# COVID-19 Mobile Apps for Contact Tracing: A Review on Technology and User Opinions

Mahmoud El Khodr, Omar Mubin, Zainab Iftikhar, Maleeha Masood, Belal Alsinglawi, Suleman Shahid, Fady Alnajjar

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## *Abstract*

**Background:** Contact tracing has been a key part of the worldwide measure in response to the COVID-19 pandemic. Many countries across the globe have released their contact tracing application. This has resulted in the proliferation of several contact tracing applications that used a variety of technologies.

**Objective:** This study analyses most of the COVID-19 Contact tracing apps in use today. Beyond investigating the privacy features, design, and implications of these apps, this research examines the underlying technologies used in contact tracing applications. It also attempts to provide some insights into their level of penetration and gauge their public reception.

**Methods:** The research sampled 13 applications corresponding to 10 countries based on the underlying technology used. The selected applications were all free to download. The inclusion criteria also ensured that most COVID-19 declared epicentre (countries) were included in the sample, such as Italy. The sampled apps included also countries that relatively did well in controlling the outbreak of COVID-19 such as Singapore. Informational apps or un-official contact tracing apps were excluded from this study except for the South Korean app as this was amongst the first app launching globally. A brute force keyword search technique was used to scrap the reviews of each of the 13 apps under reviews.

**Results:** The study identified seven distinct technologies used by or incorporated in COVID-19 tracing applications. In total 13 distinct applications were selected for this study.

**Conclusions:** Contact tracing applications come with their own set of challenges as well. Key amongst these challenges is privacy. Of course, this is anticipated as you can't expect to trace and track peoples' movement by a government authority without addressing the privacy issues.

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# Original Manuscript

# COVID-19 Mobile Apps for Contact Tracing: A Review on Technology and User Opinions

**Extended Abstract:(I believe the abstract is completed online separately and then automatically inserted in the paper)**
Contact tracing has been a key part of the worldwide measure in response to the COVID-19 pandemic. Many countries across the globe have released their contact tracing application. This has resulted in the proliferation of several contact tracing applications that used a variety of technologies. With the absence of a standardised approach used by government authorities, policymakers, and developers, many of these applications were unique. Therefore, they varied by function and the underlying technology used for contact tracing and infection reporting. Research into the efficacy of these applications remains in its infancy. This study analyses most of the COVID-19 Contact tracing apps in use today. Beyond investigating the privacy features, design, and implications of these apps, this research examines the underlying technologies used in contact tracing applications. It also attempts to provide some insights into their level of penetration and gauge their public reception. The research also investigated the data collection, reporting, retention, and destruction procedures used by each of the applications under review.

**Methods**:
The research sampled 13 applications corresponding to 10 countries based on the underlying technology used. The selected applications were all free to download. The inclusion criteria also ensured that most COVID-19 declared epicentre (countries) were included in the sample, such as Italy. The sampled apps included also countries that relatively did well in controlling the outbreak of COVID-19 such as Singapore. Informational apps or un-official contact tracing apps were excluded from this study except for the South Korean app as this was amongst the first app launching globally. A brute force keyword search technique was used to scrap the reviews of each of the 13 apps under reviews.

**Results**
The study identified seven distinct technologies used by or incorporated in COVID-19 tracing applications. In total 13 distinct applications were selected for this study. The USA was reported to release the most contact tracing applications, followed by Italy. Bluetooth was the most frequently used underlying technology, employed by 7 applications, whereas 3 applications were tracing contacts through location (e.g., GPS). The Norwegian, Singaporean, Georgian, and New Zealand apps were amongst the applications that collected the most of the users' personal information whereas some applications such as the Swiss and the Italian (Immuni) apps didn't collect any users' information. The observed minimum implemented in most of the apps with regards to Data destruction was 14 days, while the Georgian app retained records for 3 years. 30,000 reviews corresponding to the 13 apps selected in this study were scrapped and analysed. No significant battery drainage issue was reported for most of the apps. Interestingly, only about 2% of the reviewers expressed concerns about their privacy across all apps. However, many reviews complained about several technical issues encountered when using the app. The number and frequency of technical issues reported on the app store for each of the apps under review were significantly more than those reported on Google play. The highest was the New Zealand app with 27% of the reviewers reporting technical difficulties (10% out of 27% scrapped reviews reported that the app didn't work). The Norwegian, Swiss apps and the USA app (pathcheck) had the least reported technical issues sitting at just below 10%. In terms of usability, many applications such as the Singaporean, the Australian, the Swiss and the Indian apps did not provide the users with an option to sign out from their applications.

# 1- Introduction

The COVID-19 pandemic which causes respiratory infection has spread rapidly across the world surpassing 20 million cases by early August [1]. The economic impact of the pandemic is felt globally with many countries slipping into recession. The Covid-19 pandemic is also turning into a jobs crisis threatening to dismantle several industries from aviation and manufacturing to services, tourism, and agriculture [2].

The global health and government responses to the pandemic have been fragmented due to the urgency of actions required as a result of the stochastic spread of the virus. With some countries implementing policies to eradicate the virus, such as Vietnam and New Zealand[3], and countries trying to suppress and contain the spread of the virus such as Australia[4], and countries relying on building a herd immunity such as Sweden[5]. Nonetheless, the virus continued to spread arbitrarily between regions and countries and the epicentre of the pandemic has been moving between continents. It started with China, moved to Italy and Spain, USA, Brazil, with India predicted to be the next in line. Several other countries are now experiencing a second wave after initially suppressing it with clusters of new cases popping up in many countries such as in South Korea and Australia[6].

The speed of the authorities' response has proven to be a major key in containing the spread of the virus as well. For instance, many experts weighed on the relatively slow response of Italy to contain the virus[7] and the fast response of South Korea in repressing it[8]. Despite the variations in the worldwide governments-wide crisis response to the pandemic, and the lack of clear uniform advice on matters as simple as the role of a mask in containing the spread of the virus[9], the measures and policies used worldwide to contain the virus remained mostly precautionary- in the absence of a vaccine or a treatment. Consequently, the direct safety advice as a result of the novel coronavirus pandemic continues to be about maintaining good hands' hygiene, practicing social distancing between peoples, testing as soon as the earlier onset of the virus symptoms appear, quarantining, and, importantly, contact tracing.

Contact tracing is the process of identifying, assessing, and managing people who have been exposed to a disease to prevent onward transmission[10]. Until a COVID-19 vaccine is commercially available to the public, contact tracing tools are vital in breaking the chains of transmission of the virus. This means identifying infected peoples and their close contact(s), testing them, and isolating them for 14 days from day zero of the exposure. For countries that managed to control the exponential growth of the virus (known as flattening the curve), extensive contact tracing is essential to minimise large scale community transmissions. With countries recently coming out of lockdown and opening their economies and borders again such as France and USA, contact tracing is the key to rapidly identifying new cases. Hence, maintaining low levels of community transmissions to remain successful in containing the outbreak of the virus. Thus, in addition to a comprehensive testing capacity, contact tracing is seen as the silver bullet in managing this pandemic- until a vaccine or a reliable viral treatment is found.

For contact tracing to be beneficial in preventing onward transmission and thus reducing the impact of the second wave of coronavirus, it should be implemented systematically. This means having a system to securely collect, compile, and analyse data about individuals in real-time, while not impinging on their privacy. As with the lack of a uniform and standardised global response to the pandemic, contact tracing technologies and approaches adopted by several countries were also diverse. For instance, on the same day in which Canada announced that they were working on a new contact tracing app[11], the UK was abandoning their contact tracing app citing that the technology

does not work[12].

To this end, this work reviews and evaluates most of the contact tracing mobile applications in use today. To our knowledge, this is the first research that investigated the followings issues pertaining to contact tracing:

- What are the underlying technologies in use by contact tracing applications and how do they compare? That is, for each of the underlying technologies:
  - What is the underlying architecture used?
  - How is the handshake between devices performed?
  - How close contacts and infections are reported?
  - Is privacy been incorporated by design?
- What level of penetration these applications achieved?
  - How many people downloaded the apps?
  - The timeline these applications were introduced
- Investigated the privacy features and implementations
  - Did the application know the users' visited locations?
  - Did the application know the identities of the people the user was in proximity with or just their locations?
  - How much personal information each app collected?
  - How long records are kept? (Data retention)
  - Were users provided with an option to delete their records? (Right to be forgotten)
  - Were users able to logoff or opt-out from the app, without the need to uninstall the app?
  - Is the app Geo location restricted?
- What did people mostly complain about in their reviews and how was the public reception for each of the app?
  - Did people report battery drainage issue?
  - Were privacy concerns amongst the main issues reported in the reviews
  - What were the reported technical issues in terms of: installation difficulties, compatibility issues, crashes, and bugs?

# 2-COVID-19 Contact tracing applications: Background, technologies in use and penetration

Contact tracing using mobile application relies on the concept of proximity tracking. The concept behind contact tracing is to identify and keep a record of people who may have been in close proximity (e.g., typically less than 1.5 meters) to other people. So, once an individual is identified to be infected with COVID-19, the application will be used to retrieve and trace the other close contacts. There have been various implementations for contact tracing apps, and a range of technologies, security, and privacy approaches have been adopted across the globe. Notably, the effectiveness of these contact tracing technologies remains to be seen. More evidence is required to demonstrate whether these tools were successful in contact tracing and to determine their usefulness.

The current contact tracing applications, which have been widely used by several countries, mostly use Bluetooth as the underlying technology for proximity sensing. In an effort to contribute towards having a unified solution for contact tracing and to counter the limitations of using Bluetooth on the

iOS platform[13], Apple and Google have recently released a new framework to support contact tracing[14] as well. However, applications that implement this framework haven't matured enough yet. Nonetheless, surveying the current applications in use and measuring their reception by the public remains unexplored. Previous works that surveyed contact tracing applications mostly considered privacy as the main criteria of study, such as the works reported in [15-18]. Other research[19] looked further into contact tracing applications. The study classified the applications based on the infrastructure used (centralized, distributed, and hybrid). However, the study focused more on the underlying infrastructure. This study goes beyond that to investigate not only the communication technology used; but also their characteristics and their public reception as outlined in the previous section.

## 2.1 Surveying the technologies in use

This research classified the contact tracing applications based on the type of technology used for contact tracing of infected masses. The study identified six distinct technologies and an additional category commonly used or incorporated in COVID-19 tracing applications. These are **Bluetooth**, **DP-3T protocol**, **GPS**, **PEPP-PT/PEPP**, **TCN**, **Google/Apple** and **other** technology mainly QR code, and the use of a digital diary. These technologies are outlined in Table 1. The classification criteria considered the underlying technology used by the app rather than classifying the applications based on geographical or other architectural features. This is because most of the applications in use today use Bluetooth. Therefore, classifying the apps based on the underlying technology ensures that the research is capturing most contact tracing solutions in use. For instance, contact tracing solutions used by Singapore, Australia, and Malaysia use the same technology. So, there is little benefit to the research from surveying all three country solutions.

*Table 1- The main technologies used in contact tracing mobile apps.*

| **Technology** | **Description** |
|---|---|
| Bluetooth | The subject's phone uses proximity tracking in which encrypted tokens are exchanged with nearby phones via Bluetooth signals. The approach is easier to anonymize but comes with the challenge of signals' attenuation. |
| DP-3T protocol | Decentralized privacy-preserving proximity tracking is an open protocol for contact tracing enabling full anonymity. It uses Bluetooth Low Energy for measuring a subject's proximity. The subject's phone's contact logs and computation stay entirely on their device. The central reporting server nor has access to data, neither is responsible for processing information. This approach has major privacy benefits. |
| Location | The subject's phone tracks their movements and looks for nearby phones in the same vicinity either by using GPS or triangulation from cell towers. This approach raises concerns for privacy-concerned users. |
| PEPP-PT/PEPP | Pan-European Privacy-Preserving Proximity Tracing, like DP-3T, relies on Bluetooth to discover and locally logs clients in close proximity to a user. However, unlike DP-3T, this approach uses a central repository system to process contact logs. |

| | |
|---|---|
| TCN | Temporary Contact Numbers protocol is a decentralised and anonymous contact tracing protocol. It uses Bluetooth Low Energy to track and log encounters. As no central repository is involved in data collection and privacy, the protocol has huge privacy benefits. |
| Google/Apple | This is an API developed jointly by Google and Apple. Using the API, iOS and Android smartphone users communicate via Bluetooth. The protocol is highly influenced by DP-3T and TCN, but it is implemented at the operating system level. |
| Other | QR codes and digital diaries are used to log the locations visited by the users. |

Table 2 details the architecture and approaches used by each of these technologies, these are as follow:

- **Country**: For each of the technology used, a sample of countries that uses this technology in their contact tracing app is provided. Where there is more than one application used in a country, the name of the corresponding application is provided. It is worth noting that this is not a comprehensive list. The aim is to sample some of the countries for the purpose of adding context to the data presented in the table rather than creating an inventory of applications. The next section provides more details on the selection and inclusion criteria of the applications sampled in this study.
- **Architecture**: This criterion investigates whether the technology used by the contact tracing application incorporates the concept of uploading contact logs to a central reporting server or not. The criteria used are *centralised, semi-centralised, and decentralised*. It has been proven difficult to exclusively classify the architecture of each of these technologies as implementations varied from an application to another. For instance, some applications uploaded contact logs to a central server. But the server did not have access to the uploaded contact logs, nor it was responsible for any further contact tracings processing; while others had access. As such this criterion should be read in conjunction with the other criteria presented in Table 3 mainly the "**Encounter Handshake**" and "**Infection reporting"** criteria**.**
- **Encounter Handshake:** This refers to how two devices coming in close contact perform a handshake i.e. exchange identifications data. Most of the technologies surveyed exchanged some forms of a temporary ID, while others exchanged some forms of unique identifiers either encrypted or in plain text (also depending on the specific implementation of each of the apps).
- **Infection reporting:** This refers to how the contact log is reported to the central server and the role of this server in contact tracing. Most of the applications relied on the users to upload the contact logs. Implementations varied as well based on whether the health authorities had access to the contact logs or not.
- **Privacy by design**: As the name suggests, this criterion explored if the technology embedded any privacy considerations into its design specifications.

*Table 2- outlines the technologies with their salient features.*

| | **BT** | **DP-3T protocol** | **GPS** | **PEPP-PT/ PEPP** | **TCN** | **Google / Apple** | **others** |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Country** | Australia | Austria | Iceland Rakning C-19 | France | Germany ITO | Canada | New Zeala diary |
| | Singapore | Finland | Italy- Diary | Georgia | Italy | SwissCoviD | GetHomeSaf (Australia, C |
| | MyTrace Malaysia | Netherlands | Jordan Aman | Italy Immuni | US | Corona-Warn-App (Germany) | SELangkah ( |
| **Architecture** | Centralised | Decentralised | Centralised | centralised | Semi-centralised | Decentralised | Centralised |
| **Encounter handshake** | Users exchange Temporary IDs issued by the server | unique 128-bit pseudo-random identifier (PUID) by the server | Varies by implementation. Some identify users by phone numbers | Users exchange Temporary IDs issued by the server | temporary contact numbers (TCN) | unique identifiers that are encrypted with a secret daily key held by the sending device | Real ID |
| **Infection reporting** | Users triggered upload | Users triggered upload but the health authority never has access to contact log | Users triggered upload | Users triggered upload But received massive privacy backlashes | The app notifies the user to potential infection | Not provisioned - delegated to app implementation | Varies implementati (mostly user |
| **Privacy by design** | No | Yes | No | No | Yes | Yes | No |

## 2.2 Analysing their Intake and penetration

Based on the technologies presented in Tables 1 and 2, the research sampled 13 applications corresponding to 10 countries. These are presented in Table 3. All applications were free to download. These applications were chosen to cover all the contact tracing technologies presented in Table 1. The inclusion criteria also ensured that most COVID-19 declared epicentre (countries) were included in the sample, such as Italy. The sampled apps included also countries that did relatively well in controlling the outbreak of COVID-19 such as Singapore. Informational apps or un-official contact tracing apps were excluded from this study except for one, the South Korean's Corona100m app which uses the GPS technology for contact tracing. This is because Corona100m was amongst the first major contact tracing app launching across the globe. Also, because South Korea is one of the few countries that managed to suppress the transmission of the virus quickly.

The data extracted for each of the applications were:

- The country where it was launched,
- The name of the app,
- The number of installs as per Google play
- The number of installs as per the local news: this was sourced from local news outlets from the home country of each of the corresponding app (more on this below),
- The penetration percentage as per Google Play installs: this is calculated by dividing the total number of installs extracted from Google play by the total population of the home country.
- The penetration percentage as per local news sources: this is calculated by dividing the total number of installs extracted from local news sources by the total population of the home country.
- Launch day: The time taken for the app's launch is the difference between the release date and the date when the first COVID case was reported in the home country. The later were sourced from the John Hopkins portal.

A challenging aspect of sourcing the data reported in table 3 was encountered in calculating the intake of the applications under study. For instance, the number of downloads for an application does not represent a true figure of the actual intake. Downloading an application does not necessarily means the application is being used. Users may simply download the application and never use it or uninstall it. There was little data available on the number of uninstalls for each of the surveyed apps as well. Regardless of this limitation, the number of installations for an app was not available on the App Store. This has made the task of calculating the intake of an app even more complex.

Consequently, the research required access to a more precise estimate of the installation figures as compared to what Google Play was showing. Therefore, apart from consulting Google Play's number of installs, the study referred to reliable news sources to source the total number of registrations or downloads for each of the applications under review. Mainly the news sources were from government or developer announcements, verifiable local news sources, and published research (white papers). Some of the statistical information such as the download intakes and any data sourced from local news is indicative as of early July. As such there might be a slight variation in the figures presented in Table 3 as compared to when this paper will be available. Some apps were new and so this local figure was not readily available for them as well. Another challenge the research run into was the unavailability of some of the applications on the Google Play Store. This is because they were discontinued, or because they were still in demo or beta stages. All these challenges induced entries labelled as N/A for some of the apps in Table 3.

Nonetheless, the research intended as well to calculate the success rate of each of the apps in contact tracing reporting. The aim was to survey and compare the efficacy of the applications under review. However, this was challenged by the lack of any reliable relevant data, and thus this part of the review had to be dropped.

*Table 3- Summary of the 13 Selected Contact Tracing Apps penetration and intake*

| Country | App | No of installs (Local News) | No of installs (Play Store) | Penetration (as of Local News) | Penetration (as of Play Store) | Number of da app's launc patient zero |
|---|---|---|---|---|---|---|
| USA | PathCheck SafePlaces | N/A | 10,000 | N/A | 0.001% | 93 |
| | NOVID | N/A | 10,000 | N/A | 0.001% | 110 |
| | Care19 | 33,000 | 10,000 | 0.01% | 0.001% | 76 |
| Italy | Immuni | 2,700,000 | 1,000,000 | 4.47% | 1.65% | 122 |
| | SM-COVID-19 | 52,000 | 50,000 | 0.09% | 0.08% | 73 |
| Norway | Smittestopp | 1,427,000 | 100,000 | 26.32% | 1.84% | 50 |
| Singapore | TraceTogether | 2,100,000 | 1,000,000 | 35.89% | 17.09% | 57 |
| South Korea | Corona 100m | 1,000,000 | N/A | 1.95% | N/A | 20 |
| Pakistan | CoCare | N/A | 500 | N/A | 0.001% | 108 |
| Australia | COVIDSafe | 6,130,000 | 1,000,000 | 24.03% | 3.92% | 91 |
| New Zealand | NZ COVID Tracer | 573,000 | 100,000 | 11.88% | 2.07% | 82 |
| Switzerland | SwissCovid | 1,600,000 | 500,000 | 18.48% | 5.78% | 90 |
| Georgia | Stop Covid | 100,000 | 100,000 | 2.51% | N/A | 50 |

## 3- Investigating the privacy -by-design features, and privacy implementations of COVID-19 Contact tracing applications

In the rest of this work when referring to an app, the work will use the followings notation:

*App name (country of origin, technology used for contact tracing)*.

This section expands on a previous work[20] that compared the privacy aspects of COVIDSafe app (Australia, Bluetooth) and the COVID Tracer app (New Zealand, QR code). Tables 4 reviews the privacy features of the 13 applications sampled in this study. Each of these applications was downloaded and evaluated thoroughly as per the criteria shown in Table 4. The research also referred to white papers and developers' announcements for the apps that were in their testing phase or were not available/accessible on the App Store and/or Google Play. The same methodology was followed for the applications that were not available in English, such as Immuni (Italy, Google/Apple API), SM_COVID19 (Italy, ReCoVer), and Smitte|Stop (Norway, Bluetooth and GPS).

*Table 4- Privacy Features of the Reviewed Applications*

| Cntry | App | Tech | Architecture | Location Tracking | Location Tracking proxies | personal information access | Data retention | Right to forget | Optout |
|---|---|---|---|---|---|---|---|---|---|
| | PathCheck SafePlaces[1] | Location | Decentralized[2] | Acts as a private digital diary of users' locations. The app works by maintaining a time stamped log of a phone's GPS location. | No | The app does not ask for any personally identifiable information Encrypted location history is saved on phone | 14 days | No | No signup/sign is required. |
| USA | NOVID[3] | Bluetooth radio waves and ultrasound | Decentralized | No* | No (Uses Bluetooth radio waves and ultrasound ) to record interaction s | No personal information is collected. Require microphone permissions to receive ultrasound | | By uninstallin g the app | No signup/sign is required You can disable the app however. |

[1] PathCheck SafePlaces - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=org.pathcheck.covidsafepaths&hl=en. Accessed June 30, 2020.

[2] *Review of Mobile Application Technology to Enhance Contact Tracing Capacity for COVID-19*. https://www.centerforhealthsecurity.org/resources/COVID-19/COVID-19-fact-sheets/200408-contact-tracing-factsheet.pdf. Accessed June 30, 2020.

[3] NOVID - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=com.expii.novid&hl=en. Accessed June 30, 2020.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Care19[4] | GPS | Centralised | Yes | Location associated with encrypted IDs | No personally identifiable information. Location data will only be shared if consented. | 14 days | Users can delete all data | Users can opt out anytime, app can be deleted |
| Italy | Immuni[5] | Bluetooth Low Energy technology, Google/Apple | Decentralized | No | No | The app does not collect any data that would identify the user. | When no longer relevant. No later than 31 Dec, 2021 | No | No signup/sign is required You can disable the app however. |
| | SM-COVID-19[6] | ReCoVer, BLE, Bluetooth | Centralized | Optional GPS positions sharing mode | Acquires ID of nearby devices | Sm-Covid-19 does not acquire personal data or health data | As long as the app is installed. Travel data is deleted after 21 days | as long as the APP remains installed | You can uninstall. |
| Norway | Smittestopp[7] | Bluetooth and GPS signals | Centralized | Yes | No | Mobile phone number, age, GPS location, generated UUID Bluetooth data on close contact with other phones is continuously logged | 30 days | Yes | You can also delete the app itself And you can choose whether to turn logging features on or off |
| Singapore | TraceTogether[8] | Bluetooth, BlueTrace | Centralized | No | No | Medium (Name, age, nationality, passport number) | 25 days | Yes, by contacting support | No |

[4]Care19 Diary - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=com.proudcrowd.care.

[5] Immuni - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=it.ministerodellasalute.immuni. Accessed June 30, 2020.

[6] SM_Covid19 - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=it.softmining.projects.covid19.savelifestyle&hl=en. Accessed June 30, 2020.

[7] Smittestopp - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=no.simula.smittestopp&hl=en. Accessed June 30, 2020.

[8] TraceTogether - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=sg.gov.tech.bluetrace&hl=en. Accessed June 30, 2020.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| South Korea | Corona 100m[9] | Location (location histories) | Centralized | Yes | Yes | High (age, sex, location. It integrates GPS history, data from nationwide surveillance cameras, and credit card transactions.) | N/A | N/A | N/A |
| Pakistan | CoCare[11] | Bluetooth | Centralized | No | Exchangeencrypted keys not locations | Low (Mobile number) | 30 days | Yes (By deleting the app) | Yes, you can logout of the app |
| Australia | COVIDSafe[12] | Bluetrace | Centralized | No | Yes | Medium (Name, phone, age, postcode) | 21 days | Yes | N/A |
| New Zealand | NZ COVID Tracer[13] | Bluetooth, QR codes | Centralized | Yes | No | High (Name, email, address, phone, age, ethnicity, location) | 31 days | Yes, by deleting the app. | Yes |
| Switzerland | SwissCovid[14] | Bluetooth, DP-3T, Google/Apple | Decentralized | No | Yes (the app does not record locations) | No | 14 days | Delete the app | Yes, you can disable tracing or turn of Bluetooth |

[9] *Review of Mobile Application Technology to Enhance Contact Tracing Capacity for COVID-19.* https://www.centerforhealthsecurity.org/resources/COVID-19/COVID-19-fact-sheets/200408-contact-tracing-factsheet.pdf. Accessed June 30, 2020.

[10] Leswing K. Apple is rejecting coronavirus apps that aren't from health organizations, app makers say. CNBC. https://www.cnbc.com/2020/03/05/apple-rejects-coronavirus-apps-that-arent-from-health-organizations.html. Published March 5, 2020. Accessed June 30, 2020.

[11] CoCare - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=com.cocareapp. Accessed June 30, 2020.

[12] COVIDSafe - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=au.gov.health.covidsafe. Accessed June 30, 2020.

[13] NZ COVID Tracer - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=nz.govt.health.covidtracer. Accessed June 30, 2020.

[14] SwissCovid - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=ch.admin.bag.dp3t. Accessed June 30, 2020.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Georgia | Stop Covid[15] | PEPP-PT | Centralized | ID, date, time, and location. | No | User ID, Location data, Time, duration and location of the contacts Function calls in the app, the information that you are infected with COVID-19, your phone number | 3 years | By uninstalling. This does not apply to historical informatio which is kept for maximum of 3 years. | N/A |

As discussed in the Introduction, previous related works investigated the privacy architecture of the technologies used in contact tracing apps. Mainly the “encounter handshake” and “infection reporting” processes. However, these works did not consider the implementations of the specific applications. Therefore, the following criteria were considered in this review in addition to the architecture in use by each of the app:

- **Technology**: The underlying technology used for contact tracing
- **Personal information access**: The amount of personal information each app collected. The following scale was used: If an app is only collecting the name, email, and phone number of the user, then the scale is designated as *low*. If in addition to this personal information, the app collected the age of the user, then the scale is designated as *medium*. Whereas, if an application collected the name, email, phone number, age and any additional information such as the address, ethnicity, or location via GPS, of the user then this criterion was rated as *high*.
- **Location Tracking**: This criterion considers whether an application is tracking the movement of individuals or not.
- **Tracking and identifying proxies**: This criterion investigated if the application under review knew the identity of the people in close proximity to the user or just their locations or IDs (true identity vs temporary ID such as with the TCN protocol). This criterion somewhat combined between the encounter hand shake and infection reporting features.
- **Records keeping timeframe**: This criterion specifies the duration contact logs are kept on the device or the authority’s remote servers.
- **Right to forget**: This criterion considered if the users were informed about the procedures to delete the records collected by the app.
- **Opting out:** This criterion indicates If users were able to sing in and out of the application under review.
- **Geo-restriction**: as the name entails, this criterion investigated whether an application could be downloaded from anywhere or whether it is a home or region geo-restricted.

Nine of the applications were available for free on both the App Store and Google Play. Two apps:

[15] Stop Covid - let’s fight this together - Apps on Google Play. play.google.com. https://play.google.com/store/apps/details?id=gov.georgia.novid20. Accessed June 30, 2020.

SM_COVID19 (Italy, Google/Apple) and CoCare (Pakistan, Bluetooth) were only available on Google Play, while Stop Covid (Georgia, PEPP-PT) was only available on the App Store. The Corona 100m app (South Korea, Location) was not available on both stores. Smitte|Stop (Norway, Bluetooth and GPS) was not available to download due to geo-restrictions. The Australian COVID Safe app required an Australian phone number and a postcode to run.

Bluetooth was the most frequently used underlying technology, employed by seven applications for digital contact tracing, whereas three applications were tracing contacts through location (e.g., GPS). The applications using location as the underlying technology, namely Corona 100m (South Korea, Location) and PathCheck SafePlaces (USA, Location), tracked and recorded the locations visited by the users. Although Corona 100m (South Korea, Location) was removed from Google Play, the app integrated GPS history, data from nationwide surveillance cameras, and credit card transactions. This has sparked privacy concerns as users of the Corona 100m app could see the date that a coronavirus patient was infected, along with his or her nationality, gender, age, and the locations they visited.

The Norwegian, Singaporean, Georgian, and New Zealand apps were amongst the applications that collected the most of user's personal information. While some other applications such as the Swiss and the Italian Immuni apps didn't collect any user's information. Others ranged from simply collecting the phone number of the user to additionally collecting their names or email addresses.

Data destruction was incorporated in most of the applications which automatically deleted the users' records after 14 days (that was the observed minimum implemented in most of the apps) with some keeping them for 21 days (Australia) and others (Switzerland, India) for 30 days, the New Zealand's app for 31 days, while the Georgian apps kept the users 'records the longest for 3 years.

Three of the USA's applications: PathCheck (USA, Location), NOVID (USA, Bluetooth radio waves and ultrasound) and Care19 (USA, GPS) did not require the users to sign up before using their app. On the other hand, many applications such as the Singaporean TraceTogether app, the Australian CODIV Safe app, the Swiss and the Indian apps did not provide the users with an option to sign out from their app.

It is noteworthy to mention that the data presented in Table 4 are true as of 30 June 2020.

## 4- Analysing the public reception of COVID-19 Contact Tracing apps

This section aims to identify the audience uptake and users' feedback of the current COVID-19 contact tracing applications under review. Data were sourced by scrapping the publicly available users' reviews from the App Store and Google Play app's pages for each of the apps. Almost 30,000 reviews were scrapped and analysed. The users' reviews of each of the corresponding apps were then filtered and analysed using a brute force keyword search methodology. Table 5 lists the keywords used in scrapping the reviews. The methodology used when analysing these reviews also accounted for the variations of each of the keywords, referred to as sub-keywords. For instance, the results of scrapping and analysing the followings sub-keywords: *doesn't work*, *didn't work*, *not working*, *Doesn't work*, *Didn't work*, and *Not working*, were all counted towards the results of the main keyword "**Malfunctioning**". In other words, the results reported under the keyword "**Malfunctioning**" are a concatenation of each of the individual results returned by its list of sub-keywords.

*Table 5- The list of keywords used in the study*

| **Keywords** | **Sub-Keywords** |
|---|---|
| Drainage | drain \|\| battery \|\| Drain \|\| Battery |
| Spyware | spy \|\| spied \|\| spyware \|\| Spy \|\| Spied \|\| Spyware |
| Malfunctioning | doesn't work \|\| didn't work \|\| not working \|\| Doesn't work \|\| Didn't work \|\| Not working |
| Crashes | crash \|\| freeze \|\| Crash \|\| Freeze |
| Privacy Concerns | privacy issue \|\| privacy concern \|\| location concern \|\| tracking me \|\| track me \|\| tracking us \|\| Privacy issue \|\| Privacy concern \|\| Location concern \|\| Tracking me \|\| Track me \|\| Tracking us |
| Ineffective | useless \|\| rubbish \|\| garbage \|\| Useless \|\| Rubbish \|\| Garbage |
| Bugs | bug \|\| buggy \|\| Bug \|\| Buggy |
| Installation issues | can't install \|\| doesn't install \|\| couldn't install \|\| Can't install \|\| Doesn't install \|\| Couldn't install |
| Incompatible | can't download \|\| couldn't download \|\| incompatible \|\| Can't download \|\| Couldn't download \|\| Incompatible |

Table 6 shows the occurrence percentage for each of the keywords for each of the apps. Table 7 shows the average ratings of the rated reviews for each of the keyword. For example, consider if a user left a review for one of the apps saying the "the app keeps on crashing" and then gave it a rating of 2 stars. Then this review will be counted towards the average of the keyword "crushes" shown in table 6. The 2-star rating will also be counted towards the corresponding keyword average rating shown in Table 7. The N/A shown in these tables refers to the unavailability of user reviews as the corresponding apps were not available on the corresponding platforms. All small figures were rounded up to 0.001.

One of the challenges encountered in scrapping the reviews was analysing the apps that were not available in English. For example, most of the reviews for Immuni app (Italy, Google/Apple), SM_COVID19 (Italy, ReCoVer) and Smite|Stop (Norway, Bluetooth and GPS signals) were available in the Italian and Norwegian languages respectively. For these reviews, along with the rest of the app reviews that were in different languages, the keywords along with their sub-keywords were translated to their home app country language. The results were incorporated when calculating the overall average figures for all the apps. The translated keywords along with the sub-keywords used can be found in Table 1 from the Appendix.

*Table 6- Percentages of User Reviews in Each Category of Each App on Each Platform*

| | | USA | | | Italy | | Norway | Singapore | South Korea | Pakistan | Australia | New Zealand | Switzerland | G |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PathCheck SafePlaces | NOVID | Care19 | Immuni | SM-COVID-19 | Smittestopp | TraceTogether | Corona 100m | CoCare | COVID Safe | NZ COVID Tracer | SwissCovid | |
| | App Store | 0.001% | 5.560% | 1.420% | 3.730% | N/A | 15.560 % | 9.520% | N/A | N/A | 3.030% | 0.830% | 6.980% | 6. |
| | Google Play | 2.220 % | 8.470% | 0.660% | 6.420% | 3.740% | 7.280% | 11.170 % | N/A | 0.001% | 9.290% | 0.170% | 7.870% | |
| | App Store | 0.001% | 0.001% | 0.001% | 0.001% | N/A | 0.001% | 0.001% | N/A | N/A | 0.060% | 0.001% | 0.210% | 0. |
| | Google Play | 0.001% | 0.001% | 0.001% | 0.100% | 0.001% | 0.001% | 0.130% | N/A | 0.001% | 0.200% | 0.001% | 0.760% | |
| | App Store | 0.001% | 11.110 % | 12.770 % | 7.800% | N/A | 6.670% | 6.670% | N/A | N/A | 6.500% | 10.740 % | 2.110% | 6. |
| | Google Play | 0.001% | 5.080% | 1.320% | 7.210% | 1.720% | 4.970% | 1.430% | N/A | 0.001% | 0.540% | 1.670% | 2.370% | |
| | App Store | 0.001% | 0.001% | 1.420% | 0.130% | N/A | 1.110% | 6.190% | N/A | N/A | 0.630% | 4.130% | 0.210% | 0. |
| | Google Play | 0.001% | 0.001% | 0.660% | 0.390% | 1.150% | 0.001% | 0.650% | N/A | 0.001% | 1.070% | 1.670% | 0.320% | |
| | App Store | 0.001% | 2.780% | 2.130% | 0.130% | N/A | 0.001% | 0.360% | N/A | N/A | 0.940% | 0.830% | 0.001% | 0. |
| | Google Play | 0.001% | 1.690% | 1.970% | 0.210% | 0.001% | 0.001% | 0.260% | N/A | 0.001% | 0.530% | 0.420% | 0.430% | |
| | App Store | 13.330 % | 5.560% | 0.001% | 5.400% | N/A | 1.110% | 2.740% | N/A | N/A | 2.910% | 9.090% | 1.480% | 3. |
| | Google Play | 0.001% | 5.080% | 1.970% | 5.070% | 0.290% | 1.990% | 1.220% | N/A | 0.001% | 2.060% | 6.330% | 1.400% | |
| | App Store | 0.001% | 0.001% | 3.550% | 2.470% | N/A | 2.220% | 2.980% | N/A | N/A | 2.470% | 2.480% | 5.710% | 3. |
| | Google Play | 0.001% | 1.690% | 3.290% | 2.920% | 1.150% | 0.001% | 0.700% | N/A | 0.001% | 1.100% | 2.000% | 7.550% | |
| | App Store | 0.001% | 0.001% | 0.001% | 0.230% | N/A | 0.001% | 0.001% | N/A | N/A | 0.130% | 0.001% | 0.001% | 0. |
| | Google Play | 0.001% | 0.001% | 0.001% | 0.120% | 0.001% | 1.320% | 0.001% | N/A | 16.670% | 0.001% | 0.001% | 0.220% | |
| | App Store | 0.001% | 0.001% | 0.001% | 0.500% | N/A | 0.001% | 0.240% | N/A | N/A | 0.190% | 1.240% | 0.630% | 0. |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Google Play | 0.001% | 0.001% | 0.001% | 0.190% | 0.570% | 0.660% | 0.170% | N/A | 0.001% | 0.070% | 0.500% | 0.001% |

*Table 7- Average Ratings (out of 5) of User Reviews in Each Category of Each App on Each Platform*

| | | USA | | | Italy | | Norway | Singapore | South Korea | Pakistan | Australia | New Zealand | Switzerland |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PathCheck SafePlaces | NOVID | Care19 | Immuni | SM-COVID-19 | Smittestopp | TraceTogether | Corona 100m | CoCare | COVIDSafe | NZ COVID Tracer | SwissCovid |
| | App Store | 0.001 | 3 | 2 | 3.652 | N/A | 2.571 | 2.375 | N/A | N/A | 2.948 | 2 | 3.030 |
| | Google Play | 5 | 3.200 | 2 | 3.127 | 2.846 | 2.409 | 2.311 | N/A | 0.001 | 2.751 | 1.500 | 2.937 |
| | App Store | 0.001 | 0.001 | 0.001 | 0.001 | N/A | 0.001 | 0.001 | N/A | N/A | 5 | 0.001 | 5 |
| | Google Play | 0.001 | 0.001 | 0.001 | 2.727 | 0.001 | 0.001 | 1 | N/A | 0.001 | 1.571 | 0.001 | 3 |
| | App Store | 0.001 | 2 | 1.389 | 1.530 | N/A | 1.833 | 1.411 | N/A | N/A | 1.697 | 1.077 | 1.800 |
| | Google Play | 0.001 | 2.333 | 1.500 | 1.610 | 2.333 | 1.467 | 1.242 | N/A | 0.001 | 2.289 | 1.600 | 1.273 |
| | App Store | 0.001 | 0.001 | 2 | 2.500 | N/A | 1 | 1.75 | N/A | N/A | 1.400 | 1.800 | 1 |
| | Google Play | 0.001 | 0.001 | 1.000 | 1.810 | 2.500 | 0.001 | 2.267 | N/A | 0.001 | 1.800 | 1.500 | 2.333 |
| | App Store | 0.001 | 5 | 2 | 5 | N/A | 0.001 | 2.667 | N/A | N/A | 4.533 | 2 | 0.001 |
| | Google Play | 0.001 | 5 | 1.667 | 4.682 | 0.001 | 0.001 | 1.833 | N/A | 0.001 | 4.108 | 2.400 | 3.500 |
| | App Store | 2 | 1.5 | 0.001 | 1.901 | N/A | 3 | 1.522 | N/A | N/A | 1.258 | 1.136 | 1.286 |
| | Google Play | 0.001 | 2.667 | 1.333 | 1.845 | 5 | 1.333 | 1.464 | N/A | 0.001 | 1.257 | 1.079 | 1.231 |
| | App Store | 0.001 | 0.001 | 2.400 | 2.432 | N/A | 3.500 | 2.480 | N/A | N/A | 2.278 | 3 | 2.37 |
| | Google Play | 0.001 | 5 | 1.800 | 2.231 | 3 | 0.001 | 2 | N/A | 0.001 | 2.338 | 2.250 | 2.057 |
| | App Store | 0.001 | 0.001 | 0.001 | 2 | N/A | 0.001 | 0.001 | N/A | N/A | 1.75 | 0.001 | 0.001 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Google Play | 0.001 | 0.001 | 0.001 | 1.154 | 0.001 | 1 | 0.001 | N/A | 1 | 0.001 | 0.001 | 1.500 |
| t | App Store | 0.001 | 0.001 | 0.001 | 1.530 | N/A | 0.001 | 3 | N/A | N/A | 3 | 1.333 | 2.667 |
| | Google Play | 0.001 | 0.001 | 0.001 | 2.600 | 3 | 2 | 2.250 | N/A | 0.001 | 2.600 | 1 | 0.001 |

Two of the applications: CoCare (Pakistan, Bluetooth), SM_COVID19 (Italy, ReCoVer) and Corona 100m (South Korea, Location) were not available on the App Store whereas two apps: Corona 100m (South Korea, Location) and Stop Covid (Georgia, PEPP-PT) were not available on Google Play. Based on the frequency of the keywords' occurrences, **drain, malfunctioning,** and **ineffective** were the most frequent issues reported by the users in their reviews.

On the App Store, the keyword "**rubbish**" had a 13.33% occurrence for PathCheck SafePlaces (USA, Location), 5.56% for NOVID (USA, Bluetooth), 5.40% for Immuni (Italy, Google/Apple API), and 9.09% for NZ Covid Tracer (New Zealand, Digital Diary). Similarly, many users did not find contact tracing apps functional. On the App Store, many apps' users complained that their app **didn't work.** This was represented by the keyword **"malfunctioning"** which had a 10.74% occurrence for NZ Covid Tracer (New Zealand, Digital Diary), 6.50% for COVIDSafe (Australia, Bluetooth), 6.67% for TraceTogether (Singapore, Bluetooth), 7.80% for Immuni (Italy, Google/Apple API), 11.11% for NOVID (USA, Bluetooth) and a sharp 12.77% occurrence for Care19 (USA, Apple/Google). Many users also had problems with the apps' compatibility with their OS, and frequent crashes. For instance, CoCare (Pakistan, Bluetooth) had a 16.67% occurrence for the incompatibility issue.

As reviews for some apps were not available in English, it was difficult to analyse their user feedback to the same level of accuracy with which we could analyse reviews in English. Another limitation in our methodology for reviews scraping lies in the presence of false negatives in some of the reviews. This is one of the limitations of brute force keyword search methodology. Take for instance one of the reviews for COVIDSafe (Australia, Bluetooth) on Google Play:

*"Installed from it's release. Worked. No problems at all. It doesn't drain the battery. It doesn't crash. It's totally fine. I haven't been dragged into the back of a van, taken to an underground bunker and questioned by spies."*

The review is classified as a false negative for the words drain and crash. It can be debated that the number of false negatives could have been reduced by simply taking the "battery" sub-keyword out from the keyword search i.e. "battery || drain". However, in doing so, the number of 1-star reviews, shown in Table 8, were significantly reduced by more than 50%. For instance, with the NZ COVID Tracer (New Zealand, Digital Diary), the 1-star reviews dropped from 23 to 10 after taking the word "battery" out of the search filter. The reason behind this is that the users' reviews are not systematic. Most users represent their opinions in natural language. Some samples of 1-star reviews for COVIDSafe (Australia, Bluetooth) commenting on the app's draining issue are as follows:

*"It is of no use whatsoever. A waste of money & a waste of my battery life."*

Another user said:

*"Battery went from 100% to zero in 5 hours with not much use. I usually get a full day out of it."*

Another user commented:

*"Hard on the battery"*

Therefore, for the sake of including these comments, the sub-keyword "battery" was not removed from the keyword search results.

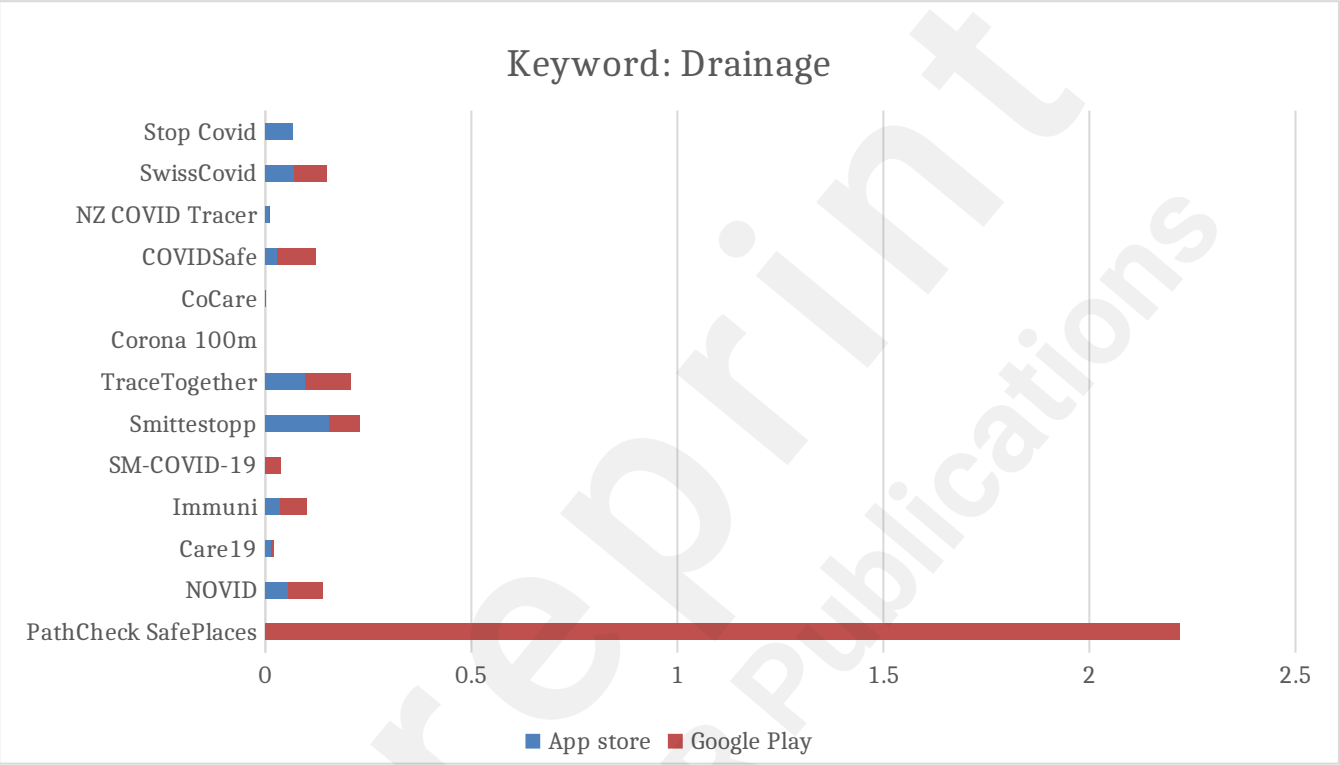


*Figure 1- Drainage keyword*

Interestingly and as shown in Figure 1, no significant battery drainage issue has been reported for most of the reviewed apps. The privacy concerns reported by the users were very minimal across all apps as well as shown in Figure 2.

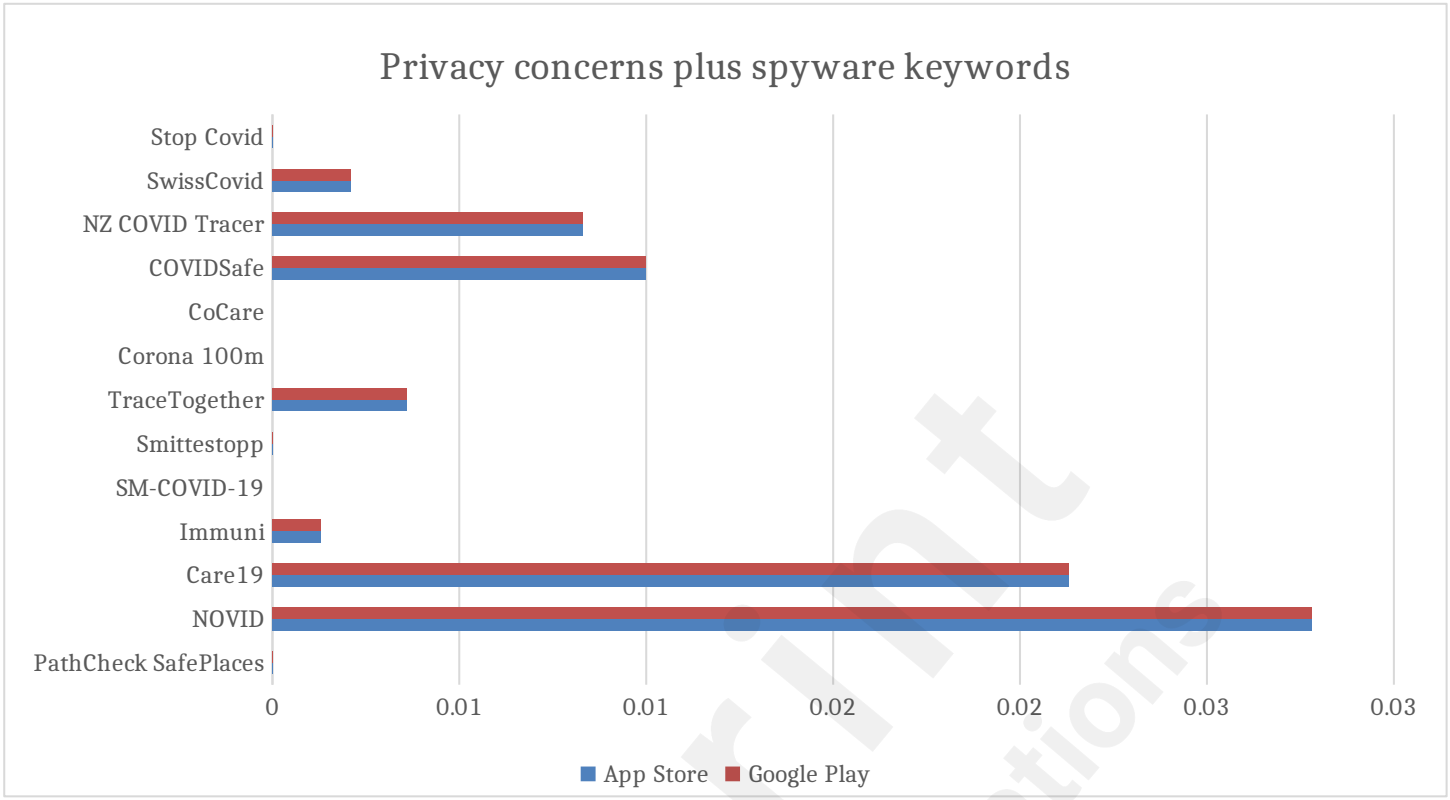


*Figure 2- privacy concerns*

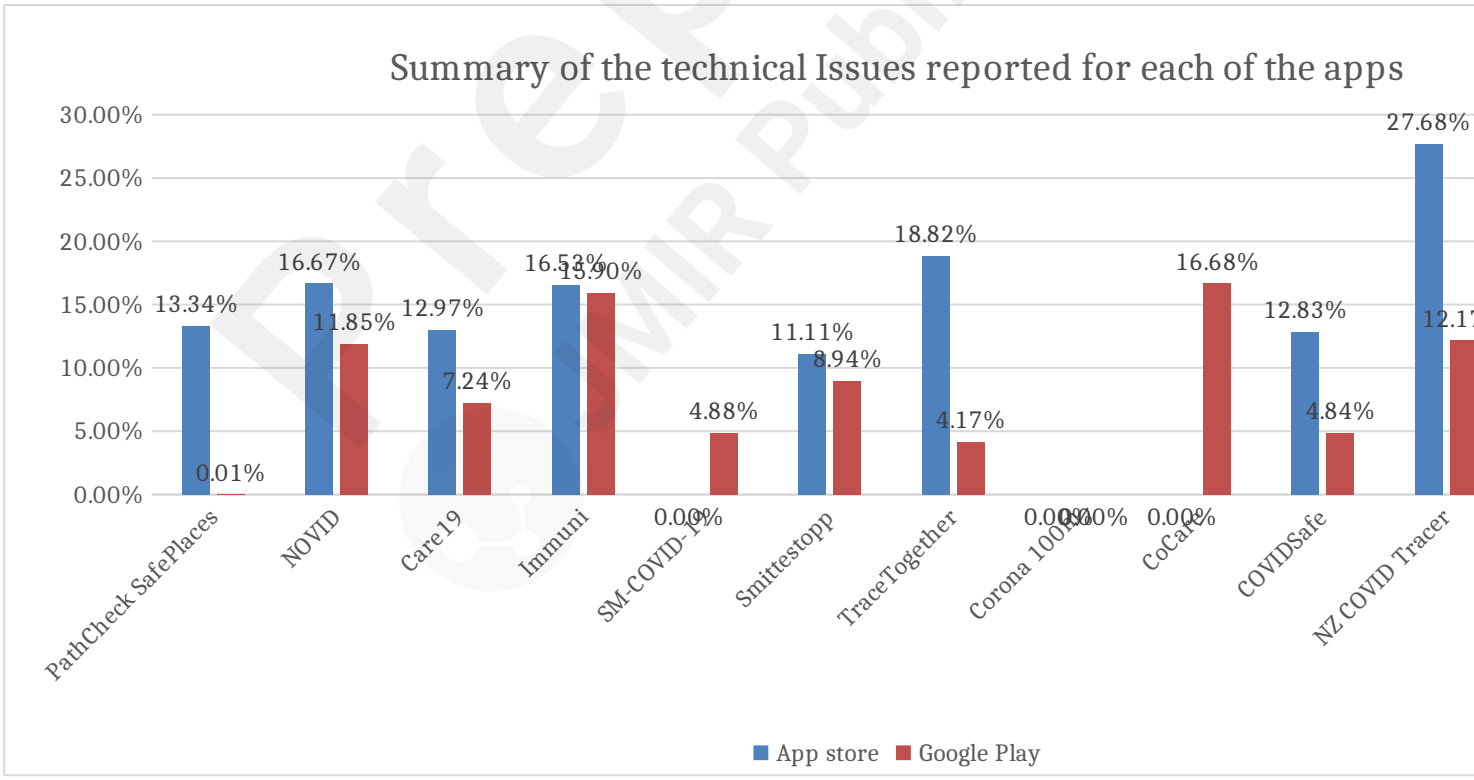


*Figure 3- technical issues reported for each of the apps*

Figures 3 provides overall insights into the technical issues reported by the users for each of the apps. These results combine the results of the following keywords, (along with their respective sub-keywords): *Malfunctioning, Crashes, Ineffective, Bugs, Installation issues, and Incompatible*. It is

obvious that most applications on the App store had the most reported technical issues when compared to their Google play counterpart except for the Swiss contact tracing app. The USA Pathcheck app has the least reported technical issues on the Google play. While the New Zealand app version on the app store had the most technical issues complained about across all apps and platforms.

## 5- Concluding remarks and Future works

Contact tracing applications come with their own set of challenges as well. Key amongst these challenges is privacy. Of course, this is anticipated as you can't expect to trace and track peoples' movement by a government authority without addressing the privacy issues. Nonetheless, privacy is not the only elephant in the room, there are many other challenges and limitations hindering the efficacy anticipated from contact tracing apps. Some of them are:

- A Mobile contact tracing application needs to be widely adopted by a population for it to be of benefit. This is challenging to achieve. The widespread adoptions of contact tracing apps requisite that people would have access to a smartphone and in most cases access to a reliable Internet connection. For instance, in countries with large populations like Pakistan[21], the smartphone penetration percentage sits at only 15% and at only 31% in Indonesia for example.
- The approaches used by contact tracing apps rely mostly on one single parameter i.e. proximity. But, proximity by itself is not enough to determine the risk of someone being exposed to the virus. There are a number of other parameters involved such as, being indoor or outdoor, in a well air-circulated room or no, in addition to the issue of surface infection exposure irrespective of the proximity of an individual to an infected person.
- There are limitations to the technology used for contact tracing. For instance, the use of GPS as a proximity technology is not reliable in indoor environments. Determining the distance between two persons using Bluetooth technology has its own set of challenges as well such as signal strength attenuation caused by some environmental factors (e.g., if phone is placed inside a thick pocket or if the phone is at angle facing a wall).

Nevertheless, contact tracing technologies surveyed in this work have been found to use a location-less tracking approach. That is, the app doesn't trace or record people's movements (obviously for privacy purposes). Therefore, most of these apps can only determine if two people were in proximity at a given time, but they don't keep a log of the users' movements. Consider for example, if an infected person, labelled as Pi is in a supermarket and Pi touches an item at t-1 at a Location designated as Li. If another person who is not infected (designated as Pn) is located at Ln. There is no proximity between Pi and Pn. Now assume Pi leaves the store at t, when at the same time i.e. at t, person Pn moves from Ln to Li. There is a high chance that Pn is going to be infected if they touch the same item Pi touched at t-1. (surface infection exposure). To be able to capture this exposure, contact tracing apps require the use of a location-oriented tracking approach in which the locations and movements of peoples are compared against each other to determine the overlapped and colluded locations. Future work will explore the use of our already well-established location obfuscation technique[22] in a contact tracing solution. The work will aim at providing a location-oriented contact tracing application without impinging on the users' privacy.

1. European Centre for Disease Prevention and Control. COVID-19 situation update worldwide, as of 11 August 2020. 2020; https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases. Accessed 11/08/2020.
2. Akkermans J, Richardson J, Kraimer M. The Covid-19 crisis as a career shock: Implications for careers and vocational behavior. In: Elsevier; 2020.
3. Baker MG, Kvalsvig A, Verrall AJ, Wellington NJTMJoA. New Zealand's COVID-19 elimination strategy. 2020:1.
4. Chang SL, Harding N, Zachreson C, Cliff OM, Prokopenko MJapa. Modelling transmission and control of the COVID-19 pandemic in Australia. 2020.
5. Qi C, Karlsson D, Sallmen K, Wyss RJapa. Model studies on the COVID-19 pandemic in Sweden. 2020.
6. Strzelecki AJapa. The second worldwide wave of interest in coronavirus since the COVID-19 outbreaks in South Korea, Italy and Iran: a google trends study. 2020.
7. Ren X. Pandemic and lockdown: a territorial approach to COVID-19 in China, Italy and the United States. *Journal of Eurasian Geography.* 2020:1-12.
8. Reis RF, de Melo Quintela B, de Oliveira Campos J, et al. Characterization of the COVID-19 pandemic and the impact of uncertainties, mitigation strategies, and underreporting of cases in South Korea, Italy, and Brazil. 2020:109888.
9. Wong T. Coronavirus: Why some countries wear face masks and others don't. 2020; https://www.bbc.com/news/world-52015486. Accessed 15/06/2020.
10. Organization WH. *Contact tracing in the context of COVID-19: interim guidance, 10 May 2020.* 2020.
11. Aiello R. PM says a national contact tracing app is coming next month, how will it work? 2020; https://www.ctvnews.ca/health/coronavirus/pm-says-a-national-contact-tracing-app-is-coming-next-month-how-will-it-work-1.4989702, 20/06/2020.
12. Sabbagh D, Hern A. UK abandons contact-tracing app for Apple and Google model. 2020; https://www.theguardian.com/world/2020/jun/18/uk-poised-to-abandon-coronavirus-app-in-favour-of-apple-and-google-models. Accessed 20/06/2020.
13. Cunche M, Boutet A, Castelluccia C, Lauradoux C, Le Métayer D, Roca V. *On using Bluetooth-Low-Energy for contact tracing*, Inria Grenoble Rhône-Alpes; INSA de Lyon; 2020.
14. Michael K, Abbas R. Getting Behind COVID-19 Contact Trace Apps: The Google-Apple Partnership. *Journal of IEEE Consumer Electronics Magazine.* 2020.
15. Cho H, Ippolito D, Yu YWJapa. Contact tracing mobile apps for COVID-19: Privacy considerations and related trade-offs. 2020.
16. Jalabneh R, Zehra Syed H, Pillai S, et al. Use of Mobile Phone Apps for Contact Tracing to Control the COVID-19 Pandemic: A Literature Review. 2020.
17. Gvili Y. Security analysis of the covid-19 contact tracing specifications by apple inc. and google inc. 2020;2020:428.
18. Fahey RA, Hino A. COVID-19, digital privacy, and the social limits on data-focused public health responses. *International Journal of Information Management.* 2020:102181.
19. Ahmed N, Michelin RA, Xue W, et al. A survey of covid-19 contact tracing apps. 2020.
20. Elkhodr M. New Zealand's COVID-19 Tracer app won't help open a 'travel bubble' with

Australia anytime soon. In. *The Conversation*. Australia: The Conversation; 2020.
21. Newzoo's K. *Global Mobile Market Report: Insights into the World's 3 Billion Smartphone Users.* 2018.
22. Elkhodr M, Shahrestani S, Cheung H. A semantic obfuscation technique for the Internet of Things. Paper presented at: 2014 IEEE International Conference on Communications Workshops (ICC)2014.

## Appendix

Table 1- Translated keywords and sub-keywords used in scrapping the reviews

| italian | German | french |
|---|---|---|
| drain \|\| batteria \|\| Drain \|\| Batteria | ablassen \|\| batterie \|\| Ablassen \|\| Batterie | batterie \|\| drainer \|\| Batter |
| spiare \|\| spiata \|\| spiato \|\| spyware \|\| Spiare \|\| Spiata \|\| Spiato \|\| Spyware | spionin \|\| spion \|\| ausspioniert \|\| spyware \|\| spionin \|\| spion \|\| ausspioniert \|\| spyware \|\| Spionin \|\| Spion \|\| Ausspioniert \|\| Spyware \|\| Spionin \|\| Spion \|\| Ausspioniert \|\| Spyware | espionne \|\| espion \|\| espio Espion \|\| Espionné \|\| Spy |
| non funziona \|\| non ha funzionato \|\| non funziona \|\| Non funziona \|\| Non ha funzionato \|\| Non funziona | funktioniert nicht \|\| hat nicht funktioniert \|\| funktioniert nicht \|\| Funktioniert Nicht \|\| Hat Nicht Funktioniert \|\| Funktioniert Nicht | ne fonctionne pas \|\| n' fonctionne pas \|\| Ne F Fonctionné \|\| Ca Ne Fonc |
| schianto \|\| congelare \|\| Schianto \|\| Congelare | absturz \|\| einfrieren \|\| Absturz \|\| Einfrieren | crash \|\| geler \|\| Crash \|\| G |
| problema di privacy \|\| preoccupazione sulla privacy \|\| preoccupazione per la posizione \|\| rintracciarmi \|\| seguimi \|\| rintracciarci \|\| Problema di privacy \|\| Preoccupazione sulla privacy \|\| Preoccupazione per la posizione \|\| Rintracciarmi \|\| Seguimi \|\| Rintracciarci | datenschutzproblem \|\| datenschutz-bedenken \|\| standortbedenken \|\| verfolge mich \|\| verfolge mich \|\| verfolgen sie uns \|\| Datenschutzproblem \|\| Datenschutz-bedenken \|\| Standortbedenken \|\| Verfolge Mich \|\| Verfolge Mich \|\| Verfolgen Sie Uns | problème de confide confidentialité \|\| souci d trouvez moi \|\| nous Confidentialité \|\| Probl Souci De Localisation \|\| Nous Suivre |
| inutili \|\| sciocchezze \|\| spazzatura \|\| Inutili \|\| Sciocchezze \|\| Spazzatura | nutzlos \|\| müll \|\| müll \|\| Nutzlos \|\| Müll \|\| Müll | inutile \|\| ordures \|\| des o Des Ordures |
| insetto \|\| passeggino \|\| Insetto \|\| Passeggino | fehler \|\| Fehler | punaise \|\| petit chariot \|\| |
| impossibile installare \|\| non si installa \|\| impossibile installare \|\| Impossibile installare \|\| Non si installa \|\| Impossibile installare | kann nicht installiert werden \|\| wird nicht installiert \|\| konnte nicht installiert werden \|\| Kann Nicht Installiert Werden \|\| Wird Nicht Installiert \|\| Konnte Nicht Installiert Werden | ne peut pas installer \|\| d'installer \|\| Ne Peut Pas Impossible D'installer |
| impossibile scaricare \|\| impossibile scaricare \|\| incompatibile \|\| Impossibile scaricare \|\| Impossibile scaricare \|\| Incompatibile | kann nicht herunterladen \|\| konnte nicht herunterladen \|\| unvereinbar \|\| Kann Nicht Herunterladen \|\| Konnte Nicht Herunterladen \|\| Unvereinbar | impossible de téléch télécharger \|\| incomp Télécharger \|\| Impos Incompatible |

| romanian | Spanish | czech |
|---|---|---|
| baterie \|\| scurgere \|\| Baterie \|\| Scurgere | batería \|\| desagüe \|\| Batería \|\| Desagüe | baterie \|\| kanalizace \|\| Ba |
| spion \|\| spionat \|\| spyware \|\| Spion \|\| Spionat \|\| Spyware | espiar \|\| espiada \|\| espiado \|\| spyware \|\| Espiar \|\| Espiada \|\| Espiado \|\| Spyware | vyzvědač \|\| špehoval Špehoval \|\| Spyware |
| nu merge \|\| nu a funcționat \|\| nu funcționează \|\| Nu Merge \|\| Nu A Funcționat \|\| Nu Funcționează | no funciona \|\| no funcionó \|\| no funciona \|\| No Funciona \|\| No Funcionó \|\| No Funciona | nefunguje \|\| nefungoval Nefungovalo \|\| Nejde To |
| prăbușire \|\| îngheţa \|\| Prăbușire \|\| Îngheţa | choque \|\| congelar \|\| Choque \|\| Congelar | pád \|\| zmrazit \|\| Pád \|\| Zm |
| problema de confidențialitate \|\| preocupări de confidențialitate \|\| preocuparea locației \|\| urmărindu-mă \|\| urmărește-mă \|\| urmărindu-ne \|\| Problema De | asuntos de privacidad \|\| preocupación de privacidad \|\| preocupación por la ubicación \|\| siguiéndome \|\| Sígueme \|\| rastreándonos \|\| Asuntos De Privacidad \|\| | problém s ochranou soul lokalitu \|\| mě sleduje \|\| Problém S Ochranou So |

| | | |
|---|---|---|
| Confidențialitate \|\| Preocupări De Confidențialitate \|\| Preocuparea Locației \|\| Urmărindu-mă \|\| Urmărește-mă \|\| Urmărindu-ne | Preocupación De Privacidad \|\| Preocupación Por La Ubicación \|\| Siguiéndome \|\| Sígueme \|\| Rastreándonos | O Lokalitu \|\| Mě Sleduje |
| inutil \|\| gunoi \|\| gunoi \|\| Inutil \|\| Gunoi \|\| Gunoi | inútil \|\| basura \|\| basura \|\| Inútil \|\| Basura \|\| Basura | zbytečný \|\| odpadky \| Odpadky \|\| Odpadky |
| gândac \|\| trăsură pentru două persoane \|\| Gândac \|\| Trăsură Pentru Două Persoane | insecto \|\| calesa \|\| Insecto \|\| Calesa | chyba \|\| buggy \|\| Chyba \|\| |
| nu pot instala \|\| nu se instalează \|\| nu a putut instala \|\| Nu Pot Instala \|\| Nu Se Instalează \|\| Nu A Putut Instala | no se puede instalar \|\| no instala \|\| no se pudo instalar \|\| No Se Puede Instalar \|\| No Instala \|\| No Se Pudo Instalar | nelze nainstalovat \|\| nainstalovat \|\| Nelze Nai \|\| Nelze Nainstalovat |
| nu se poate descărca \|\| nu a putut descărca \|\| incompatibil \|\| Nu Se Poate Descărca \|\| Nu A Putut Descărca \|\| Incompatibil | no se puede descargar \|\| no se pudo descargar \|\| incomaptible \|\| No Se Puede Descargar \|\| No Se Pudo Descargar \|\| Incomaptible | nelze stáhnout \|\| nelze s Nelze Stáhnout \|\| Nelze S |

| portugese | Norwegian | lithuanian |
|---|---|---|
| bateria \|\| drenar \|\| Bateria \|\| Drenar | batteri \|\| tappe \|\| Batteri \|\| Tappe | baterija \|\| nusausinti \|\| Ba |
| espiã \|\| espião \|\| espionada \|\| espionado \|\| spyware \|\| Espiã \|\| Espião \|\| Espionada \|\| Espionado \|\| Spyware | spion \|\| spionert \|\| spyware \|\| Spion \|\| Spionert \|\| Spyware | šnipas \|\| šnipinėjo \|\| šnip \|\| Šnipinėjo \|\| Šnipinėjime |
| não funciona \|\| não funcionou \|\| não está funcionando \|\| Não Funciona \|\| Não Funcionou \|\| Não Está Funcionando | fungerer ikke \|\| fungerte ikke \|\| jobber ikke \|\| Fungerer Ikke \|\| Fungerte Ikke \|\| Jobber Ikke | neveikia \|\| neveikė \|\| neve Neveikia |
| batida \|\| batido \|\| congelar \|\| Batida \|\| Batido \|\| Congelar | brak \|\| fryse \|\| Brak \|\| Fryse | avarija \|\| užšaldyti \|\| Avar |
| questão de privacidade \|\| preocupação com a privacidade \|\| preocupação com a localização \|\| me rastreando \|\| rastreie-me \|\| nos rastreando \|\| Questão De Privacidade \|\| Preocupação Com A Privacidade \|\| Preocupação Com A Localização \|\| Me Rastreando \|\| Rastreie-me \|\| Nos Rastreando | spørsmål om personvern \|\| bekymring for personvern \|\| beliggenhet bekymring \|\| spore meg \|\| spore meg \|\| spore oss \|\| Spørsmål Om Personvern \|\| Bekymring For Personvern \|\| Beliggenhet Bekymring \|\| Spore Meg \|\| Spore Meg \|\| Spore Oss | privatumo klausimas \|\| susirūpinimas dėl vietos mane \|\| sekdamas mus Rūpestis Dėl Privatumo \|\| Sekdamas Mane \|\| Steb |
| sem utilidade \|\| lixo \|\| lixo \|\| Sem Utilidade \|\| Lixo \|\| Lixo | ubrukelig \|\| søppel \|\| søppel \|\| Ubrukelig \|\| Søppel \|\| Søppel | nenaudingas \|\| šiukšlės Šiukšlės \|\| Šiukšlių |
| erro \|\| buggy \|\| Erro \|\| Buggy | bug \|\| buggy \|\| Bug \|\| Buggy | klaida \|\| pakvaišęs \|\| Klai |
| não pode instalar \|\| não instala \|\| não foi possível instalar \|\| Não Pode Instalar \|\| Não Instala \|\| Não Foi Possível Instalar | kan ikke installere \|\| installerer ikke \|\| kunne ikke installere \|\| Kan Ikke Installere \|\| Installerer Ikke \|\| Kunne Ikke Installere | negaliu įdiegti \|\| neįdi Negaliu Įdiegti \|\| Neįdieg |
| não pode baixar \|\| não foi possível baixar \|\| incompatível \|\| Não Pode Baixar \|\| Não Foi Possível Baixar \|\| Incompatível | kan ikke laste ned \|\| kunne ikke lastes ned \|\| uforenlig \|\| Kan Ikke Laste Ned \|\| Kunne Ikke Lastes Ned \|\| Uforenlig | negaliu atsisiųsti \|\| nesuderinamas \|\| Negal Atsisiųsti \|\| Nesuderinam |

| danish | chinese | indonesian |
|---|---|---|
| batteri \|\| dræne \|\| Batteri \|\| Dræne | □□\|\|□□\|\|□□\|\|□□ | tiriskan \|\| baterai \|\| Tirisk |
| spion \|\| spioneret \|\| spyware \|\| Spion \|\| Spioneret \|\| Spyware | □□\|\|□□\|\|□□□□\|\|□□\|\|□□\|\|□□□□ | mata-mata \|\| mata-mata Mata-mata \|\| Spyware |
| fungerer ikke \|\| fungerede ikke \|\| virker ikke \|\| Fungerer Ikke \|\| Fungerede Ikke \|\| Virker Ikke | □□□□\|\|□□□□\|\|□□□□\|\|□□□□\|\|□□□□\|\|□□□□ | tidak bekerja \|\| tidak bek Bekerja \|\| Tidak Bekerja |
| krak \|\| fryse \|\| Krak \|\| Fryse | □□\|\|□□\|\|□□\|\|□□ | crash \|\| membekukan \|\| C |
| spørgsmål om beskyttelse af personlige oplysninger | □□□□\|\|□□□□\|\|□□□□\|\|□□□\|\|□□□\|\|□□□□\|\|□□□□\|\|□ | masalah privasi \|\| masala |

| | | |
|---|---|---|
| \|\| bekymring for beskyttelse af personlige oplysninger \|\| placering bekymring \|\| sporer mig \|\| spore mig \|\| spore os \|\| Spørgsmål Om Beskyttelse Af Personlige Oplysninger \|\| Bekymring For Beskyttelse Af Personlige Oplysninger \|\| Placering Bekymring \|\| Sporer Mig \|\| Spore Mig \|\| Spore Os | □□□\|\|□□□□\|\|□□□\|\|□□□\|\|□□□□ | melacak saya \|\| melaca Masalah Privasi \|\| Masal \|\| Melacak Saya \|\| Melaca |
| ubrugelig \|\| vrøvl \|\| affald \|\| Ubrugelig \|\| Vrøvl \|\| Affald | □□□\|\|□□\|\|□□\|\|□□□\|\|□□\|\|□□ | tidak berguna \|\| sampah Sampah \|\| Sampah |
| insekt \|\| buggy \|\| Insekt \|\| Buggy | □□\|\|□□□\|\|□□\|\|□□□ | bug \|\| buggy \|\| Bug \|\| Bug |
| kan ikke installeres \|\| installerer ikke \|\| kunne ikke installeres \|\| Kan Ikke Installeres \|\| Installerer Ikke \|\| Kunne Ikke Installeres | □□□□\|\|□□□\|\|□□□□\|\|□□□□\|\|□□□\|\|□□□□ | tidak dapat menginstal bisa menginstal \|\| Tidak Menginstal \|\| Tidak Bisa |
| kan ikke downloade \|\| kunne ikke downloades \|\| uforenelig \|\| Kan Ikke Downloade \|\| Kunne Ikke Downloades \|\| Uforenelig | □□□□\|\|□□□□\|\|□□□\|\|□□□□\|\|□□□□\|\|□□□ | tidak bisa mengunduh tidak kompatibel \|\| Tida Bisa Mengunduh \|\| Tidak |

| vietnamese | turkish | dutch |
|---|---|---|
| cống \|\| pin | boşaltma \|\| pil \|\| Boşaltma \|\| Pil | afvoer \|\| batterij \|\| Afvoer |
| gián điệp \|\| gián điệp \|\| phần mềm gián điệp | casus \|\| casusluk \|\| casus yazılım \|\| Casus \|\| Casusluk \|\| Casus Yazılım | spion \|\| bespioneerd Bespioneerd \|\| Spyware |
| không làm việc \|\| không làm việc \|\| không làm việc | çalışmıyor \|\| çalışmıyor \|\| çalışmıyor | werkt niet \|\| Werkte Niet |
| sụp đổ \|\| đóng băng | gürültüyle çarpmak \|\| dondurmak \|\| Dondurmak | crash \|\| bevriezen \|\| Crash |
| vấn đề riêng tư \|\| mối quan tâm riêng tư \|\| mối quan tâm vị trí \|\| theo dõi tôi \|\| theo dõi tôi \|\| theo dõi chúng tôi | gizlilik sorunu \|\| gizlilik endişesi \|\| konum kaygısı \|\| beni takip et \|\| beni takip et \|\| bizi takip et \|\| Gizlilik Sorunu \|\| Gizlilik Kaygısı \|\| Konum Kaygısı \|\| Beni Takip Et \|\| Beni takip et \|\| Bizi Takip Et | privacyprobleem \|\| priva over de locatie \|\| mij v volgen \|\| Privacyprobl Bezorgdheid Over De L Volgen \|\| Ons Volgen |
| vô dụng \|\| rác rưởi \|\| rác rưởi | yararsız \|\| çöp \|\| çöp \|\| işe yaramaz \|\| | nutteloos \|\| vuilnis \|\| vui Vuilnis |
| lỗi \|\| lỗi | böcek \|\| buggy \|\| Hata \|\| Buggy | bug \|\| buggy \|\| Bug \|\| Bug |
| có thể cài đặt \|\| cài đặt \|\| không thể cài đặt \|\| cài đặt | yüklenemiyor \|\| yüklenemiyor \|\| yüklenemiyor \|\| Yüklenemiyor \|\| Yüklenemiyor \|\| Yüklenemedi | kan niet installeren \|\| ka installeren \|\| Kan Nie Installeren \|\| Kan Niet In |
| có thể tải xuống \|\| tải về \|\| không thể tải xuống \|\| không tương thích | indiremiyorum \|\| indiremedi \|\| uyumsuz \|\| Indiremiyorum \|\| Indiremedi \|\| Uyumsuz | kan niet downloaden \|\| k compatibel \|\| Kan Niet Downloaden \|\| Niet Com |

| polish | malay | georgian |
|---|---|---|
| drenaż \|\| bateria \|\| Drenaż \|\| Bateria | longkang \|\| bateri \|\| Longkang \|\| Bateri | გადინება \|\| ბატარეა |
| szpieg \|\| szpiegowanie \|\| oprogramowanie szpiegowskie \|\| Szpieg \|\| Szpiegowanie \|\| Programowanie Szpiegowskie | pengintip \|\| pengintip \|\| perisian pengintip \|\| Perisik \|\| Pengintip \|\| Perisik | ჯაშუში \|\| ჯაშუში \|\| sp |
| nie działa \|\| Nie Działa | tidak berfungsi \|\| Tidak Berfungsi | არ მუშაობს \|\| არ იმუ |
| crash \|\| zamrażanie \|\| awaria \|\| Zamrażanie | crash \|\| beku \|\| Crash \|\| Freeze \|\| Beku | კრახი \|\| გაყინვა |
| problem dotyczący prywatności \|\| obawa o prywatność \|\| problem dotyczący lokalizacji \|\| śledzenie mnie \|\| śledzenie mnie \|\| śledzenie nas \|\| | masalah privasi \|\| kebimbangan privasi \|\| masalah lokasi \|\| menjejaki saya \|\| menjejaki saya \|\| menjejaki kami \|\| Masalah Privasi \|\| Kebimbangan Privasi \|\| | კონფიდენციალურო კონფიდენციალურო ადგილმდებარეობის |

| | | |
|---|---|---|
| Problem Dotyczący Prywatności \|\| Obawa O Prywatność \|\| Problem Dotyczący Lokalizacji \|\| śledzenie Mnie \|\| śledzenie Mnie \|\| śledzenie Nas | Masalah Lokasi \|\| Menjejaki Saya \|\| Menjejaki Saya \|\| menjejaki Kami | თვალყურის დევნ დევნება \|\| ჩვენს თვა |
| bezużyteczne \|\| śmieci \|\| śmieci \|\| Bezużyteczne \|\| Śmieci \|\| Śmiec | tidak berguna \|\| sampah \|\| Tidak Berguna \|\| Sampah | უსარგებლო \|\| ნაგავ |
| bug \|\| buggy \|\| Bug \|\| Buggy | pepijat \|\| buggy \|\| Bug \|\| Buggy \|\| Pepijat | bug \|\| buggy |
| nie można zainstalować \|\| nie można zainstalować \|\| nie można zainstalować \|\| Nie Można Zainstalować \|\| Nie Można Zainstalować \|\| Nie Można Zainstalować | tidak dapat memasang \|\| tidak memasang \|\| tidak dapat memasang \|\| Tidak Dapat Memasang \|\| Tidak Memasang \|\| Tidak Dapat Memasang | არ შეიძლება დააინსტალიროთ \|\| |
| nie można pobrać \|\| nie można pobrać \|\| niezgodne \|\| Nie Można Pobrać \|\| Nie Można Pobrać \|\| Niezgodne | tidak dapat memuat turun \|\| tidak dapat memuat turun \|\| tidak serasi \|\| Tidak Dapat Memuat Turun \|\| Tidak Dapat Memuat Turun \|\| Tidak Serasi | ვერ გადმოწერეთ შეუთავსებელია |

| greek | arabic | |
|---|---|---|
| αποστράγγιση \|\| μπαταρία | استنزاف \|\| بطارية | |
| κατάσκοπος \|\| κατάσκοπος \|\| λογισμικό υποκλοπής | تجسس \|\| تجسس \|\| برامج التجسس | |
| δεν λειτουργεί \|\| δεν λειτουργεί \|\| δεν λειτουργεί | لا يعمل \|\| لا يعمل \|\| لا يعمل | |
| συντριβή \|\| πάγωμα | تحطم \|\| تجميد | |
| ζήτημα απορρήτου \|\| ζήτημα απορρήτου \|\| ανησυχία τοποθεσίας \|\| παρακολούθηση \|\| παρακολούθηση \|\| παρακολούθηση | مشكلة الخصوصية \|\| مخاوف الخصوصية \|\| قلق الموقع \|\| تتبعني \|\| تتبعني \|\| تتبعنا | |
| άχρηστα \|\| σκουπίδια \|\| σκουπίδια | عديمة الفائدة \|\| القمامة \|\| القمامة | |
| σφάλμα \|\| λάθη | علة \|\| عربات التي تجرها الدواب | |
| δεν μπορώ να εγκαταστήσω \|\| δεν εγκαθιστώ \|\| δεν μπορώ να εγκαταστήσω | لا يمكن التثبيت \|\| لا التثبيت \|\| لا يمكن التثبيت | |
| δεν είναι δυνατή η λήψη \|\| δεν ήταν δυνατή η λήψη \|\| ασύμβατη | لا يمكن التنزيل \|\| لا يمكن التنزيل \|\| غير متوافق | |