

Tracing Contacts to Control the COVID-19 Pandemic

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Abstract—The control of the COVID-19 pandemic requires a considerable reduction of contacts mostly achieved by imposing movement control up to the level of enforced quarantine. This has led to a collapse of substantial parts of the economy. Carriers of the disease are infectious roughly 3 days after exposure to the virus. First symptoms occur later or not at all. As a consequence tracing the contacts of people identified as carriers is essential for controlling the pandemic. This tracing must work everywhere, in particular indoors, where people are closest to each other. Furthermore, it should respect people’s privacy. The present paper presents a method to enable a thorough traceability with very little risk on privacy. In our opinion, the latter capabilities are necessary to control the pandemic during a future relaunch of our economy.

Index Terms—COVID-19, corona, tracing contacts, privacy

I. INTRODUCTION

THE COVID-19 pandemic has spread all over the world. It has already led to a very large number of fatalities, more than 40’000 as of end of March 2020. The first priority of humanity is to take all possible actions to prevent more people from dying. In some places, this led to enforcing a quarantine on large portions of the population. The economic damage is substantial. The US alone is investing USD 2’000 Billions to alleviate the consequences of the pandemic. Thus, limiting the economical damage by restarting the economy as soon as possible, while at the same time protecting people, is of immense importance. The present document aims at contributing specific suggestions on how to achieve this.

Three important properties of the COVID-19 pandemic are that

- The sickness is limited to roughly three weeks in time. After this period, people are either healthy again, hopefully without impairments, or dead. All evidence expressed publicly, so far, indicates that former carriers of the disease are not contagious anymore after that time. A strictly observed quarantine of three weeks has thus the potential to basically eliminate all carriers of the disease. A quarantine is never perfect, e.g. due to the need to restock food supplies. As a consequence some chains of infection will persist.
- The spreading of the disease in the population is characterized by an exponential growth. The characteristic

parameter R_0 , which describes the number of people infected by a single carrier, is estimated to be around 2-2.3. Any value above 1 leads to an exponential growth, as long as there is no substantial immunity. More detailed epidemiological models are more differentiated but show a similar threshold behavior[1]. The value of R_0 , mentioned above is determined by the period during which a carrier is contagious, the probability of transmitting the disease, and the number of contacts that the carrier had during that time. There is no means to control the first factor. The second may be somewhat influenced by carrying masks but not to a level considered sufficient. Thus, the most important option for controlling R_0 is to reduce the contacts between carriers and other citizens.

- The diagnoses of sick people is a critical element. Some people do not show symptoms that they associate with the sickness but are nevertheless infectious. They may be a cause for requiring a longer quarantine than described above. In addition and most importantly, no one shows symptoms before being infectious, which means that as long as there are no tests that everyone can apply at regular intervals, there will always be a delay before the spreading by a particular individual can be discontinued. Furthermore, extensive testing as practiced and further expanded in Germany will be most effective if the most likely carriers are being tested.

Currently, there is a variety of attempts to contain the pandemic, which should all be followed in parallel. The development of vaccines and of medications are essential but may not be available in the near future. This has led to an enforced reduction of contacts by various levels of quarantine. The concept of achieving immunity by letting the epidemic spread have rightfully been abandoned, due to the heavy toll in human lives. Bill Gates formulates what most of us think “But bringing the economy back ... that’s more of a reversible thing than bringing people back to life. So we’re going to take the pain in the economic dimension — huge pain — in order to minimize the pain in the diseases-and-death dimension.”¹

The “how” of restarting the economy remains. Some authors studied the effect of relaxing the quarantine at the cost of a regrowth of infected people before shutting down again [2]. This leads to an increasing level of immunity in a series of waves. In view of the small percentage of people that are immunized at each step and in view of the risk of an unmanageable growth, the number of waves needs to be

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¹<https://www.cnn.com/2020/03/25/what-bill-gates-would-do-to-fight-covid-19-if-he-were-us-president.html>

substantial. Furthermore, each wave costs lives. China, South Korea and to a much smaller scale Webasto in Germany have shown an alternative, which consists in a careful tracing of contacts, associated with testing, and quarantining positively tested people. We will call these people “carriers” throughout the paper.

II. TRACING CONTACTS

Tracing contacts is a rather natural concept for containing the pandemic. It aims at identifying and subsequently isolating people, who might potentially be carriers. Since the incubation time until an infected person becomes infectious herself is around 3 days and since first symptoms only occur after 5 days at the earliest, with a diagnosis available at an even later time, there is a lag during which infectious carriers continue spreading the disease. Thus, knowing contacts to people who have been identified as carriers, allows isolating unidentified potential carriers. The frequent absence of clear symptoms is a second critical cause for the spreading of the infection. In this case contact tracing allows identifying carriers without symptoms through their contact to people with symptoms. In that case, the carrier with symptoms is not the originator but rather helps discovering the originator. Independent on who is the originator, contact tracing and subsequent isolation eliminates sources of disease spreading. An immediate testing and determination of contacts allows to identify further contact whenever the outcome of the test was positive. In the case of a negative outcome, testing is repeated after an incubation time, with isolation being lifted in the case of a second negative outcome.

At my institute (160 people), we traced a number of contacts and noticed that the complexity of a manual process becomes quickly unmanageable. Due to the exponential character of the network of relations, there are simply too many contacts to be traced. We ended up isolating everyone first at the Institute level, shortly after that and independently of us at DLR level and finally at national level. This observed complexity led us to the conclusion that automatic means of tracing are essential. Raskar et al. [3] have analyzed an approach based on locating people with a particular focus on privacy-protection and self-protection against the disease. We follow a somewhat different approach. It is primarily based on contacts, rather than on locations, although locations may be used in addition. Furthermore, it is focusing on the control of the pandemic as a whole. The protection of the individual turns out to reach a similar level as in the approach by Raskar et al. [3].

The present exposition is developed against the background of German regulations. The public authorities responsible for health is the “Gesundheitsamt.” The Gesundheitsämter (many of them, distributed all over the country) register every person affected by the pandemic and organize the testing of people. Thus the identity of any person which either has symptoms, is tested positively or is affected by the disease is currently known to the local Gesundheitsamt. We shall subsequently just speak of the Gesundheitsamt as if it was a single entity. That Gesundheitsamt is a trusted authority independent of any use of electronic means to trace contacts. It shall thus

also be the trusted authority in our approach, which will be responsible to operate the server needed to manage the list of carriers. They do furthermore manage people in quarantine, who have to follow strict rules in Germany. Not doing so may lead to fines and imprisonment [4]. Additionally, Germany has imposed limitations on the movement of people, which should not be confused with the stricter quarantine. In our view, it should be acceptable that regaining new degrees of freedom may be associated with certain restrictions, which ensure the traceability of contacts, without unduly exposing privacy. Recent polls in Germany show a high level of acceptance of restrictions to combat the pandemic. It may well be acceptable to enforce the use of tracing, although this is not the focus of the paper.

III. TECHNICAL IMPLEMENTATION

The precondition for traceability is to use of a smartphone running a COVID-19 tracing app (the app) or alternatively the use of a low cost device. For simplicity, the focus of the exposition will be on an app running on a smartphone. Every person leaving their home shall be requested to carry such a device, with the app installed and active. This might be an expectation, which people are free to follow or not. Whatever solution is preferred is a political decision. The main elements of its implementation are

- The automated creation of a list of contact instances `my_ctc`, maintained in the personal device of the user. The number of such entries could be up to a few thousand entries per day as soon as big events take place again.
- The maintenance of a list of infectious carrier of the disease `ga_icd` on the server of the Gesundheitsamt, currently around 70'000 entries in total with a growth rate of less than 4000 per day.
- The search for entries from the personal list `my_ctc` in the list `ga_icd` retrieved from the Gesundheitsamt.
- In the case of a hit, the app informs the server of the Gesundheitsamt about the identifier found.
- The server and the app cooperate in classifying the category of the contact (Category 1 or 2, see below). The associated contact persons might be involved in this classification process.
- Based on the result, the Gesundheitsamt decides about the quarantining and testing of the device's owner.

The best possible cooperation of the contacts and the Gesundheitsamt in assessing the category of the contact reduces both the test load and the necessity of a quarantine. In an initial phase, this may include the indication of the seat used on a joint train ride, the confirmation of a joint lunch or the like. Clearly, further technical developments in sensing of both the mutual placement and orientation of people will be of great help in automating this process but are not needed in an initial phase. Such developments could follow similar lines as the work for indoor position, which achieves high levels of accuracy [5].

A. Actors

The above description identified a number of actors. Before entering into this discussion, it is useful to differentiate three categories of contacts [6]:

- Category 1 contacts are those to which a face-to-face contact accumulated to more than 15 minutes.
- Category 2 contacts are those to which a face-to-face contact accumulated to less than 15 minutes.
- Uncritical contacts are all others.

The consequences of being a Category 1 or 2 contact are defined by the Gesundheitsamt and may be changed over time. Both categories are quarantined. Currently, the main difference is in the level of testing. The Category 2 defines the sampling time of our contact monitoring.

With this preparation, we have the following actors:

- The Gesundheitsamt (trusted authority): it tests people for COVID-19 infection, it publishes an anonymized list of carriers and it facilitates the categorization of contacts.
- Roaming users: their devices monitor contacts at regular intervals (30 second) and store the list of contacts `my_ctc` as well as a list with location and orientation information `my_loc`, their devices check whether there was a contact to an infected person (at least once per day), and provide support to the categorization of the contacts, potentially using location and orientation information. Note that all information is kept locally with the exception of information exchanged in the categorization of a contact.
- Users tested positively: their devices provide their lists `my_ctc` as far back as their owner's infection may have been contagious to the Gesundheitsamt, they go into treatment or at least quarantine, and cooperate in determining the category of contacts that they had. The device uses the list `my_loc` to support the classification of contacts to other people. Although the position information is kept locally, it is partially disclosed to the Gesundheitsamt in the assessment of contacts' categories.
- Users with a critical contact (Category 1 or 2): they also go into quarantine and are subject to an immediate test. In the case of a positive outcome, they change category. Otherwise, they are tested again after an incubation time. In a second negative testing, they are freed from quarantine obligations.

B. Tracing Method

There is a number of options to detect the proximity of people. We propose to use Bluetooth transceivers to send beacons and monitor for such beacons at regular intervals. The benefit of using Bluetooth is that corresponding interfaces are included in nearly every smartphone and that they are furthermore available on cheap platforms. In addition, Bluetooth creates a direct relationship between the potential contact persons, which works everywhere, including shopping malls or the underground metro station. Although not too reliable, the power level can be used as an indication of the distance between the transmitter and the receiver, and could thus be used as a filter. The details of this aspect need further assessment. Furthermore, the use of Bluetooth

is associated with a low power consumption. The proposal made in Section V uses functions available in the Application Programming Interfaces (API) of Android and Apple iOS. More refined solutions may be implemented by Google and Apple, themselves providing improved power management, relative contact positioning, safety against manipulation and the like.

Tracing may either be performed on a voluntary basis or enforced. The knowledge of being a carrier (positive testing) does not provide benefits to people without or with marginal symptoms. It rather puts them into quarantine and thus reduces their freedom of movement. Quarantining carriers has a huge benefit for society, however. Thus, the incentives to individuals are purely ethical, which seems to be sufficient at the time. Thus, we focus on the voluntary approach but provide some hints for enforcement as well.

- In a preparatory phase, the user installs the tracing app. In the case of enforcement, the app creates a connection of data from an official ID-card and the device and then registers the user with that data. This creates a permission to roam and is communicated to the mobile operator. It can furthermore be used to prevent a number of manipulations to evade quarantining, for example. In the case of a voluntary roll out, this registration does not exist, and even in the mandatory case, it is only used to prevent manipulations and does in particular not create any additional means of tracking.
- Every day, the app chooses a random daily identifier `my_rdi`, which it broadcasts at regular intervals using a Bluetooth protocol (see Section V). The identifier provided by the device is `C0F1D19|my_dri`. The randomness of the `my_rdi` prevents any correspondence with a particular device or user. It is changed daily to prevent tracking by any fixed monitoring stations.
- In parallel, the device searches for the beacons of other devices. This monitoring is performed every 30 seconds. Whenever the device detects an identifier of the form `C0F1D19|fg_dri` for the first time, it adds `fg_dri` to its list `my_ctc` and stores the current time (in 30 second units). If it sees the identifier again, it updates the duration of the contact. In total, there are 720 two-minute intervals in 24 hours. Assuming that someone is surrounded by up to 6 people during 12 hours would lead us to 2160 entries. There is no difficulty in storing that number, but this exposes the importance of applying simple filtering to control the complexity of later processing steps.
- Whenever the Gesundheitsamt updates its list `ga_ctc`, which is signed using its private key, the device checks for matches between `ga_ctc` and `my_ctc`. The increase in carriers is around 4000 per day in Germany. The list shall include these entries as well as those of the day before, which is perfectly manageable. The random device identifier and the date must both match, since the identifier is changed every day. Note that a very high level of anonymity is preserved up to this point.
- If there are matches in the device's list `my_ctc` and in the list of the Gesundheitsamt `ga_ctc`, there are two different

options:

- The device notifies its owner and asks him about his preferences. If the preference is to enter quarantine without further checking, no further action is needed and no information is ever exchanged.
- In all other cases, the Gesundheitsamt and the device aim at categorizing the contact. This requires a negotiation, which can be handled by a mailbox to prevent the disclosure of the person's identity. In advanced negotiations, the information from `my_loc` will typically be used in the process of categorization.
- Once the category of a contact is determined, the Gesundheitsamt either asks the person to quarantine herself and organizes testing, or just drops the alert if the contact was uncritical. In the latter case, no further data is exchanged and the data associated with the inquiry is erased.
- In the case of a critical contact, the Gesundheitsamt invites the person for testing. All exchanges can again be handled through a mailbox. This does again not require the disclosure of the identity of the person. If the testing is twice negative, the person leaves the quarantine and the data is erased.
- In the case of a positive testing, the app provides the contact history `my_ctc` from the beginning of the estimated infection period to the Gesundheitsamt. The disclosure of the identity of the person is not needed for pandemic control. The app maintains the list of locations from the estimated infection onward in order to respond to further inquiries from the Gesundheitsamt.
- The device continues comparing its list `my_ctc` with later provisions of `ga_ctc`. This is necessary, due to the significant delay before some carriers are found and since it is the last contact, which is determining the end of the quarantine period.
- Whenever the Gesundheitsamt receives a list of `my_ctc` including the timing and the duration, it will add the random identifiers to its list `ga_ctc`. Depending on the evolution of the pandemic and future experience, it may decide to only trace contacts to Category 1 or to both categories. It will add these contacts to its list and publish a signed copy of `ga_ctc` at regular intervals. As a consequence, listed identifiers will trigger an inquiry of the associated devices with the Gesundheitsamt to ask for categorization. Once every user device has performed its matching, there will be no unidentified hits in the past. Thus, the Gesundheitsamt can erase all non-public information associated with the published list. Since some devices may not have contact to the Gesundheitsamt for a few hours, there should be a margin in erasing this data, e.g. one extra day.

C. Tracking

From an epidemiological perspective, users that are quarantined would ideally be tracked. The procedure is straight forward: whoever leaves the location of the quarantine is warned. In the case of a continued breach of rules, the

Gesundheitsamt is informed and takes action. From this time onward, the person could be continuously tracked to support her repatriation into her quarantine zone. This is certainly controversial and not too compatible with a voluntary tracing. It may be activated if enforcement of tracing turns out to be necessary. Currently, this seems not to be the case.

IV. THREATS

The tracing described above is meant to control the pandemic and to enable a restart of the economy, while keeping citizens as protected as possible. In the case of a voluntary use of the system, the main threats are attacks on the privacy of users. They are not only serious but may additionally jeopardize the acceptance of tracing as a method to control the pandemic. In the case of enforced tracing, there are additionally options for evading tracing or tracking. This is mentioned but not discussed in any depth.

A. Attacking Privacy and other Misuses

The primary line of attack to access the personal profile of a particular person is through the app. Thus, the app needs a thoughtful design and implementation. This is, however, a requirement, which it shares with any other software using personal data and localization. A similar statement holds for the software run on the server of the Gesundheitsamt. It should avoid any deficiencies but is still exposed to exploits of the operating systems and the like. We also assume that the public key cryptosystem is secure in the relevant time. The data base of the Gesundheitsamt is only of limited interest, since it contains very little information and since the data is not personalized. The bigger threat is the impersonation of the Gesundheitsamt, it may lead to a number of options, which mostly don't have a clear benefit, like

- The removal or addition of contacts.
- The false categorization of contacts.
- The undue convocation of people to testing.
- The quarantining of healthy people.

The most influential possibility is to add a carrier to `ga_ctc` and to thus retrieve the list of his contacts. This, however, requires finding a valid random daily identifier, e.g. by creating an explicit contact to a person as well as a major software bug at the Gesundheitsamt e.g. by exposing its private key. Other sophisticated attacks are conceivable, e.g. using a network of cooperating Bluetooth units to profile users by tracking their passage near those units. This is not particular to the present system, however. Otherwise, we did not find an obvious other critical attack so far. In the end the usefulness of tracing carriers of COVID-19 and of restoring normality to our daily life have to be balanced against fears of potential attacks.

B. Escaping Control

The consequence of having been in contact with an infected fellow citizen is to become quarantined. Some people may want to avoid that, even in the case of enforcement. Most options such as roaming without an active device, breaking quarantine rules, using different devices, uninstalling and

reinstalling the app or cheating during the categorization can all be handled by appropriate measures. They will have to be addressed if enforcement is really desired. This is currently not the case.

V. PROTOTYPE IMPLEMENTATION

An implementation of the above system could easily be performed by the companies Google for Android devices and Apple for iOS devices. A more detailed design will need a further specifications of the protocols, which should be done jointly to achieve the fastest possible availability of a fully inter-operable system. We studied different mechanisms provided by Bluetooth in Application Programming Interfaces (API). iBeacons, which is a protocol used for indoor location services, became our initial candidate. This protocol allows devices to broadcast identifiers, which are received by other devices in the neighborhood. The received signal strength can be used as an indicator of the transmitter to receiver distance. The concentration of transmission and monitoring around 30 seconds intervals of the time of the day can be used to implement a simple form of power management.

The focus of our testing was on verifying the possibility of using a mechanism provided by an API. Thus, we implemented an app on iOS to transmit iBeacons and used the nRF Connect for Mobile app to monitor these beacons. This worked whenever the app was in the foreground of the iOS device. The transmission was, however, discontinued, whenever the app was sent into the background. As a consequence, we implemented an alternative approach using the standard Bluetooth Low Energy (BLE) protocol. A corresponding app was written for iOS and another one for Android. Both apps implement the beacon transmission and beacon monitoring. The source code can be downloaded from <https://github.com/danielgnt>. The subdirectories bletrack-android and bletrack-ios contain the associated code. These apps could successfully monitor beacons between Android phones as well as between iOS and Android phones. All associated trials worked with the apps in the background on both phones. However, we could not get the iOS to iOS scenario working with both apps in the background. It only works when one of the apps is in the foreground, which is not sufficient. If this could be solved, a large community of programmers could implement the tracing system described above.

VI. CONCLUSIONS

The present paper exposes an automated, privacy preserving, tracing method based on Bluetooth radio contacts, which consequently works indoors, where people come closest to each other. The approach uses random daily identifiers to trace contacts. The randomness and daily updates prevent most attacks on privacy. The information needed to trace contacts is maintained locally in the personal device. The health agency “Gesundheitsamt” is a trusted authority, which only stores contact profiles of positively tested people. This data does not have to include any means of identification of physical person.

The next step in bringing this approach to reality would be to setup a task force force designing the details of the protocol,

as well as implementing and testing the mobile and server components. The aim should be for a quick and stable initial operational systems. The outcome should be further optimized in a second phase to improve contact classification in order to reduce unnecessary testing and quarantining.

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