COVID-19 CONTACT TRACING TOOL FOCUSED ON PRIVACY PROTECTION

by

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Contact tracing is the process of identification of persons who may have come into contact with an infected person and subsequent collection of further information about these contacts. Most of the contact tracing applications present in the market today use GPS and Bluetooth technologies to perform contact tracing where data is collected in the background without the user's knowledge. The idea of this thesis is to build a tool in the form of a lightweight mobile application with technologies like QR code scanning and NFC tagging using which every user would provide information about the places they've been to voluntarily. This would put the user in control of his privacy. Once the user id of the infected patient is shared with the backend, the tool uses this information to perform contact tracing by backtracking to all the places that the patient has been in the past to find out all users who have ever come in contact with the patient. The backend then quickly computes the risk level for each user who has come in contact with the patient in the past and sends a push notification to the user alerting him about the risk of infection. This tool provides its users with services like Privacy protection, Awareness, Maintenance, Authentication, Safety which collectively can be called PAMAS services.

DEDICATION

Dedicated to all the medical workers who armored up in this tough time of COVID-19 and are fighting with an enemy which has taken down several countries. Also dedicated to all those workers of every nation who are consistently trying to contain the pandemic. And finally, this work is dedicated to all those innocent people who have succumbed to this deadly virus and their families who had to go through a lot of pain with the unexpected loss of their loved ones.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE PAGE

CHAPTER 1

INTRODUCTION

In the month of November 2019, a new virus has begun its path in the Hubei region of china and has spread around the world in a matter of months. The disease that is caused by the virus was dubbed as Covid-19 or Corona Virus Disease 2019. Even though it was named COVID 19 due to the year 2019, its major impact on the world can be seen in the year of 2020. Many nations have taken severe lockdown measures in an attempt to contain the virus, some of them were successful while some of them weren't. Almost after completing majority of the first two quarters of 2020 in lockdown, countries have decided to slowly open up to the world, not because they've won against the virus, but because they can't afford to lose on their economy.

In such critical times, where people have been house arrested for the better part of six months, it is not surprising if they want to go to places they always wanted to go, meet people whom they couldn't meet, but even in such desperate times, we must remember that the virus is still out there. One process which helps the health officials stay alert and proactive in preventing the spread of the virus is Contact tracing. Briefly speaking, contact tracing can be defined as a process of notifying individuals (contacts) who have a potential of being exposed to the virus because they might have come in contact with a patient in the past.

The goal of this thesis report is to talk about some popularly used technologies like QR code scanning and NFC tagging and how can they be put into use in making a contact tracing tool that can be built with public contribution and for public protection.

1.1 Challenges with GPS and Bluetooth technologies

There were several other apps that have emerged using the GPS and Bluetooth technologies. While some of them used these features exclusively, some others have used one of them to augment the other. Though these technologies might seem promising at the beginning, they have their fair share of disadvantages.

For instance, in case of GPS tracing a key feature that is missing 3D positional data. Phones can track the co-ordinates of a particular location at a specific point in time forming a dataset of spatiotemporal data entries. Say, one of these spatiotemporal data is at empire state building, then the application treats every other person who is present in the building at that instant of time as a potential contact. Which might result in way too many false positives which can make this technology less reliable. Moreover, recording a patient's complete location data would violate patient's privacy since the information about all the whereabouts of the patient's travel history including personal places like his house address are stored in a central server.

Bluetooth on the other hand does not depend on storing of any sort of spatiotemporal data. In most of the implementations of Bluetooth technology, the application exchange signals/tokens to its nearby devices to record that these two users have come in contact with each other. Later these tokens are used to perform contact tracing if and when required. The main drawback of this approach is that, this approach considers only those people who have been in the same place in the exact same time. But however, one of the modes of transmission for Covid-19 is through surfaces and it is not possible to capture that using Bluetooth [1]. Besides, Bluetooth also suffers a similar criticism as GPS. For instance, if an infected person was present in the 2nd floor of a building, and there is a user of the app present in the first floor, right underneath our carrier. Then the app alerts the user of a potential contact since Bluetooth signals can also transmit through walls and ceilings again leading to false positives [2]. Though this is a drawback, it can be considered negligible when compared with the drawback of GPS.

One important point to consider when it comes to using technologies like Bluetooth or

GPS is that they are always running in the background without any conscious efforts put by the user. Though it might seem convenient in the beginning, there is a good chance that this can be used to collect data from the devices even in scenarios where the user has no intention to share[3]. The user would have no control over the data that he gives out to other devices through Bluetooth. For instance, even though using Bluetooth for contact tracing seems less intrusive since the location history of the user is not compromised, there is an easy hack to get this information. The authority whoever is handling the application can always place some Bluetooth devices in public places that exchange tokens with devices present in its surroundings. Since the exchanged tokens are stored only in the device and are not shared with any central server, the authority is perfectly capable of going through all the tokens these planted devices have received over time and can easily connect the dots. Thus it is perfectly possible to track a user's location history without their consent just using Bluetooth. [4]

One of the ways to address this issue is to make the user aware of the data that he is recording. One such approach is to use a QR code or an NFC tag to record every entry and exit of a person by doing which a person's entry and exit are always tracked and if one gets diagnosed, we can always get information about the places one has visited in the past.

The next section of this chapter discusses the motivation behind this approach and also a brief introduction to QR and NFC technologies.

CHAPTER 2

RELATED WORK

In this chapter, we take a look at various approaches taken towards contact tracing and other technical aspects that are to be known for better understanding of the approach taken in this thesis report.

The Covid-19 pandemic caused by the Coronavirus has spread to over 200 countries in a very short span of time. One of the main reasons for the spread is the asymptomatic nature of the spread, or in other words, the virus can be transmitted from an agent (infected person) to several others who come in contact with the agent even when the agent shows no symptoms of the virus [5]. Thus, people who seem to be in perfect health become the carrier of the virus and can infect several others. While a good fraction of the people who become infected have built immunity towards the virus, several others who could not put up a fight against the virus have lost their lives. Unlike in the past where viruses like these were limited to a particular area and have not spread from one place to the other so easily, advancements in the transportation industry has led to the spread of this particular virus as quickly as a wildfire.

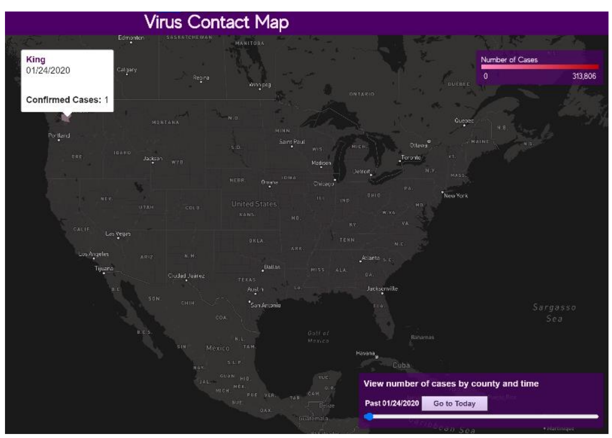

Figure 1 Spread of Corona Virus in the US as of 24th Jan 2020 [6]

Specifically, in the US, the virus outspread began in the King county of Seattle on 24th of January 2020 (Figure 1) and since then has engulfed the entire country (Figure 2) in less than six months. In the same way, the virus outbreak has spread through several countries at a very different pace. The virus spread rapidly in some countries like Italy while it spread very slowly in a few other countries like S. Korea.

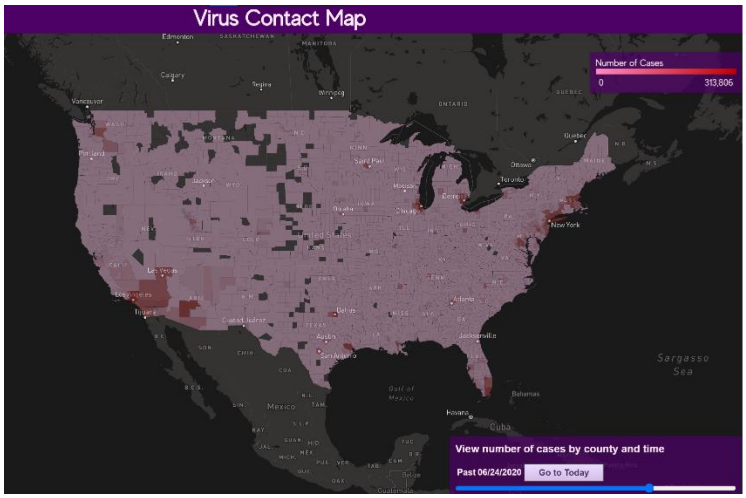

Figure 2 Spread of Corona Virus in the US as of 20th Jun 2020 (Majority of the country is affected) [7]

One of the main reasons why countries like Italy failed while countries like S. Korea were able to contain the virus well was due to the way in which the countries worked on reducing the social contact and maintaining a system of contact tracing to identify and isolate all those who have come in contact with a diagnosed patient [8]. A good contact tracing mechanism leveraging technology has proven to be effective in containing the spread of the virus. In the next section of this chapter we shall present an overview of how various countries handled their contact tracing program, and also how each of them addressed the very important issue of preserving privacy of sensitive user data.

2.1 How different countries handled Contact tracing

2.1.1 South Korea

In South Korea, the government has maintained a central database of known patients and publishes the movements of people before they were diagnosed with the virus[9]. This particular approach could be very effective in certain ways since every person can be aware of whether or not they have crossed paths with carriers. This however, shows almost negligible concern about the privacy of the carriers. Even though information like the name or address of the patient are not made public, the mere idea of using GPS phone tracking, credit card records, surveillance videos can make people raise eyebrows about the system.

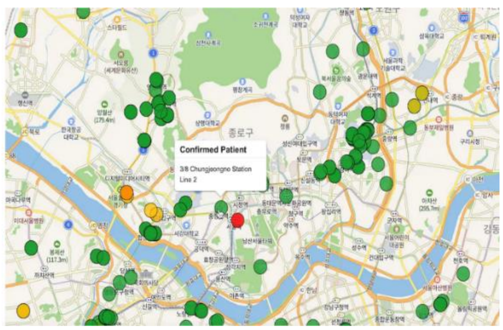

Figure 3 A snapshot of the South Korea's contact tracing tool [9]

2.1.2 India

India with its enormous population has decided to take the technology route to keep COVID spread in check. India introduced an app called Arogya Setu [10]. The app uses phone's Bluetooth and location data, to track the activities of users. It maintains a database of known cases of infections and inform its users whenever they come in the proximity of a COVID-19 infected patient. The data that is collected through the individual devices is then shared with the government. The app collects personal information from every user such as their name, phone number, gender, travel history, whether or not the user is a smoker etc. According to the government, when a user registers the application, the app assigns a unique "anonymized" device ID and all interactions with the government server from the device are done through this ID only and no personal information is exchanged after registration. But that begs the question of why does the government need all the information to register a used in the first place.

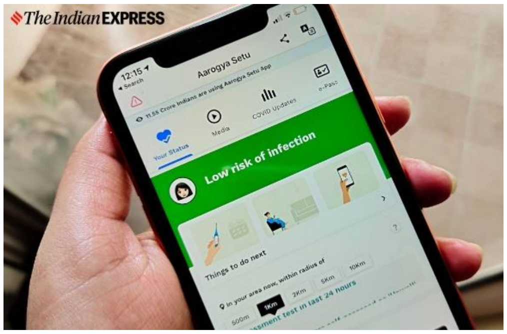

Figure 4 A snapshot of the Arogya Setu app showing the infection rate at a specific location [11]

2.1.3 Singapore

Singapore is one of those countries which became popular for using Bluetooth technology for contact tracing and implementing it in a way that it is less intrusive to people's privacy. The government released an app called TraceTogether[12] which works by exchanging short-distance Bluetooth signals between phones to detect other participating TraceTogether users in close proximity[13]. These signals/tokens are time varying strings that are sent to nearby users. All the tokens received by a user are stored locally on the user's phone. Government also keeps a central database linking the tokens with the phone numbers and identities of the user who is the source for a token. If the user is interviewed by Ministry of Health (MOH) for contact tracing purposes, then the user can consent to send the data captured by their phone to MOH. If someone is tested positive, Health officials will ask the list of tokens their app has collected. Using all those tokens and the central database where the mapping is provided, the government will contact the other people who have come in contact with this person.

2.2 Our proposed approach

The idea here is to ask every individual to record his entry or exit into a particular room or space. This is something that is implemented in almost all secured facilities like banks, museums and nowadays even in the corporate industry and it is done through access control systems. Access control is the selective restriction of access to a specific location. One can only enter if he has an authorization given by someone who already is authorized [14]. It has become increasingly simple and robust to provide access control with the help of electronic access controls. Organization who take up electronic access control systems have an ability to allow or revoke access to individuals remotely and also have the ability to monitor the entries and exits of the members of the organization. Most of the access control systems use some kind of key card to provide authorization to the user. These key cards could either be Magnetic Stripe cards, Prox cards that use RFID technology or Smart cards which use high frequency RFID signals that are more secure than the traditional RFID.

Figure 5 A typical RFID based access point [15]

For the sake of this thesis, we use a similar system but instead of using the scans to verify whether or not a user is eligible to enter a particular facility, we use it, in a more passive way, to record that a user has entered/exited a particular facility. As opposed to using technologies like Prox cards or magnetic stripe cards which involve issuing physical cards to all the users, we rely on QR code and NFC technologies to perform the task of recording the movements.

In the next section of this chapter we discuss in detail about the apps that use QR codes in their system of contact tracing, how efficient are the systems and what is the impact on users' privacy.

2.3 Countries that use QR code in their contact tracing process

2.3.1 Japan

In Japan after the lockdown was lifted and the bars and restaurants were opened, the owners were required to sign up for a program with the government and receive a QR code in return, which they are supposed to display at the entrance of their facilities.

Figure 6 A demonstration of how the QR code is placed and a user scanning it [16]

Customers are required to use their smartphones to scan the QR code in order to reach an online form where they provide their email address. If anyone who visited the place are diagnosed with the coronavirus, then all the registered customers will be notified by email [16].

The government manages email addresses but does not collect the names of registrants [17]. Though Japan later came up with a Bluetooth based contact tracing approach, QR codes were their initial solution.

2.3.2 Taiwan

Taiwan integrated its national health insurance(NHIA) database with its immigration and customs database to identify risks based on travel history and the clinical symptoms. On February 14, the Entry Quarantine System [18] was launched, so travelers can complete the health declaration form by scanning a QR code that leads to an online form, either prior to departure from or upon arrival at a Taiwan airport.

Later this information is used to classify travelers' risk of infection based on their past 14-day travel history. Persons with low risk (no travel to level 3 alert areas) were given a "health declaration border pass" sent via SMS to their phones and allowing them to complete the process of their immigration; however those with higher risk were asked to be home quarantined and their whereabouts were tracked through their mobile phones to enforce the restriction [19]. In this system, QR codes were merely used as a quick access to the URL where the users can fill their health declaration form.

2.3.3 France

France uses an app called StopCovid [20] (or TousAntiCovid) that uses QR codes only to share data with the medical professionals. As far as contact tracing is concerned they use Bluetooth technology to collect the ephemeral ids of users that are in the vicinity of the agent. When a patient is diagnosed positive, they are asked to share all the ephemeral ids that are tracked by their phone with the medical professional using the QR code given to them [21]. This app has all the challenges that are faced by other Bluetooth apps discussed in a previous section.

2.3.4 UAE

UAE is another such example where a QR code system is in place but is used in a different way than discussed above. UAE uses an app called ALHOSN [22], which is mandated for every member of the country. ALHSON also uses Bluetooth to perform contact tracing, however uses QR codes to indicate whether or not a person is infected or not. Every citizen has to present ones' QR code in public places to show that one is not a risk for spreading the disease.

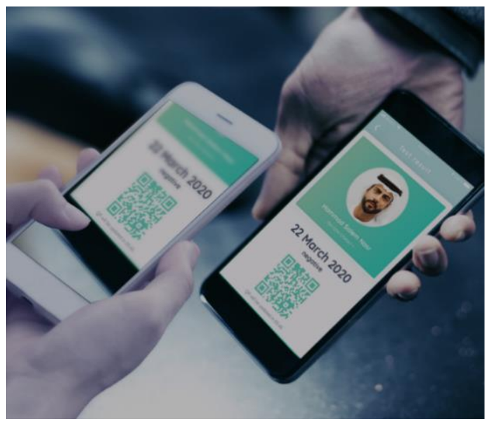

Figure 7 A person presenting his QR code before entering a public space [22]

If a person comes in contact with an infected patient, the app can recognize it by checking the anonymized ID received through Bluetooth and the QR code in the person's app changes along with its color to inform the user that he has come in contact with an infected patient and has to get tested. Though it has been accepted in UAE, a similar approach would not be a norm in countries like US, since mandating every citizen to represent their health state to another person in public would be a violation of the individual's rights.

2.3.5 Thailand

Thailand government came up with an app known as Thai Chana [23]. In places like shopping malls, restaurants and other venues around the country, customers and patrons are required to scan a QR code with their mobile phone whenever they enter and leave. Thus recording a check-in and check-out of every customer enabling the authorities to monitor the movement of people [24]. This information is used by medical staff to locate people at risk of infection when new cases are reported at a specific location.

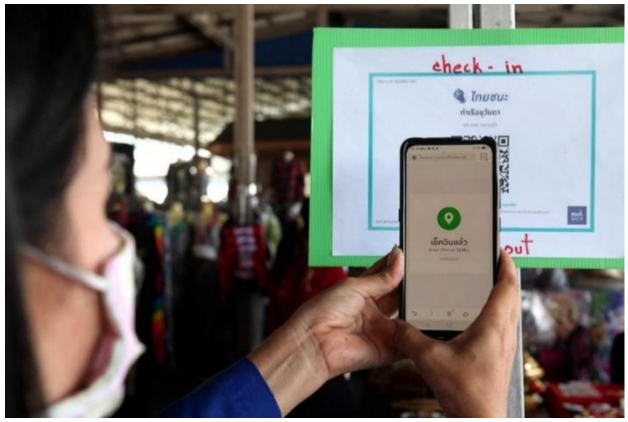

Figure 8 A user checking in to a mall using the Thai Chana App. [25]

When the user scans the QR for the first time, the website shows a user agreement form asking for the users' consent in sending the registration data to the Public Health Ministry. Registration data consists of users' phone number, check-in/out location and time spent at the location [26]. The government officials say that this information is used to reach out to the users who have a higher risk of infection based on their check ins. The system also places restrictions to the check-ins if the number of people in a particular location is larger than what that place can accommodate while maintaining social distancing.

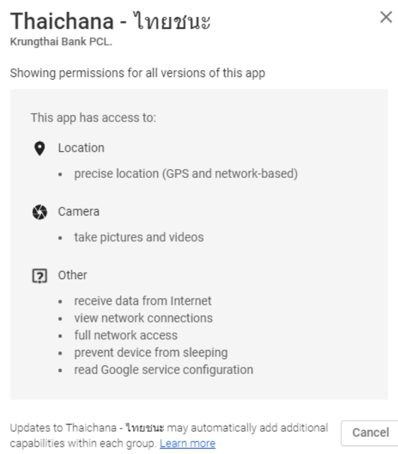

Figure 9 Permissions requested by Thai Chana App in the google play store [27]

2.3.6 Singapore

SafeEntry is a national digital check-in system that logs the NRIC/FINs and mobile numbers of individuals visiting hotspots, workplaces of essential services, as well as selected public venues to prevent and control the transmission of COVID-19 through activities such as contact tracing and identification of COVID-19 clusters [28]. Similar to Thai Chana this app also records all the check ins and check outs of every individual and associate the movements directly with their national identification number. Government has mandated all the businesses that fall under the categories that are mentioned in their website to implement this check in and check out system.

This app is an extension to Singapore's Bluetooth based tracking system known as TraceTogether. If a patient is diagnosed, then the government officials look for people who have crossed paths with the patient using the check-in history of the patient, in addition to the Bluetooth tokens that the user has collected overtime.

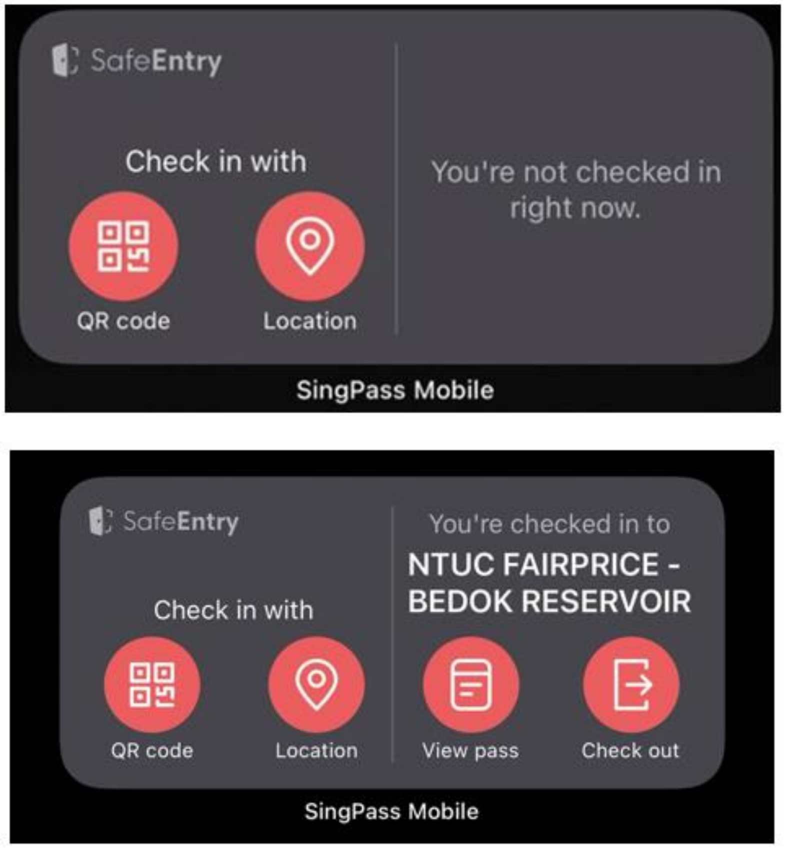

Figure 10 SafeEntry Widget in iOS 14 giving a quick access and information at glance [29]

The use of Safe Entry would allow data to be made available to MOH quickly. Information of visitors and employees who may have come into contact with COVID-19 cases to be sent to the authorities automatically in order to facilitate efforts to prevent and control the transmission of COVID-19 through contact tracing and identification of COVID-19 clusters.

2.3.7 New Zealand

New Zealand's approach to contact tracing is by far the one that is most focused on user privacy when it comes to digital contact tracing. Unlike other apps where usage of technology plays a vital role in the process of contact tracing, New Zealand uses technology only to augment its manual contact tracing process. New Zealand uses an app called NZ Covid tracer [30] which follows a check-in and check-out system like several other countries' apps. Unlike those apps, NZ covid tracer does not send all the user movement information to a centralized server right away, instead the information is stored on the users' mobile device.

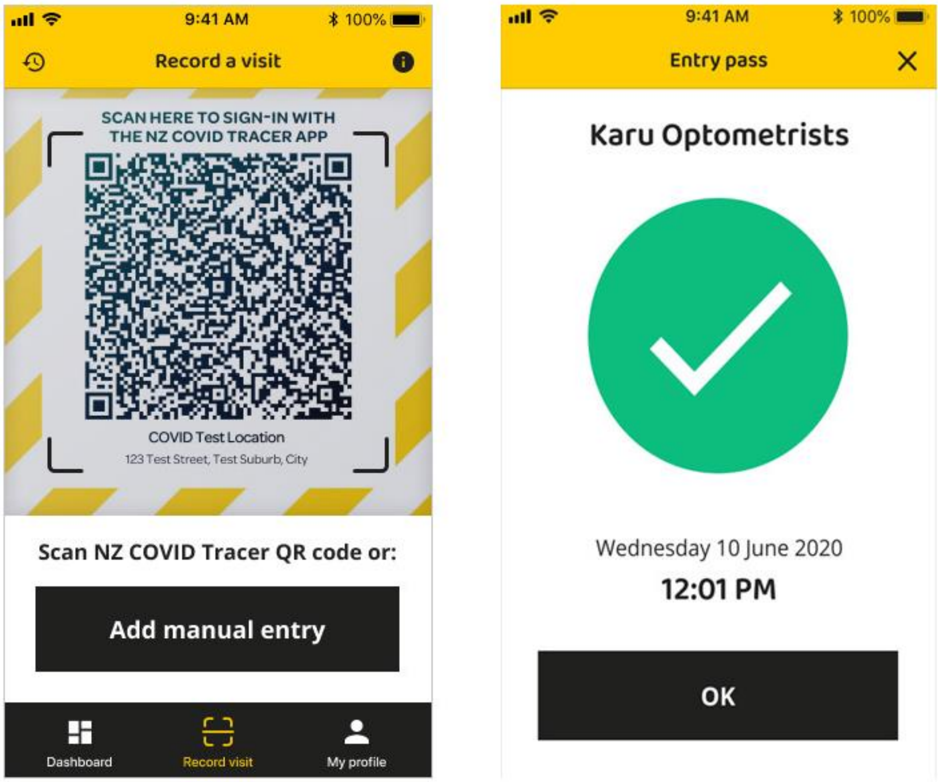

Figure 11 NZ Covid tracer app screenshots[31]

Consumers can 'check-in' to Locations by scanning a QR code that is placed at the entrance of businesses or other public places. This will record the Location visited, the date and the time of the scan and are stored on the user's device as a digital diary.

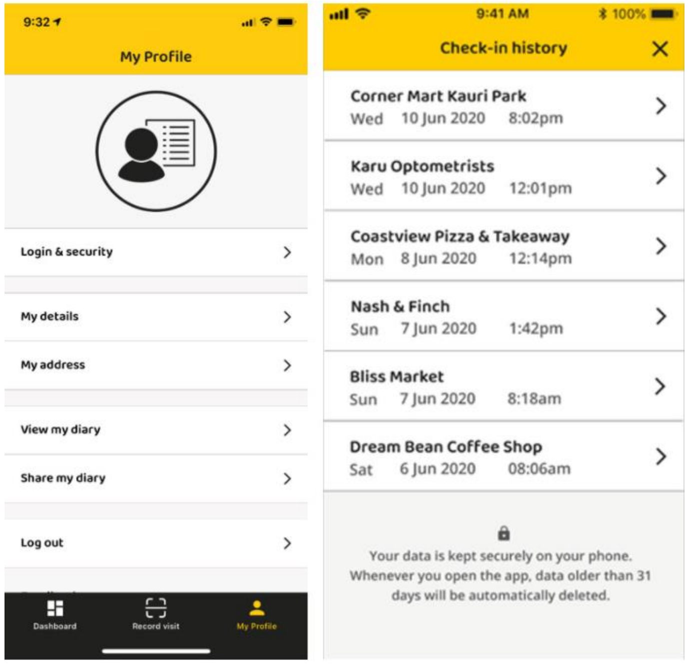

Figure 12 NZ Covid Tracer app -- digital diary and other options [31]

New Zealand chose to have a manual contact tracing procedure where the ministry of health appointed several people as Contact Tracers and they connect with people who have been diagnosed with COVID-19 to narrow down all the people that have come in contact with an infected person in the past few days [32]. If a user is identified as a confirmed or probable case of COVID-19, a contact tracer will contact the user to ask for information about the places and people that the user has been in contact with. Users are expected to use their digital diary to view and share the information. Users can manually mention the places they've been or share their digital diary with the Ministry of Health electronically through the app.

After thorough examination, a contact tracer has a facility to create an Exposure event. An exposure event contains information about the place and timespan where the risk of the spread was high. If found appropriate to share this information with common public, contact tracers can send this information as a notification to the app. When a user receives such a notification, the app tries to match the details of the exposure event with the places that are visited by the user. This computation is performed on the device itself. If there is a match, the Consumer is provided with an alert mentioning that they may have been in contact with someone infected by COVID-19. In a few cases, a Call Back option may be initiated by the contact tracer. If the call back option is accepted by the Consumer, then the Consumer may choose to send their name and contact phone number as part of the Call Back request in order to have a detailed discussion about their condition [33].

Though NZ has given very good preference users' privacy in their contact tracing process, most of the steps involved some kind of human intervention. It may have been possible in a country like New Zealand with population slightly to the north of 5 million [34] but implementing such a system in USA with a population that is more than 80 times [35] that of New Zealand would be considered unrealistic.

CHAPTER 3

METHODOLOGY

In the above chapter we have seen how different countries have built apps to perform contact tracing and we have also seen they are handling the privacy of an individual in each case. There was S Korea where the location data of an infected person is a public record. There were countries like Singapore, France and UAE where contact tracing is performed using technologies like Bluetooth and/or GPS which run in the background where user may not exactly have complete control on what data is being transferred. In case of UAE, we have also seen how every user will have to present his health status in terms of covid-19 at every place they visit. And on the other side of the coin, we have New Zealand where privacy of the patient is given a high priority, but the process of contact tracing is manual for the most part.

In the upcoming sections we discuss the technologies that are used to implement our approach, and also a detailed description of our algorithms are given in the form of flowcharts.

3.1 QR Code

A QR code or a Quick Response code is a two dimensional code where the information is encoded in both horizontal and vertical directions. A QR code consists of black squares arranged in a square grid on a white background, which can be read by an imaging device such as a camera. It can be quickly scanned and read in any direction and is damage and dirt resistant since one can easily scan and get the complete information from a QR code even if parts of it are destroyed [36]. QR codes are used over a much wider range of applications such as commercial tracking, entertainment and transport ticketing, product and loyalty marketing, in-store product labeling etc., [37]

Figure 13: A typical image of a QR code [38]

3.2 Near-Field-Communication (NFC) technology

NFC or Near field communication is defined as a set of communication protocols that establish a form of communication between two devices that follow NFC standards over a short range of distance. This technology is based on the Radio Frequency field that is generated by one (or two) of the devices that participate in the communication. The Radio frequency field that is created during the communication is also supplies power for the operation and thereby making the other NFC device independent of a power source [39]. This enables NFC targets to take very simple form factors such as unpowered tags or stickers that typically contain read-only data. There are two main modes of communication that takes place in Near field communication. One being an Active mode of operation and the other being a passive mode of operation. In both modes, there exists an "initiator" that is responsible for initializing the communication by generating a RF field. Both modes differ in terms of the target device that they are communicating with. In the case of a passive target device, the initiator device provides a carrier field and the target device, acts as a transponder. A good example for this mode of communication can be a key fob. On the other hand, for an active target device, communication between the initiator and the target device happens by alternately generating their own RF fields.

Communication stops when the devices go out of range or one of the devices issue a terminate command [40].

Figure 14 NFC enabled device communicating with an NFC tag [41]

For the sake of this thesis we choose a passive NFC target device in the form of an NFC tag and the communication shall be initiated by a mobile device that is NFC compatible. Considering the privacy as a key priority, we need a system for contact tracing where the entire process is automated and voluntary. In order to achieve this objective, we have opted for a check-in and check-out based system where users can either scan a QR code or tap on an NFC tag to record their entry and exits.

There are two different approaches for contact tracing that I want to present through this thesis, one being a centralized contact tracing system which is capable of offering its users some incentive data about any place they check in and the other being a decentralized contact tracing system where the information about any check-in or check-out does not leave the user's device unless he is diagnosed with the infection. Before we dive into the details of these systems let us take a look at the logistics and the terms that we use in the later parts of the book. For the sake of this thesis, let us assume that we are dealing with contact tracing at an organization level where every room is a place to visit and we have "Building Management People" (BMP) who periodically sanitize the rooms every day.

Every room in the organization has two QR codes and two NFC tags that are encoded with in the format of a room ID- {1, 0} where 1 indicates the code for entering into the room and 0 indicates the code for exiting the room. Every user who enters a certain room may either use their mobile camera to scan the QR code or if their mobile supports Near-Field Communication, can place their phone near the NFC tag and record his visit. Both Camera and NFC have their own share of advantages and disadvantages in this system and they shall be discussed in the later sections. Similar to an access management system, this system also is built in a generic way to fit any organization. When an organization decides to sign up with this system, the organization is responsible to provide information about all the rooms that are present in their organization and also the maximum capacity that a room can withhold without compromising on social distancing norms. Whenever an employee of organization signs up with the app, he is asked to choose an id that is unique with the organization and no other information of the employee is required to the server. On the other hand, when a Building Management person signs up, he is also offered with a similar user-id however his id will always be prefixed by the term “BMP-”.

Every time a user records an entry/exit, an “Event” is created in the system which consists of 4 fields – User ID, Room ID, Status (Entry/Exit) and Timestamp. Every scan will capture these 4 pieces of information. Every BMP is also required to check in and check out from a facility when they sanitize it and an event created in such scenarios is called as a “Sanitized Event”.

$$Event(UserId, RoomId, Status, Timestamp)$$

$$SanitizedEvent(BmpUserId, RoomId, Status, Timestamp)$$

A “Room” object is used to identify every facility in the organization. Every room consists of the following fields of information – Room ID, Maximum capacity, Current Strength, Last Sanitized time. While Maximum capacity is a field that is fed to the system during the initial configuration and can be updated later on demand, the Current Strength and Last sanitized time are the fields that are updated by the algorithm based on the check-ins and check-outs.

$$Room(RoomId, Maximum\ Capacity, Current\ Strength, Last\ Sanitized\ Time)$$

A "Window" object is used to define a specific time-frame. It has two fields – Start and End which denote the beginning and the end timestamps of the time-frame. Two windows are said to be identical if they both have the exact same start and end timestamps. An object that is derived from the window object, called as "VisitWindow" has a User ID field associated with the standard Start and End timestamps.

$$Window(Start, End)$$

$$VisitWindow(UserId, Start, End)$$

"Infected Window" is the term used to define the time frame between the end timestamp of the last sanitized event that happened before the entry and the end timestamp of the first timestamp that happened after the exit of an infected person, hereafter called as an "Agent".

$$IW = Window(\ AW_{start}, FST_{end})$$

Where,

$$AW_{end} \rightarrow Start\ timestamp\ of\ Agent\ Window$$

$$FST_{end} \rightarrow End\ timestamp\ of\ First\ Sanitized\ event\ after\ Agent\ exit$$

An "Overlap" is an object that is used to determine the intersection between two time-frames or Windows. Every Overlap object consists of four fields – Room ID of the room where the overlap has occurred, Visit window of the agent, Visit window of the user, the infected window corresponding to the agent visit. The overlap object also has a derived field known as Overlap Duration.

$$Overlap\ (RoomID, AgentVisitWindow, UserVisitWindow, InfectedWindow)$$

There are two kinds of overlaps that will be discussed. One of them is when both patient and the other user are physically present in the same room together for some period of time and is called as the "Direct Overlap", the overlap duration field will determine how much time they have been present in the same room. The other kind of overlap is called "Indirect Overlap" and it is when a user visits a room after the agent has left the room but before the next sanitized event has taken place. In this case, the value of overlap duration would be zero.

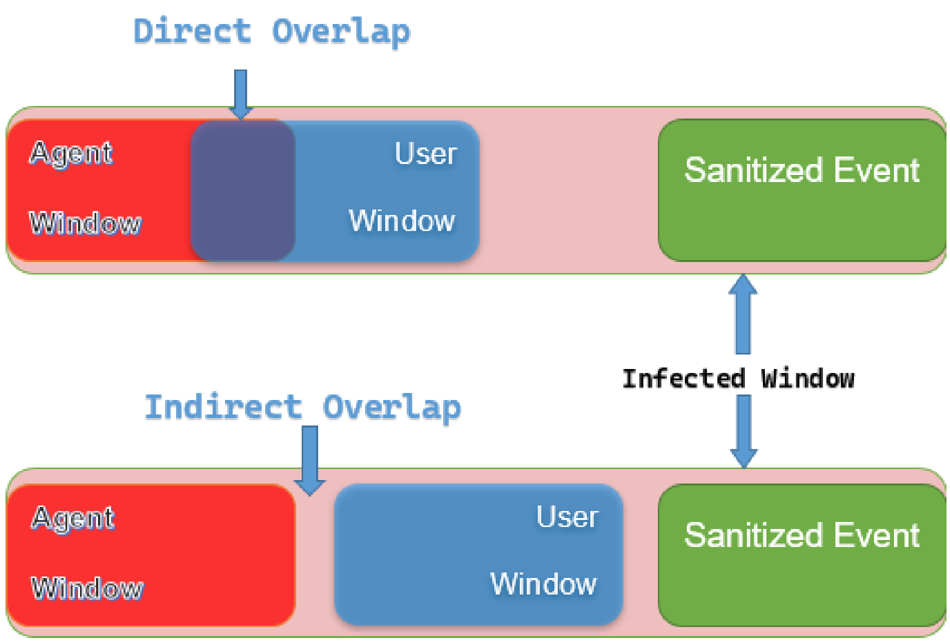

Figure 15 Representation of Direct and Indirect overlaps along with the Infected window given a pair of user and agent windows

3.4 Core Algorithms

In this subsection we shall take a look at some core algorithms that are used in both the approaches. For instance, when a user is diagnosed positive, they must share their movement information with the server regardless of the approach being centralized or decentralized.

3.4.1 Add_Sanitized_Event

- Whenever a particular room is sanitized, it is the responsibility of the BMP to update the information through their app.
- When a BMP records their entry and exit through their app, a distinct event called "Sanitized Event" gets generated and is crucial in computing the infected windows.

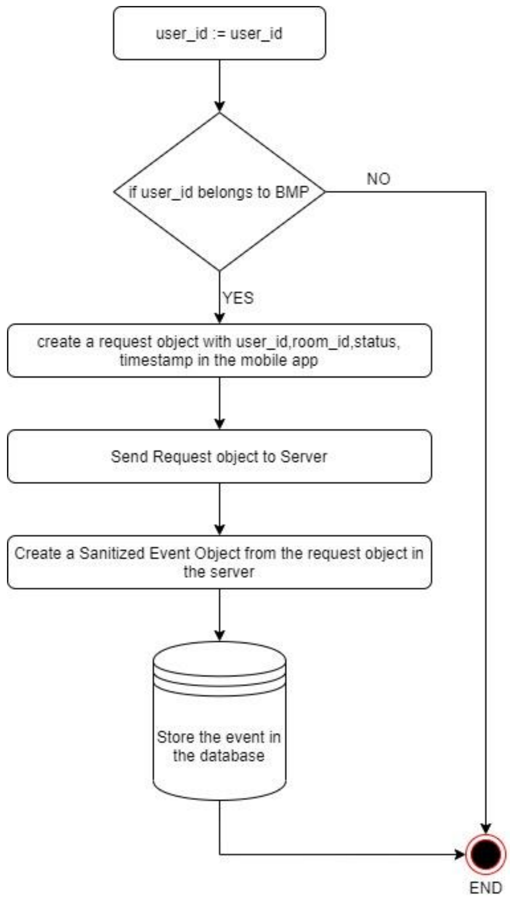

Figure 16 Flow of add_sanitized_event when a BMP records a cleaning event

3.4.2 Populate_room_visits

- In this routine, we perform the task of fetching all the events from a suitable source and adding them as visits to corresponding rooms.
- In this routine, we internally call another sub routine called "record_agent_visit"

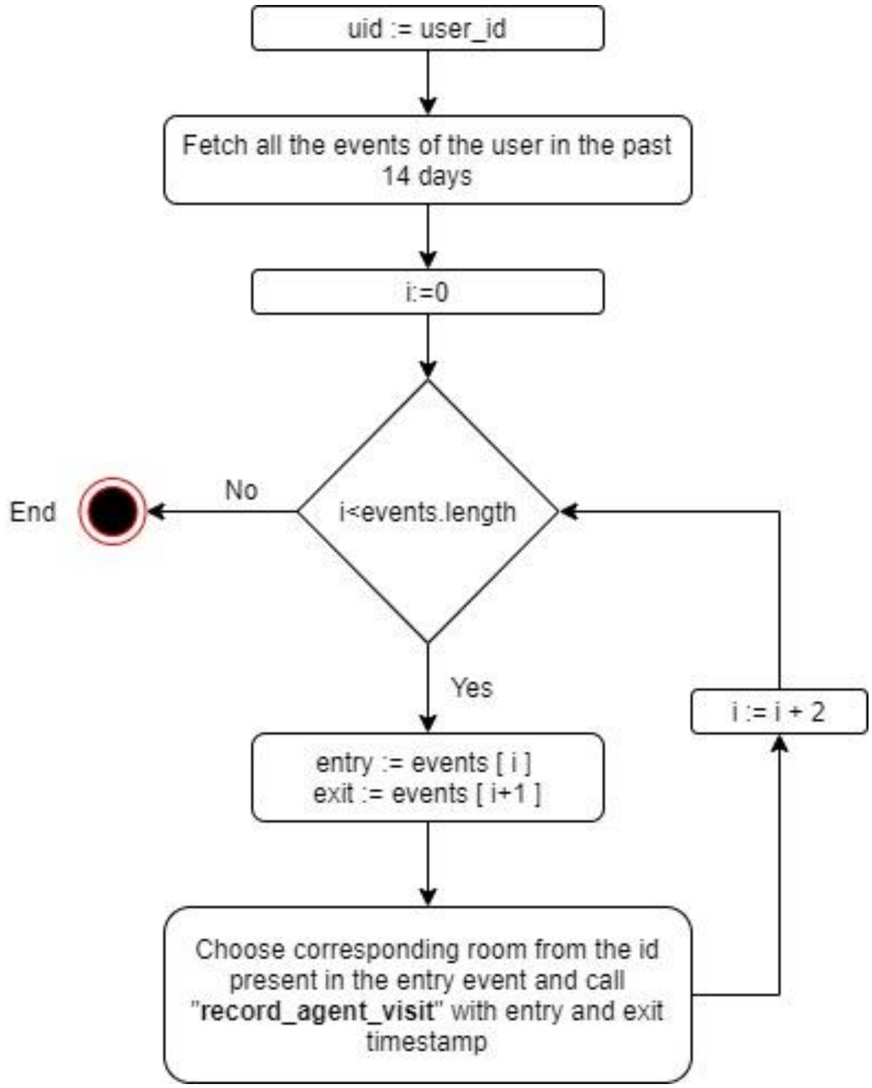

Figure 17 Flow of populate_room_visits after a medical official enters the user_id

3.4.3 Record_agent_visit

- Given an entry and exit event of the agent into a particular room we perform the following steps in order to record his visit

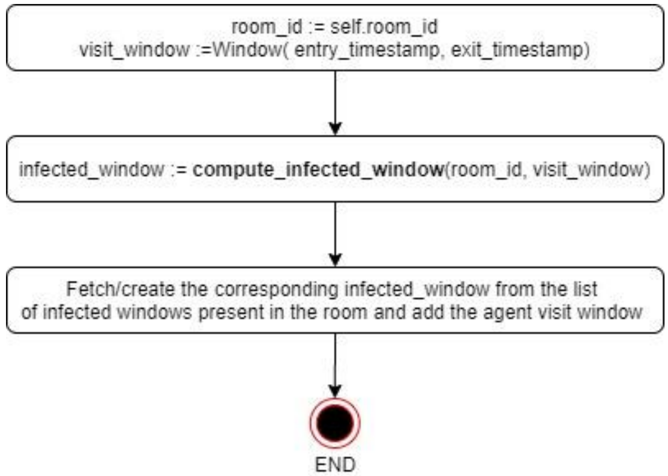

Figure 18 Flow of record_agent_visit

3.4.4 Compute_Infected_Window

- Given a visit window of the agent, we compute what is the total infected widow for that visit, using information about next sanitizing event from the database

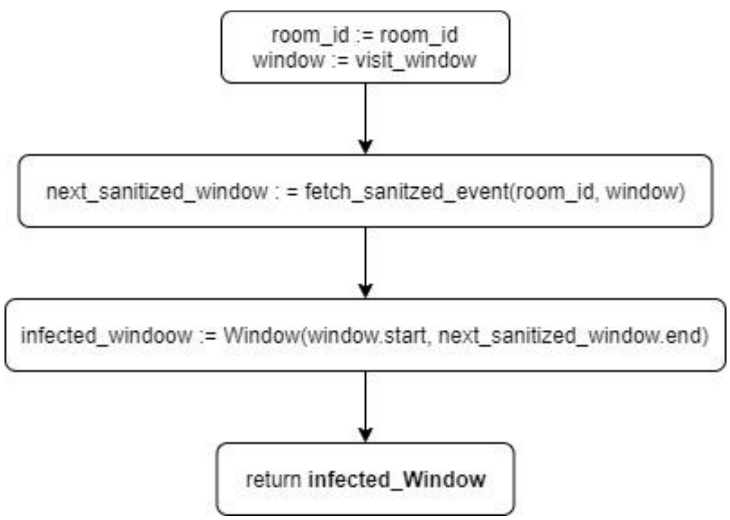

Figure 19 Flow of the function compute_infected_window

3.5 Centralized Contact tracing system

In a centralized contact tracing system, all the data related to the check-ins and check-outs of the users are stored in a central server. Every time a user scans a QR code or an NFC tag, an “Event” gets created. This event is then sent to the server and then stored in the database. All such events are collected in the server and are later used to perform contact tracing. Let us take a look at a few algorithms that are exclusively used in Centralized Contact Tracing.

3.5.1 Check in / Check out

- Every time a user scans the QR or the NFC tag, the following actions take place in case of a centralized contact tracing system.

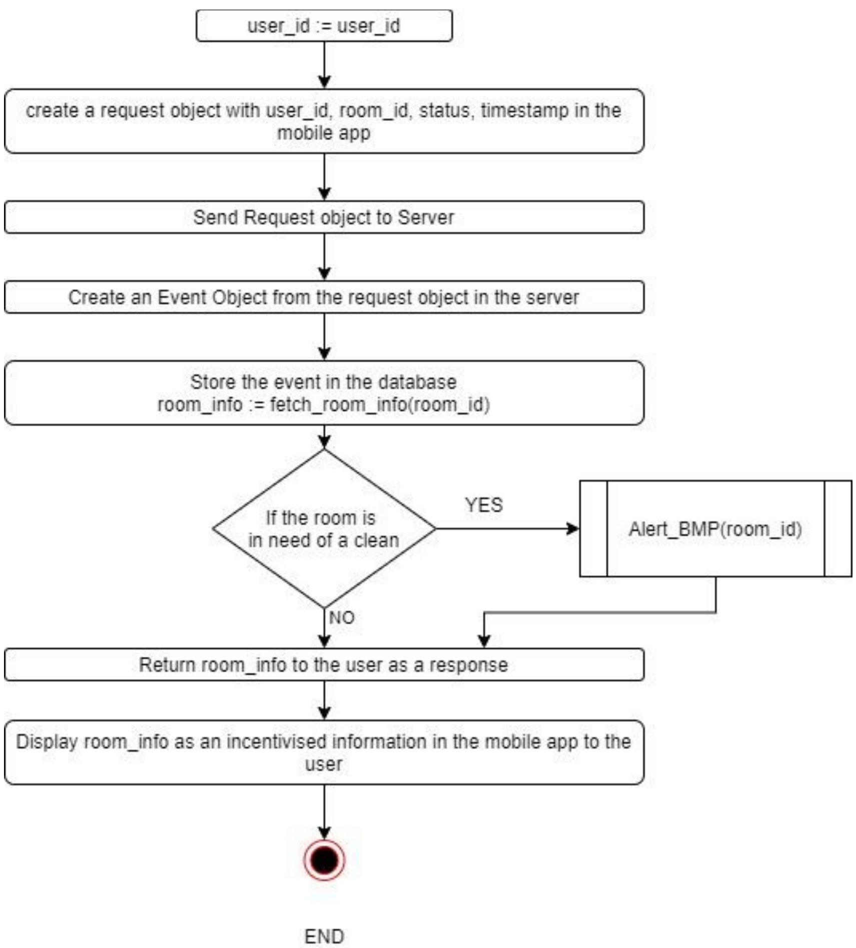

Figure 20 Flow of check-in/check-out of a regular user

3.5.2 Populate overlapped users

- In case of centralized contact tracing system, this routine is called as soon as the infected windows are created (*Flow of the function compute_infected_windo*

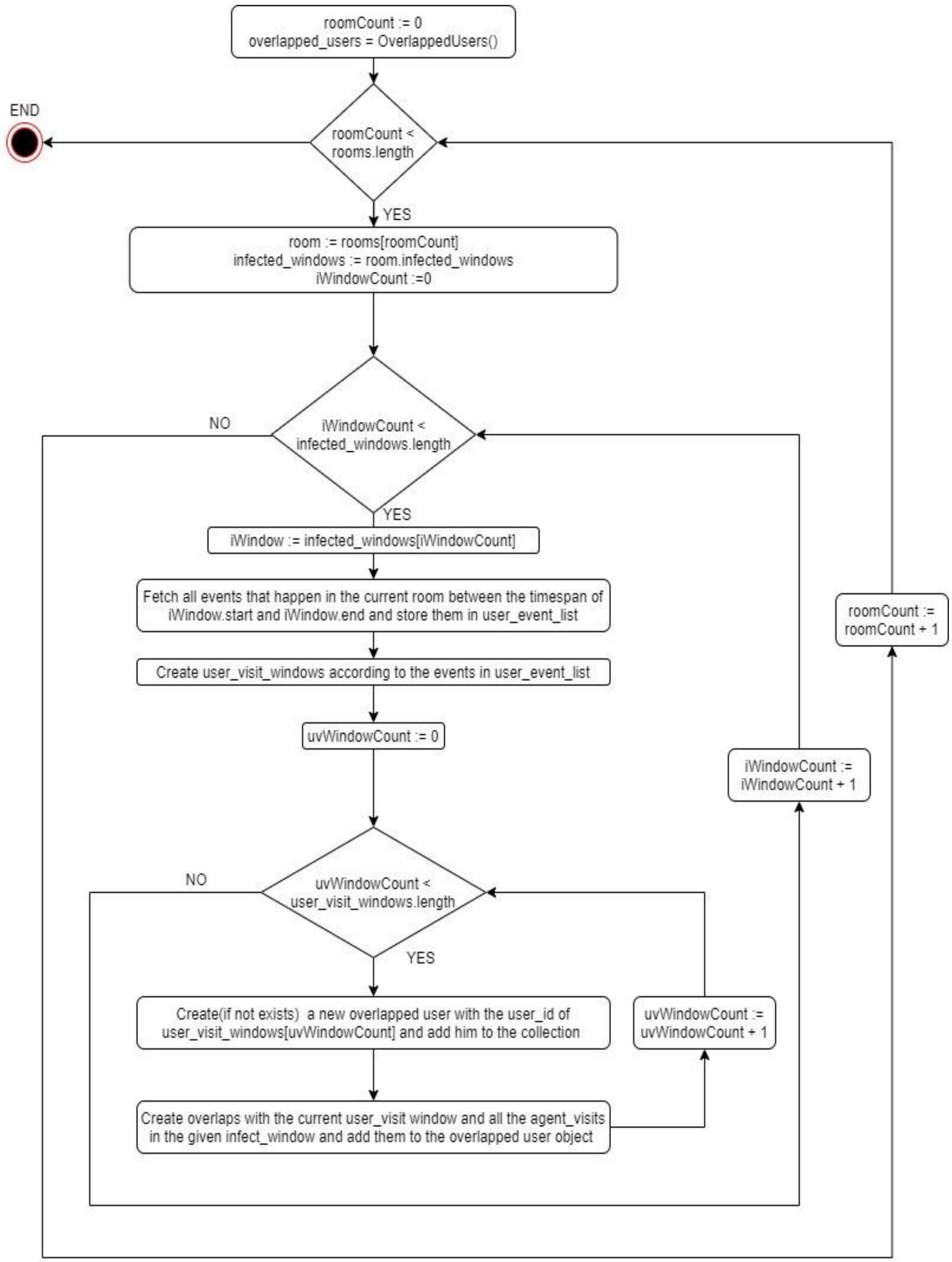

Figure 21 Flow of populate overlapped user's algorithm

3.5.3 Notify user

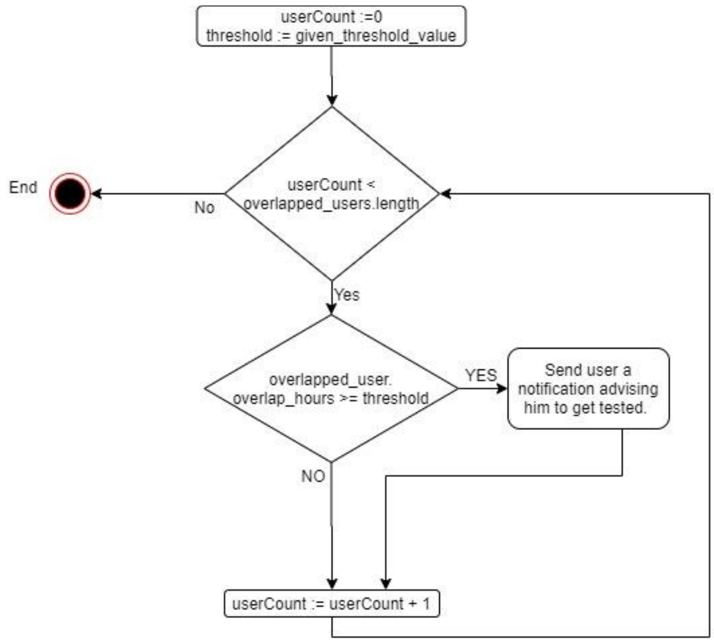

Figure 22 Notify user flow diagram

Since the server is always aware about all the user check-ins and check-outs, there are some added advantages to this system. Every time a server receives a check-in event, it keeps track of number of people present in the room at that instant of time, and sends back certain information related to the room back to the user. The information consists of three fields namely, *Last Sanitized time*, *Current capacity* of the room, *maximum allowed capacity* of the room. This information can be useful for a user because it can help the user in deciding how careful he/she is supposed to be while he is present in the facility.

Another possible benefit of having a system where server is aware of all the visits as they are happening is that, if and when a particular room becomes over-populated server can identify that and send an alert to a BMP user to sanitize the room at the earliest. By having such convenient facilities, one can make sure that the organization is always sanitized and maintained safely.

3.6 Decentralized Contact tracing system

In a decentralized contact tracing system, all the data related to the check-ins and check-outs of the users are stored in the users' device only. Every time a user scans a QR code or an NFC tag, an "Event" entry is added to the users' digital diary. When a user clicks the "Get Verified" button the act of contact tracing begins.

3.6.1 Check in/check out

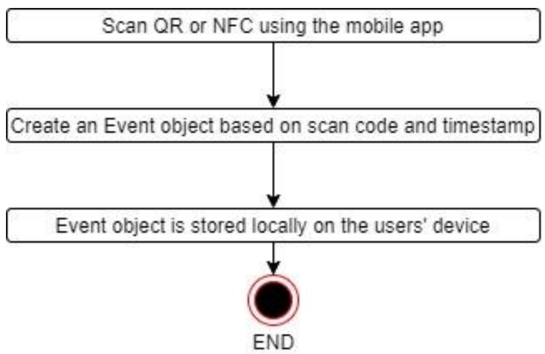

Figure 23 Check in and check out in a decentralized contact tracing system

3.6.2 Get verified

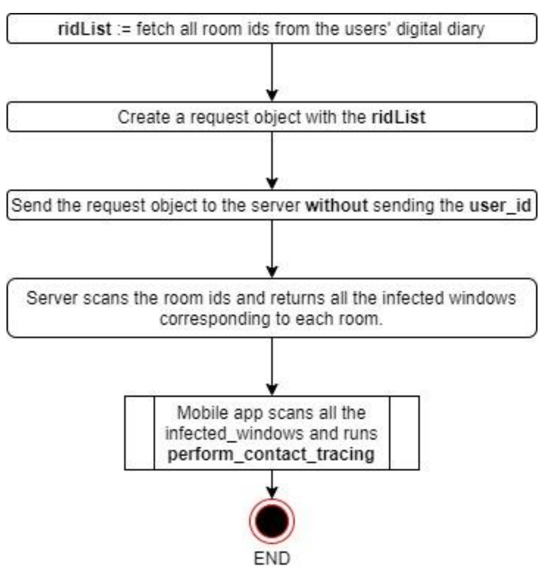

Figure 24 Flow of what happens when a user selects "Get Verified"

3.6.3 Perform_contact_tracing

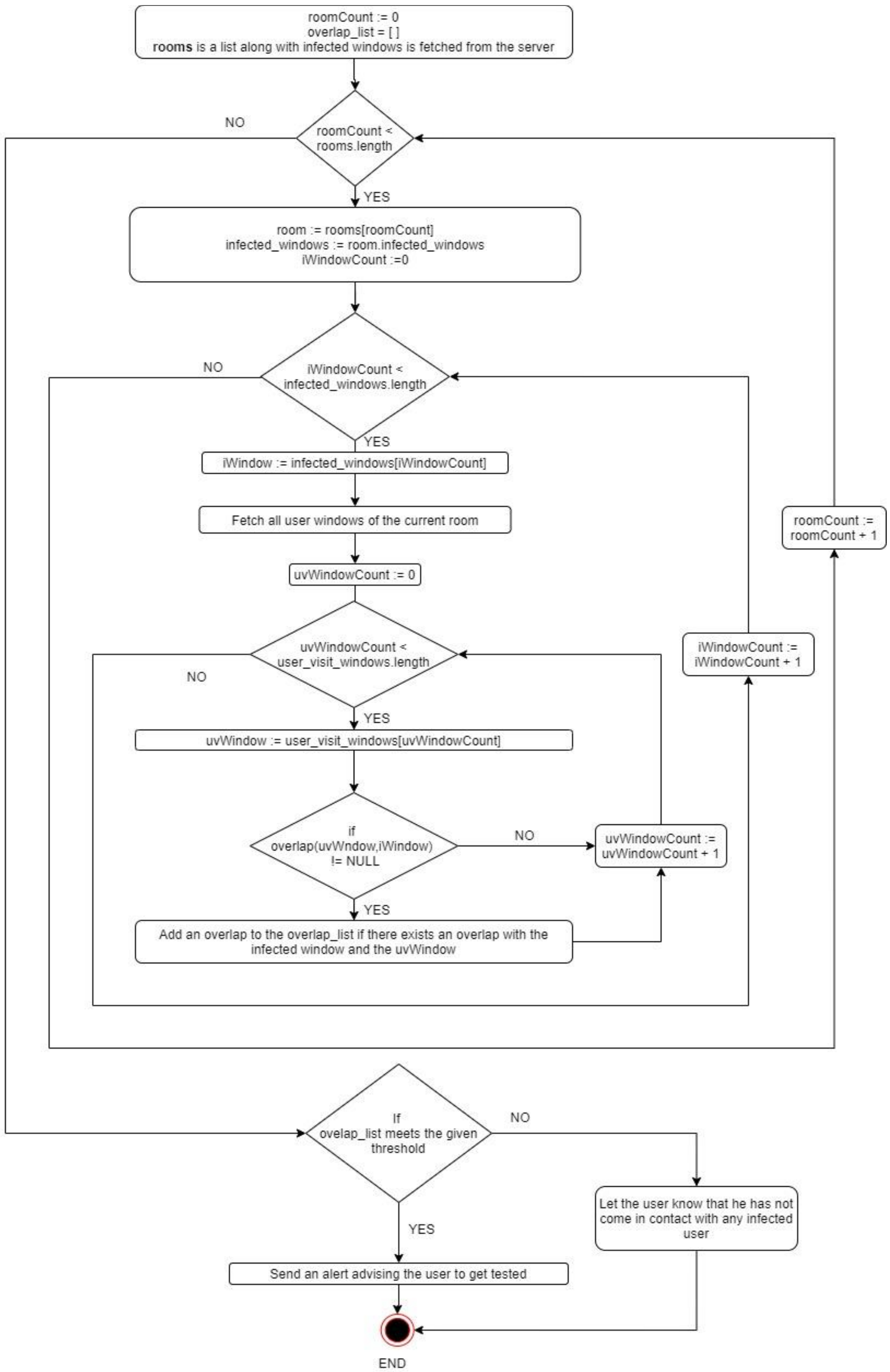

Figure 25 Flow of the contact tracing algorithm in the case of a decentralized contact tracing system

3.6.4 Share_location_data

- Once a medical professor confirms that a patient is tested positive, medical professional has a button called "update infected windows" on his dashboard which upon clicking will generate a unique QR for every instance. When a user scans the QR code through his app, he will be taken to a special page in his app, which will have a consent form to share his location and movement data for marking infected windows and a button called "share movement history".

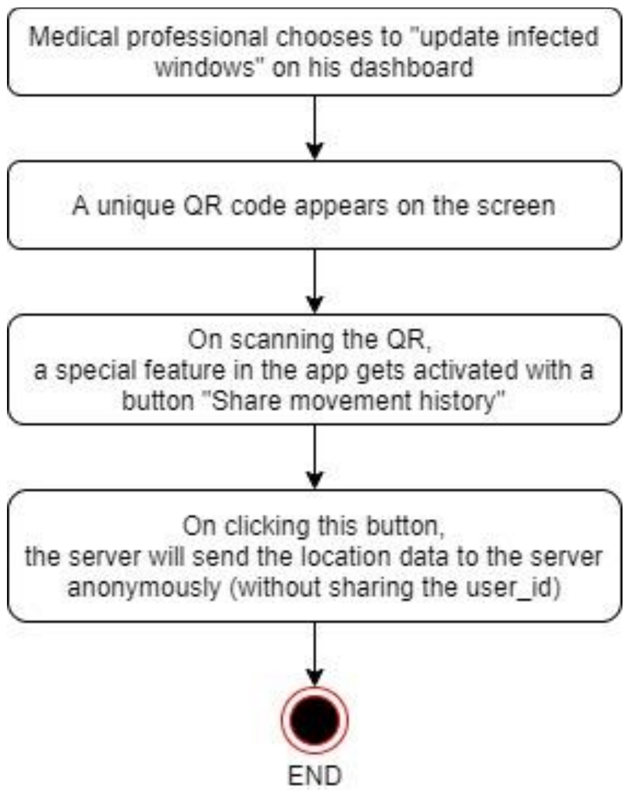

Figure 26 Flow for "share movement history" performed

A decentralized contact tracing system would not be able to fetch any additional information about the sanitized time or number of people in the room, but in some scenarios it is a preferred approach due to its extreme focus on privacy. There is absolutely no way for the server to find out any information about the user, including the user_id of the user.

3.7 Generating test data

For the sake of this thesis we've decided to generate mock data along with some constraints in order to best replicate a real time scenario. We have taken the liberty to assume that every user who check in will also check-out prominently since handling such events does not come under the discussion for this thesis.

The following are the constraints that are enforced when generating the dataset

1. A user can stay in a room for at most 10 hours in a room.
2. There must be 100 check-ins per room per day.
3. Every room is sanitized at least twice by the BMP every day.
4. Room ids start with an uppercase character and a 5-digit code.
5. All BMP users shall have a "BMP" prefix before their user id.
6. Check-in and Check-out data is sorted by timestamp.

There are mainly three main collections in the database namely,

- Room collection
    - Collection of Room objects with room_id and other metadata.
- Sanitized events collection
    - Collection of Sanitized Events sorted by timestamp
- Events collection (only in case of centralized system)
    - Collection of all entry and exit events sorted by timestamp
- Infected window collection (only in the case of a decentralized system)
    - For each room, list of all infected windows are stored in this collection

CHAPTER 4

IMPLEMENTATION AND APPROACH

We've performed the implementation of Centralized contact tracing algorithm using the following platforms,

- Python as the sever side scripting language.
- Check-in/out data, and Sanitized data of all the rooms in the organization are stored in MongoDB database in the form of JSON-like documents
- Flutter as the mobile app framework to scan QR codes and interact with the server
- We use FLASK to write micro-services that handle requests and provide responses.
- Firebase messaging service is used to send notifications to the users.

Detailed discussion of the architecture, information about each platform and the interaction with other systems are discussed in the next subsections.

4.1 Architecture

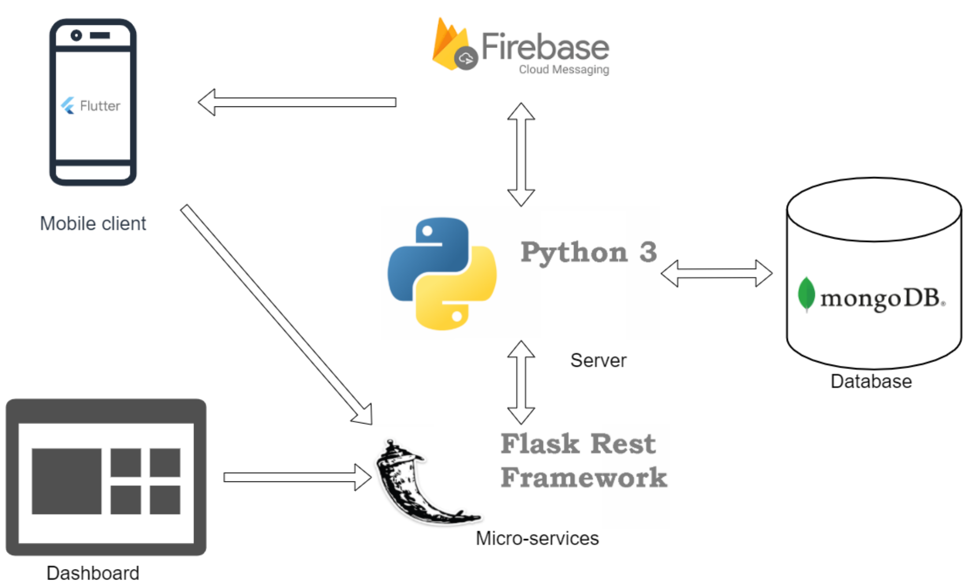

Figure 27 System architecture

4.2 Implementation details

4.2.1 Back-end (Python, FLASK, MongoDB)

Python is a high level, dynamically typed scripting language which supports both procedural and object oriented programming paradigms simultaneously. Though Python is slower than other languages like C++ due to it being an interpreted language, it is chosen for this implementation because of its prototyping nature and its rich library support. Python effortlessly connects with the NoSQL database MongoDB using a library called “pymongo” where one can implement all the CRUD operations efficiently. Python also offers a web application framework through FLASK that allows users to write micro-services through which mobile app users can interact with the server.

4.2.2 Front-end (Flutter)

Futter is a cross platform mobile app (software) development kit developed by Google. Apps built using flutter SDK are written in dart language and can be run on both Android and iOS operating systems using platform specific SDKs. Flutter helps us develop both Android and iOS apps using a single codebase. In our implementation we use flutter to create a mobile app that allows users to scan QR codes and interact with the server in the centralized contact tracing system. We use two packages namely “barcode_scan 3.0.1” by mintware.de and “flutter-nfc-reader” by matteocrippa for qr code scanning and NFC scanning respectively.

4.2.3 Firebase Cloud Messaging

Firebase cloud messaging (FCM) is a platform that is developed by google focused on cross platform notification service. In our implementation we integrate FCM into the Flutter application in order to facilitate the user with an ability to register for a notification service so that the server can alert the user if and when the server identifies a user as a possible contact after performing contact tracing as soon as the infected windows are computed in the server.

FCM can also be handy in the case of decentralized contact tracing since the server can send a notification to all its users at once based on certain thresholds like too many infected windows on the server. This common notification can be a simple reminder that asks users to ‘Get verified’. This is the best the server can do to be proactive in the case of decentralized system. Since the server is blinded to all other user information such as their movement pattern or their location history.

CHAPTER 5

RESULTS

In this chapter we shall look at the results obtained on performing the implementation of centralized contact tracing algorithm on the mock data that was generated.

5.1 Looking at sample data

For the sake of this thesis we see the results on a simulated setup of centralized contact tracing system. As discussed in the methodology chapter we have three main data collections, one for room data, another for all entry and exit events and the third one is for all the sanitized events.

Collection Name ▲	Documents	Avg. Document Size
eventsCollection	20,000	86.0 B
roomsCollection	10	128.7 B
sanitizedEventsCollection	10,680	95.0 B

Figure 28 Mock data collections in the database

In the mock dataset that we have generated for the simulation, we have 10 rooms and 100 users. We've generated 20,000 entries and exits overall starting from 22nd Jan 2020 for over a month in the events Collection. There exists BMP staff who clean all the rooms at least twice every day whose entries and exists are recorded in the database as well in the sanitized events collection. All the information of the 10 rooms, such as its last sanitized time, max capacity and current strength are stored in the rooms collection.

5.1.1 Sample Events Collection data


```
_id: ObjectId("5f892199258a7533e6a94a8f")
user_id: 51669
room_id: "J28929"
status: 1
timestamp: 2020-01-22T01:09:02.027+00:00

_id: ObjectId("5f892199258a7533e6a94a90")
user_id: 35004
room_id: "P72143"
status: 0
timestamp: 2020-01-22T01:13:17.040+00:00
```


Figure 29 Sample Records from Events Collection

As mentioned in previous sections, we have 4 main fields in the events collection, which are the user_id, room_id, status and timestamps. The sanitized events collection also has a very similar data structure where user_id is replaced by employee_id of the BMP.

5.1.2 Sample Room Collection data


```
_id: ObjectId("5f892199258a7533e6a94a73")
id: "B21970"
name: "Faner Hall"
max_capacity: 17
last_sanitized_time: 2020-10-14T05:55:23.115+00:00
current_strength: 0

_id: ObjectId("5f892199258a7533e6a94a74")
id: "J28929"
name: "CS Main office"
max_capacity: 21
last_sanitized_time: 2020-10-14T12:50:25.173+00:00
current_strength: 3
```


Figure 30 Sample data from Rooms Collection

A collection of all the rooms of an organization, whether or not to reveal the name of the room based on the encrypted room_id is a decision that is left to the organization, however the system expects to know information about the max capacity of each room. Other information like current strength and last sanitized time are updated automatically by the system whenever an entry or an exit event is triggered.

5.1.3 Visualizing overlaps

From the mock data we generated let us assume the user with id “54860” is marked as positive by a Health official. Now in the centralized contact tracing algorithm we have the potential to identify all the users and their overlaps with the original infected patient. Though this information will not be made available for the end user when he is being alerted, we are currently producing it to be visualized for the purpose of this thesis to check the validity of the algorithm.

First we identify all the rooms that are visited by the agent and identify all the infected windows corresponding to each room.

```
Room - P72143
Agent Visits
(2020-01-22T05:27:05.059000 to 2020-01-22T13:32:15.111000)
(2020-01-23T19:56:46.533000 to 2020-01-24T04:11:56.553000)
(2020-02-04T08:35:54.013000 to 2020-02-04T14:58:01.107000)
(2020-02-06T05:10:17.438000 to 2020-02-06T06:31:18.525000)
(2020-02-07T09:06:43.676000 to 2020-02-07T17:13:53.692000)
(2020-02-08T19:02:29.900000 to 2020-02-08T23:07:37.909000)
(2020-02-12T05:49:44.736000 to 2020-02-12T12:55:53.782000)
(2020-02-12T22:58:58.811000 to 2020-02-13T03:24:03.865000)
(2020-02-15T08:39:10.532000 to 2020-02-15T10:04:16.589000)
(2020-02-15T16:07:19.620000 to 2020-02-15T17:16:26.693000)
(2020-02-16T21:16:30.974000 to 2020-02-17T03:46:35.986000)
(2020-02-19T00:28:21.278000 to 2020-02-19T03:46:23.289000)
(2020-02-19T12:53:26.350000 to 2020-02-19T23:20:27.425000)
(2020-03-01T10:58:46.023000 to 2020-03-01T20:13:54.030000)
```

Figure 31 All the visits made by the user to the room with id P72143

Then we look at each user’s entry and exit pattern to enlist all the overlaps that happen between each user and infected window caused by the agent.

```
Infected Window:-
(2020-02-06T05:10:17.438000 to 2020-02-06T13:26:26.248000)
User Visits
[ user-id: 15909, (2020-02-05T20:34:38.648000 to 2020-02-06T06:58:48.701000) ]
[ user-id: 16125, (2020-02-06T08:01:54.392000 to 2020-02-06T08:05:03.467000) ]
[ user-id: 20182, (2020-02-06T05:58:21.559000 to 2020-02-06T15:00:25.584000) ]
[ user-id: 29100, (2020-02-06T01:40:08.316000 to 2020-02-06T07:46:17.405000) ]
[ user-id: 31127, (2020-02-06T06:15:05.008000 to 2020-02-06T08:32:10.051000) ]
[ user-id: 33796, (2020-02-06T09:24:43.590000 to 2020-02-06T09:42:52.661000) ]
[ user-id: 36869, (2020-02-06T11:23:43.768000 to 2020-02-06T18:51:49.785000) ]
[ user-id: 39332, (2020-02-06T08:51:05.991000 to 2020-02-06T11:15:09.069000) ]
[ user-id: 44554, (2020-02-06T03:44:54.931000 to 2020-02-06T06:11:04.026000) ]
[ user-id: 53327, (2020-02-06T00:31:17.465000 to 2020-02-06T09:49:22.476000) ]
[ user-id: 59151, (2020-02-06T00:57:29.832000 to 2020-02-06T06:09:30.873000) ]
[ user-id: 63480, (2020-02-06T10:19:38.003000 to 2020-02-06T10:25:42.054000) ]
[ user-id: 69158, (2020-02-06T11:14:11.714000 to 2020-02-06T16:16:20.756000) ]
[ user-id: 80257, (2020-02-06T08:56:49.510000 to 2020-02-06T09:11:59.545000) ]
[ user-id: 80275, (2020-02-06T05:59:04.606000 to 2020-02-06T06:29:13.668000) ]
[ user-id: 89452, (2020-02-06T10:58:11.653000 to 2020-02-06T21:08:13.748000) ]
```

Figure 32 List of all users who have an overlap with the agent in the given room in the given infected window

In the above image we can see that the infected window lasted for about 9 hours before the next BMP sanitized the room. During this period, there were quite a few users who have visited the room "54860". If we observe carefully, we can gather the information related to each user visit using his entry and exit timestamps. A user is said to have an overlap even when he is not present in the room along with the agent. This happens due to the consideration of surface contacts or in other words secondary contacts.

Besides this information where the infected windows are the primary perspective for the data, we can also collect and analyze the data in terms of individual users. In that case we can get a better insight on how long a user has an overlap with the agent across all the rooms the agent has visited over all the infected windows.

```
user_id: 12265
Overlap_frequency: 17(12 direct overlaps)
 total_overlap_duration: 1 day, 0:49:20.983000
    Overlaps:
    room_id: P72143
        agent-window : (2020-02-12T22:58:58.811000 to 2020-02-13T03:24:03.865000)
        user-window : (2020-02-12T22:47:39.442000 to 2020-02-13T03:49:48.467000)
        overlap duration : 4:25:05.054000
        infected-window : (2020-02-12T22:58:58.811000 to 2020-02-13T09:33:07.059000)
    room_id: S15838
        agent-window : (2020-02-28T05:35:25.404000 to 2020-02-28T10:47:32.438000)
        user-window : (2020-02-28T07:36:43.669000 to 2020-02-28T08:04:48.703000)
        overlap duration : 0:28:05.034000
        infected-window : (2020-02-28T05:35:25.404000 to 2020-02-29T10:22:06.128000)
    room_id: D49972
        agent-window : (2020-02-10T00:08:03.062000 to 2020-02-10T09:35:03.080000)
        user-window : (2020-02-10T07:45:28.950000 to 2020-02-10T10:51:30.971000)
        overlap duration : 1:49:34.130000
        infected-window : (2020-02-10T00:08:03.062000 to 2020-02-10T13:30:32.225000)
    room_id: L89485
        agent-window : (2020-02-21T14:13:10.784000 to 2020-02-21T22:14:14.829000)
        user-window : (2020-02-21T17:43:09.189000 to 2020-02-21T19:45:16.189000)
        overlap duration : 2:02:07
        infected-window : (2020-02-21T14:13:10.784000 to 2020-02-22T04:42:09.158000)
    room_id: L89485
        agent-window : (2020-03-02T18:00:09.145000 to 2020-03-03T01:28:14.164000)
        user-window : (2020-03-03T00:13:02.422000 to 2020-03-03T09:40:11.521000)
        overlap duration : 1:15:11.742000
        infected-window : (2020-03-02T18:00:09.145000 to 2020-03-03T04:35:04.080000)
    room_id: G19247
        agent-window : (2020-02-08T08:11:24.845000 to 2020-02-08T16:38:27.884000)
        user-window : (2020-02-08T16:18:59.589000 to 2020-02-08T18:47:59.667000)
        overlap duration : 0:19:28.295000
        infected-window : (2020-02-08T08:11:24.845000 to 2020-02-09T05:55:06.157000)
    room_id: G19247
        agent-window : (2020-02-27T09:43:55.201000 to 2020-02-27T14:54:00.234000)
        user-window : (2020-02-27T06:34:23.340000 to 2020-02-27T09:56:26.400000)
        overlap duration : 0:12:31.199000
        infected-window : (2020-02-27T09:43:55.201000 to 2020-02-28T01:30:04.080000)
    room_id: J28929
        agent-window : (2020-02-13T08:49:13.942000 to 2020-02-13T14:19:16.028000)
        user-window : (2020-02-13T05:58:57.511000 to 2020-02-13T15:12:57.546000)
        overlap duration : 5:30:02.086000
        infected-window : (2020-02-13T08:49:13.942000 to 2020-02-14T02:54:03.167000)
```

Figure 33 Overlap details of a user 12265 with the agent across all the rooms

In the above figure we see that there are a total of 17 overlaps between the agent and the user, out of which 12 of them were direct overlaps where both the user and the agent were present in the same room at the same instant while the other 5 were indirect overlaps which would count all the secondary contacts.

We can use the information about total overlap duration, total overlaps, total indirect overlaps and then verify whether the resultant values are above a set threshold and then alert the user accordingly.

All the aforementioned information is generated during runtime when a patient shares his user id with the medical official. As soon as the server receives a request with the user id, it runs the contact tracing algorithm and identify all the users that might have an impact and then alert them accordingly.

5.2 Mobile app

The mobile app is used to scan QR codes or NFC and send them to the server informing the server about an entry or exit. It is also used to receive notifications from the server when the algorithm suspects an impact. Following are a few screenshots which show how the app looks and functions along with screenshots of the database when the entry/exit has been recorded.

Figure 34 Welcome screen of the app

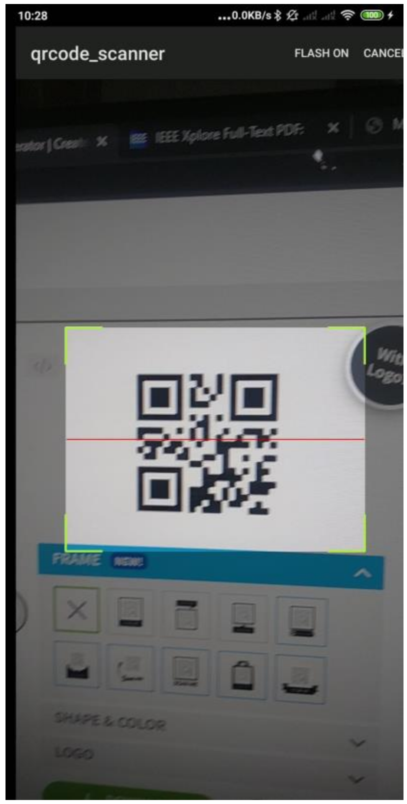

Figure 35 Scanning QR code to enter into a room

```
_id: ObjectId("5fa428343386179defa06320")
user_id: "70983"
room_id: "G19247"
status: 1
timestamp: 2020-11-05T10:28:36.483+00:00
```

Figure 36 Entry timestamp in the database

```
_id: ObjectId("5f892199258a7533e6a94a7a")
id : "G19247  "
name : "Grad School  "
max_capacity  : 82
last_sanitized_time  : 2020-10-14T12:32:28.303+00:00
current_strength  : 1
```

Figure 37 Room info of the checked in room

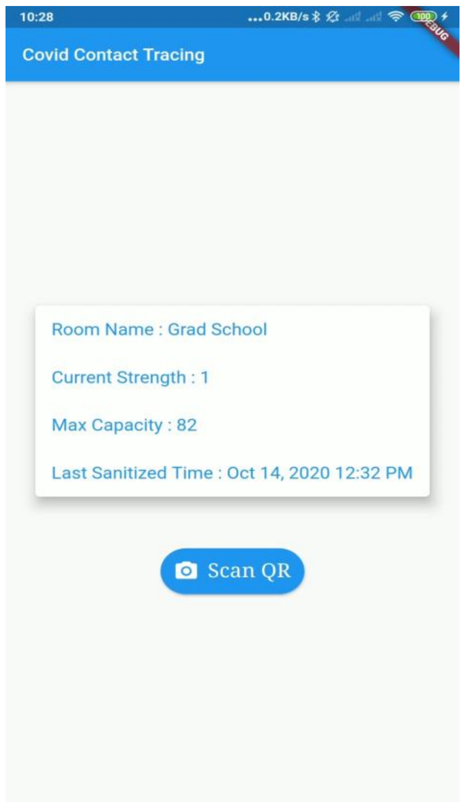

Figure 38 Room info displayed to the user

```
_id: ObjectId("5fa428ba3386179defa06321")
user_id: "70983"
room_id: "G19247"
status: 0
timestamp: 2020-11-05T10:30:50.032+00:00
```

Figure 39 Database record after recording an exit

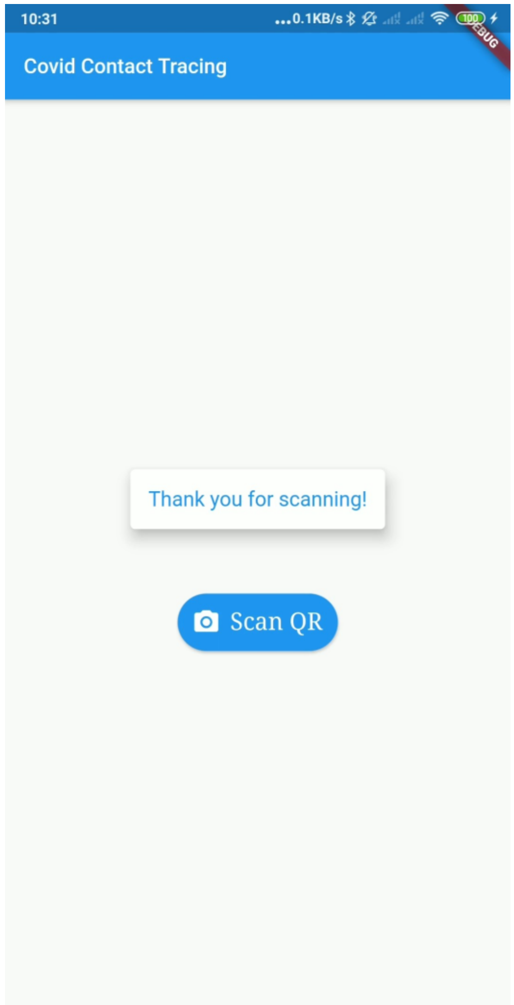

Figure 40 Mobile app after scanning an exit

_id: ObjectId("5f892199258a7533e6a94a7a")
id: "G19247"
name: "Grad School"
max_capacity: 82
last_sanitized_time: 2020-10-14T12:32:28.303+00:00
current_strength: 0

Figure 41 Updated room info after exit

CHAPTER 6

CONCLUSION

The purpose of this thesis is to introduce two different approaches of contact tracing where the users are alerted about the risk of being infected by coming in contact with an infected person without compromising on the privacy of both the user and the infected person (agent). When every user checks in or check out from every room we record that visit either on the server or on the phone based on whether we choose a centralized or a decentralized approach respectively. This thesis also talks about the advantages of having a centralized system where information like last sanitized time of the room, or number of visitors to the room since last sanitization are shared with the user before he enters into the room. It would help the user be more conscious and aware of his actions. By knowing information like maximum recommended people in the room and the approximate number of people in the room, a user can get an idea of how crowded the room is and what precautions he must take during the time of his stay.
This thesis introduced the idea of using NFC (Near-Field-Communication) to record a visit which is faster and more responsive than other forms of checking-in or checking-out. Using technologies like QR and NFC we propose an approach where the user is in the center of the system. We were able to achieve this by enforcing a strict restriction on background data collection by the app.

We have seen the implementation of Centralized contact tracing system by generating mock data where check-ins and check-outs for 100 users across 10 rooms over a certain long period of time are generated and one user is assumed to be tested positive. We then look at all the infected windows and overlaps with other users.

6.1 Future Work

The scope for using a check in and check out based system to perform contact tracing is rather vast. We currently rely completely on the users' entry and exit information to perform contact tracing. However, this cannot be assumed to be very smooth in practice. It is not uncommon that users' may forget to update an entry or exit and this in turn might affect the credibility and effectiveness of the contact tracing algorithm. This problem can be ameliorated by augmenting the system with a couple of sensors that can let the user know if he has missed marking an entry or an exit. One such approach is the use of Wi-Fi access points. By determining the unique ID of the Wi-Fi AP with which a smartphone is currently associated, it is possible to determine at a coarse-granularity the location of a user. Whenever a user scans or checks in to a facility we can keep track of any Wi-Fi signals that the phone captures at that instant. We then try to associate the Wi-Fi MAC address to the location of the user with the help of a specific predefined look up table that is set up during the implementation of this system for an organization. As the mobile app notices that there was a switch in the Wi-Fi address, it can alert the user and ask him if he has entered into a new facility or exited from an existing facility. This can be implemented in both Centralized and Decentralized systems since all the computations regarding the access points can be directly embedded into the mobile app making this completely independent of the server.

Using anonymized data in the case of a centralized contact tracing system to build machine learning models to understand and predict the spread of covid is another task one can perform. Data scientists can use this data to develop a correlation between fields such as number of overlaps, extent of overlap, circumstances of overlaps like how crowded was the place etcetera and the chance of testing positive. As the models get stronger and stronger, we can learn from the movement patterns of the users to estimate the risk level for a particular user based on their overlap history. Doing this would avoid creating unnecessary panics in the cases of false positives.

Using Accelerometer-based inertial navigation system can provide useful location-data in scenarios where Wi-Fi signals cannot penetrate (e.g., inside an elevator or in basements). Accelerometers are present in almost all modern smartphones and can be a good augmentation to the existing system.

Using active NFC devices at the entry and exit points and allowing users to set up a passive NFC band associated with their user id. This can reduce the effort of using a phone to scan the NFC tag every time. Instead, user can use a passive NFC chip embedded band to mark his entry or exit and the active NFC device at the door will perform the action of interacting with the server. This can be useful when the check in and checkout areas are much finer than a whole room. For instance, at a table in a restaurant or a specific seat in a conference room or using an equipment in a gym

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