE Xplore, ACM Digital Library, Science Direct, PubMed, The Lancet, Springer Link ,ELSEVIER and any other peer reviewed journal related to the theme. The targeted search items were journal papers, conference papers and articles. Automatic search was used to perform the search, in the selected databases by entering search strings on the search engines of the electronic data source and the relevant studies were selected. The search string "COVID-19 contact tracing" and "Contact tracing Technologies" were used and articles and publications from Scopus, IEEE Xplore, and ACM Digital Library, The Lancet, PubMed and papers with high number of citations were preferred.

Inclusion criteria was based on

- Studies written only in English;
- Studies referencing any of the subjects related to COVID-19 and Contact tracing technologies
- Peer reviewed journal papers, conference papers, articles, and workshop papers.

Exclusion criteria was:

- Repeated studies found in different search engines only one study was considered;
- Duplicate studies reporting similar results the most complete study was considered;
- Inaccessible papers and books.

Digital Contact Tracing Technologies (DCTT)

Digital contact tracing technologies (DCTTs) employs technology to trace and track contacts (Anglemyer, 2020) with the smartphone being the key tool for digital contact tracing. Users around the world today carry their phones everywhere. Based on the various features present in a smartphone, the digital contact tracing solutions can be designed based on GPS, Bluetooth, Wi-Fi, etc. with each technology having its benefits and limitations (Trivedi & Vasisht, 2020). A smartphone is used to register close contacts with other smartphones, running the same contact tracing application. Hardware devices such as the Trace Together token that uses Bluetooth, but operates independently of a phone; wearables like wristwatches that can track the location using GPS and a few apps like NOVID also broadcast ultrasound signals using a phone's speakers and other apps in the vicinity detect them using their microphone (Simmhan et al., 2020). DCTTs heavily rely on applications installed on the smartphones (Hernandez-Orallo et al., 2020) and DCTTs solutions enables for the creation of logs of visited locations and visited time, no human intervention required to passively login, reaches a large audience and the interface notification is easy and quick (Trivedi & Vasisht, 2020). The mobile phone is the core tool used for digital contact tracing where contact tracing applications use smartphone based applications that track digitally an individual's contacts through locations proximity using either QR Codes, Bluetooth or GPS solutions (Zetterholm et al., 2021). The involvement and use of mobile software technology was used by researchers in the United Kingdom to allow users install Flu phone a mobile software application that anonymously collected information on social encounters using Bluetooth, GPS coordinates and self-reported data (Owusu, 2020). The various smartphone features present enable for the development of digital contact tracing systems based on DCTTs like Bluetooth, GPS,QR Codes, Wi-Fi with each of the DCTTs solution having its benefits and limitations (Trivedi & Vasisht, 2020).

Bluetooth Technology

Bluetooth protocol is a wireless technology standard with different modes of transmission and functionality (Magklaras & López-Bojórquez, n.d.) that uses radio waves for short distance wireless communication, and requires a Bluetooth chip and Bluetooth communication enabled for two devices to communicate (Trivedi & Vasisht, 2020). Bluetooth Low Energy (BLE) works by performing proximity sensing calculations that are used to estimate the distance between index case and contacts thus being applied for the implementation of COVID-19 contact tracing (Magklaras & López-Bojórquez, n.d.).

Bluetooth Low Energy (BLE) applications works by advertising a unique ID that is recognizable by nearby devices with an application that scan for and save the advertised IDs (contacts). A local device stores the information and if a user tests positive their Bluetooth contacts are uploaded to a central database and their contacts are alerted thus reducing time required for contact tracing thereby containing the spread of the infectious diseases (Kretzschmar et al., 2020). In regards to its application for COVID-19 Bluetooth Low Energy is widely used because it consumes less energy and costs less though it requires use of smartphone and for Bluetooth to be active always, has implications on security and privacy, has low data quality, is inaccurate for proximity tracing (Sharon, 2021) and it covers a short range preferably indoors.

Bluetooth based contact tracing apps use a wireless technique to detect the smartphones of nearby positive diagnosed cases that have Bluetooth activated in their application. The technology emits Bluetooth Low Energy (BLE) "chirps" and sustains a database exchange mechanism by recording a pseudorandom bit sequence emitted by the chirping smartphones, along with the estimated power of the chirp's delivery (Min-Allah et al., 2021). To alleviate the short range problem,

Bluetooth and Google and Apple provided an Application programming interfaces(APIs) for the interaction between mobile devices in close proximity whereby Bluetooth communication features in iOS and Android devices assigns a unique, anonymous identification code for all contacts of a person's device in close proximity (Owusu, 2020). Bluetooth technology can be used for COVID-19 contact tracing activities to detect crowd and help maintain safe distance between two or more people to enhance social distancing thus mitigating the spread of the virus.

Countries that have implemented Bluetooth based applications among others include India's Aarogya Setu, Singapore's Trace Together, Switzerland's Swiss Covid mainly due to the ubiquity of the smartphone where the applications are deployed (Trivedi et al., 2021). Bluetooth signal strength is used by most COVID-19 contact tracing apps to infer distance between smartphones and define exposure status based on distance from, and duration of proximity to, an individual identified as infected (Kleinman & Merkel, 2020).

Wireless Fidelity (Wi-Fi)

Wi-Fi is a communication technology that uses a wireless transmitter called Wi-Fi Access Point (WAP) to communicate with its user devices (Shahroz, Ahmad, Younis, Ahmad, Boulos, et al., 2021) and is very effective for contact tracing in indoor environment such as multi-story buildings (Yang & Shao, 2015) through positioning (Shahroz, Ahmad, Younis, Ahmad, Boulos, et al., 2021). In Wi-Fi networks with many access points (AP), user devices sometimes are connected, disconnected, and move between access points where the events across access points are logged internally by each access point in a system log (syslog) file.

When the logged in events in the systems log file are analyzed for each device, mobility trajectory of each device is identified hence deriving mobility trajectories of users connected to the network using Wi-Fi logs to get information about locations visited and the time of visit as logged by the connection, disconnection time by the access points in the system log files (Trivedi & Vasisht, 2020).

There is myriad of information, such as mobile device MAC address, Access Point (AP) MAC address, and user ID. These tools analyze the overlapped time and date sequence of all connected devices to the same access point, and alert all users to the risk of contacting an infected person. The architecture used in Wi-Fi based is network based, and the way it uses location sensing is by using access point level or Wi-Fi locating, the method that Wi-Fi uses to collect the data that is in the network (Min-Allah et al., 2021).

Wi-Fi contact tracing is used because of their provision for use in indoor contact tracing, it works with existing Wi-Fi network, is wholly passive, collects details of time and duration of a user's visit and Wi-Fi system log's systems don't require application installation on mobile phone (Trivedi & Vasisht, 2020). However, Wi-Fi based contact tracing range of the access point determines the spatial location granularity, to measure the time it takes for a sound to go from one device to another is different for different devices and a person might be connected to the same access point but be in different rooms.

Wi-Fi-based contact tracing might state that the 2 persons are in contact when in reality they might have never come in contact (Trivedi & Vasisht, 2020).

Global Positioning System (GPS)

The Global Positioning System (GPS) provides geographic location and time details to devices furnished with a GPS receiver through a set of GPS radio navigation satellites to locate the position of the GPS-enabled device (Shahroz, Ahmad, Younis, Ahmad, Boulos, et al., 2021) thus providing a way of tracking individuals. Most smartphones are GPS enabled and GPS works worldwide (Shahroz, Ahmad, Younis, Ahmad, Kamel Boulos, et al., 2021). GPS has some challenges firstly, it raises serious privacy questions because the location (not just a contact) is being logged, and secondly, it fails on the accuracy front as well. GPS suffers from poor accuracy, especially indoors and outdoors urban tunnels (Trivedi & Vasisht, 2020). GPS traces reveal a lot about individuals such as their daily routines, activities, and frequent co-locators.

Overall, the accuracy of Global Positioning System is low for contact tracing with errors of 20-30 feet, especially indoors where humans spend a lot of their time, so using it for contact-tracing won't help much anyway. In addition, sharing location details with a central entity can lead to leakage and data misuse. However, with explicit user consent to upload selective data, it can provide other benefits like help governments visualize the locations of high-risk individuals, and allocate healthcare resources, thereby preempting the outbreak (Trivedi & Vasisht, 2020).

Global Positioning System is used to locate or trace people to identify individuals that are exposed to, or have been infected with COVID-19. Using GPS signals, an application will collect and record user movements as coordinates with a timestamp. The application looks for matches in a multidimensional grid of longitude, latitude, and time. The system is composed of a user device that sends the location and a server that stores and encrypts the data. Global Positioning System is used mostly to enforce a quarantine on COVID-19 patients with an application that would highlight areas where a high number of COVID-19 cases are located. GPS location tracking requires the users to always have their phone charged and working and with location tracking enabled on the device (Min-Allah et al., 2021).

Through the use of GPS location or by Bluetooth signals, Internet of Things (IoT) can enable a scalable, automated contact tracing system that can cope with the ever-increasing workload of contact tracing (Shahroz, Ahmad, Younis, Ahmad, Boulos, et al., 2021). GPS technology can help limit physical contact between people thus enhancing social distancing between people (Shahroz, Ahmad, Younis, Ahmad, Boulos, et al., 2021).

Quick Response (QR) Codes

QR codes enables a user to manually contribute to the database by taking a picture of visual computer-aided code at multiple places of business (Shahroz, Ahmad, Younis, Ahmad, Boulos, et al., 2021). Mobile phone application automatically reads hidden geolocation of these QR codes and populates the database with user details. If a person is tested positive, their contacts at places they have visited can be identified using contact tracing based on QR codes. QR codes uses location-coupled QR contact tracing and symptom-based QR health code approaches and the use of QR health code technique in contact tracing has several concepts (Min-Allah et al., 2021).

Symptom based Quick Response health codes are released by health authorities with two colors red and green to identify the health status of individuals where green code signifies the individual is not infected and green code signifies the individual is infected or has a high probability of being infected. QR scanners automatically analyzes and reads the information in the code thus reducing errors, data credibility is maintained and speed of processing is faster compared to manual operation.

To reduce spread of COVID-19 QR Codes technique detects whether individuals are healthy or infected, by their movements in crowded public places and through traceability, governments can quickly identify potentially infected people and take timely measures (Min-Allah et al., 2021).Such techniques are globally used, with China being a prime example that has a far higher rate of adoption of QR codes (Shahroz, Ahmad, Younis, Ahmad, Kamel Boulos, et al., 2021).

Zigbee Technology

Zigbee is a standard-based wireless communication technology used for wireless networks that are low-cost and low power. Devices that are ZigBee based communicate with each other in unlimited hops and in the range of about 65 feet (20 m) (Shahroz, Ahmad, Younis, Ahmad, Kamel Boulos, et al., 2021). The technology defined by the ZigBee specification is supposed to be simpler and less expensive than other WPANs such as Bluetooth, or more general wireless networks that use Wi-Fi (McHeick et al., 2021).

The ZigBee control hub can determine the user's location, which can be used for crowd control thus the ZigBee communication technology can be used for contact-tracing purposes to avoid the spread of the virus(Shahroz, Ahmad, Younis, Ahmad, Kamel Boulos, et al., 2021).

Discussion

Majority of Countries around the world have adopted digital contact tracing technology (DCTT) solutions most using applications to support the manual tracing processes. These applications (apps) vary in the way contact tracing is performed. Some of the applications use GPS to track the users' movements, while others use a more privacy preserving design based on Bluetooth advertisements to register close contacts. There are governments that have made use of their apps mandatory, while others it is voluntary and some apps have their source code released for the public to scrutinize. Most of the digital contact tracing apps are based on Bluetooth and Global Positioning System technology (Mbunge, 2020), while some also use Quick Response

Codes with many of the apps based on Bluetooth. Besides the use of smartphone based applications as digital contact tracing technology solutions , others have also developed hardware devices such as the Trace Together token that uses Bluetooth, but operates independently of a phone; wearables like wristwatches that can track the location using Global Positioning System and a few apps like NOVID do broadcast ultrasound signals using a phone's speakers and other apps in the vicinity detect them using their microphone (Simmhan et al., 2020). The COVID-19 pandemic has impacted people, businesses, society and has had implications for the design, development, and use of technologies (He et al., 2021).

Future pandemics are likely to come and contribution towards knowledge, experiences, and time can help society better prepare for them (He et al., 2021).Digital contact tracing Technology solutions can be useful for reducing the severity of corona virus disease 2019 (COVID-1`9) and any future infectious disease impact on people, organizations, society and the world as a whole. There is need for the development of a uniform global standard and technologies that are acceptable to all to provide an enabling environment for the use of Digital Contact Tracing Technologies (Thayyil et al., 2020). There are also emerging digital contact tracing technologies which include but not limited to the internet of things (IoT) with next generation telecommunication networks (e.g., 5G); big-data analytics; artificial intelligence (AI) that uses deep learning and block chain technology (Shahroz, Ahmad, Younis, Ahmad, Kamel Boulos, et al., 2021),virtual reality, Internet of Medical Things (IoMT) that have also been implemented to tackle COVID-19 pandemic (Mbunge et al., 2021).

However, the use of these technologies to combat the COVID-19 pandemic have had challenges such as security, privacy, biases, ethics, and the digital divide (He et al., 2021).

Digital technology	Function	Digital Technology Application (app) description	Merits of Digital technology	Demerits of digital technology
Global positioning system (GPS)	Locates the exact position of devices that are GPS-enabled using a network of satellites thus limiting physical contact between people.	-Jordan's Aman -Rhodes Islands CRUSH COVID RI - Egypt's COVID app	-Enables location and identification of individuals for testing and quarantine -Tracks the viral spread of an infectious disease. -Visually depicts the spread of virus -Border restrictions and resource allocation are guided	-Breaches privacy -Costly -Needs to be managed and regulated -Fails to detect exposed individuals if the application is deactivated
Bluetooth technology	-Estimates the distance between an index case and contact through proximity sensing calculations	-Singapore's Trace Together App -Switzerland's Swiss Covid app -Austria's Stopp Corona app. -Australia's COVID Safe app.	-consumes less energy - less costly -Users receive real time notification wherever they are	-covers a very short range -mostly used indoors -Requires use of smartphone with Bluetooth always on -Implications of privacy
Wireless Fidelity (Wi-Fi)	Uses Wi-Fi access points to communicate with user's devices and mainly uses positioning for contact tracing.	TraceFi	-Compared to Global Positioning System Wi-Fi is very accurate -Faster than Bluetooth technology -Convenient to use their hardware because they cost less to maintain and deploy.	-Only used in an indoor environment -Requires use of Wi-Fi Access Point (WAP)
Quick Response (QR) Codes	Works by users taking a picture of visual computer-aided code at multiple places of business manually thus contributing to the database as it allows users to log visited locations	-New Zealand's NZ COVID Tracer -Canada's COVID-10 Alert -Chinas Alipay health code app	-Reduces errors -Ensures privacy of users by avoiding retrieving the location data of users	-Requires use of smartphone -Doesn't provide enough accurate data -Acceptance by individuals is low.

Table 1. *Digital contact tracing technologies, function, Apps, merits and demerits*

Conclusion

Digital contact tracing technologies (DCTTs) have been adopted widely by countries worldwide amidst the COVID-19 pandemic with the use their solutions specifically applications (apps) that have been developed from these technologies. Digital contact tracing technologies (DCTTs) helps in picking contacts that are manually untraceable. Several researchers have reviewed contact tracing applications and techniques, this paper gives an analysis of digital contact tracing technologies (DCTTs) highlighting their successes, failures, and pitfalls. Beyond their use for mitigating and containing COVID-19, digital technology can complement or in some cases amplify the traditional approach to global health program implementation.

Digital contact tracing technologies (DCTTs) have their challenges, of key to note is low smartphone adoption, poor user acceptance, privacy concerns and digital training skills, to mention a few, that have all hampered digital contact tracing. The health benefits of DCTTs solutions overshadow their challenges with the digital contact tracing being used in addition to manual contact tracing. As Digital Contact Tracing Technologies (DCTTs) are being used to provide solutions for COVID-19, they should not store more information than is required or reveal it for privacy reasons, and data misuse should be prevented. In addition to this additional policy efforts are needed that give convenient preventive technologies in an ethical way and provide wide spread adoption of Digital Contact Tracing technologies (DCTTs) among the public as a valuable means for containing the effects of the Covid-19 pandemic.

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