The Corona Warning App of the German Federal Government – How perceived data protection issues hindered any effectiveness

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Abstract
Since June 17th, 2020 the Corona Warn App of the German Federal Government has been available for download. After a sharp increase downloads stagnate around a total of 20 million, which is roughly one fourth of the population. Whether everyone who downloaded it actually uses it, is questionable.
Objectives We want to show that the underlying concept of an app is questionable, even if each inhabitant with a smartphone downloads and uses it, it would cover barely half of each encounter where COVID-19 could actually be transmitted.
Prior work This work is the scientific, extended version of a short article we published in the September 2020 issue of the "Behördenspiegel", a monthly magazine covering German public administration issues.
Approach We use statistical methods to show that, (i) even in the very best case with a perfectly working app the coverage would have been roughly half of all relevant encounters (ii) and that the voluntary usage of this app as well as the free decision of the infected individual to publish its (anonymized) data to warn others in fact reduces any effectiveness considerably. In addition we show that (iii) due to the design of the app there is a likely limit where the app will not be able to warn its users for mathematical and cryptographical reasons.
Results We demonstrate by statistical means that this app could never have worked and why similar apps neither would work, let aside probably the "Trace Together" initiative of Singapore, which is based on a combination of an app plus physical tokens for those who do not own nor use smartphones (https://www.tracetogether.gov.sg/). We define some requirements a successful COVID-19 tracing solution must fulfill.
Implications We show that such apps are not a solution for the problem, rather an obstacle to a real solution, because they lull their (few) users into a false sense of security which is obviously wrong, based on real figures.
Value The paper contributes to transparency of government action during the COVID-19 pandemic. We show that other ways of contact tracing must be pursued in order to be effective and hinder the pandemic from escalating rather than providing a false feeling of safety.

Keywords: Bluetooth, contract tracing, COVID-19, smartphone.

1. Introduction
A pandemic is always also a problem of collecting and processing information. Relevant questions are e.g. "Is the person in front of me infected?", "Am I infected myself?" or "Whom did the infected person meet?". Nowadays it seems natural, to solve these information problems with ICT.

Germany's answer to these information problems was the Corona-Warn-App (cf. [1]), issued by the Robert Koch Institute, the government's central scientific institution in the field of biomedicine, on behalf of the German Federal Government on 16 June 2020.

Unfortunately the app cannot, as per today, be considered a success. According to the press and the public the verdict is pretty clear:

- "It does not help us at all", as the Medical Officer of the Berlin district of Reinickendorf is cited; [2]
- "The app is useless", was the main reason for not downloading it, according to a survey of Appinio on 17 June 2020; [3]
- Downloads reached quickly 15 m within two and a half weeks, however, only 5 m more downloads until mid-October 2020; [4]
- In public transport the app has substantial issues to the point of rendering the app virtually non-functional, according to an Irish study which concludes "[w]e find that the Swiss and German detection rules trigger no exposure notifications on our data, while the Italian detection rule generates a true positive rate of 50% and a false positive rate of 50%." [5].

The quotes above are but a selection, but what is undeniable is that barely a quarter of the population – assuming that each single download was from an inhabitant of Germany and if we rule out multiple downloads - at least downloaded and probably also installed the app at one stage. This means, that assuming no one has either deleted or deactivated it, barely one quarter of the population in the very best case uses it.

In this paper we apply statistical methods to show that even in this very best case the app would never have worked in the sense that it would have covered more than half of the meetings between two people, i.e. potential transmissions of the COVID-19 virus (Section 2). Also in this section we discuss the applied mechanism to publish infections and hence warn contacts only when the infected user explicitly takes action. Based on real data we will show that such concerns driven by data protection issues effectively hinder an app from functioning as intended. Then we examine the underlying mechanisms of the app, namely the design based on the Exposure Notification Framework developed by Google and Apple [17]. Here we question whether a Bluetooth-based mechanism is a proper way of designing such an app (Section 3). Furthermore in Section 3 we raise the issue whether an app based on voluntary usage may be an appropriate solution for controlling a pandemic. Finally, in Section 4 we define requirements for such solutions for the issue of effectively tracing infections. The paper closes with a summary, which contains recommendations and lessons learnt.

2. How Germany is covered or not covered by the app

According to official data the app has been downloaded 20.3 m times [4]. This figure includes all multiple downloads, all downloads on smartphones thrown away since and of course all downloads from people (or machines) who do not live in Germany. If we simply ignore these cases and assume that each single download is installed and still used on a smartphone in Germany, the app covers a little less than a quarter of the population of 83.1 m people [6], precisely 24.4 percent of the resident population. When two individuals meet on German soil (bilateral meeting), we cannot take for granted that each of the two individuals carries a smartphone with this very app. Note that only approx. 81.7 percent of

the German inhabitants use a smartphone [9], particularly the age cohorts most vulnerable to the virus own significantly less, only 44 percent of those older than 70 years; the highest percentage of people owning a smartphone, around 97 percent, can be found with the younger generation – the least vulnerable [9].

Only inhabitants of Germany are considered, we omit all meetings with tourists, business travelers, commuters, shoppers etc. from abroad. So e.g. a French national doing his or her shopping on the other side of the Rhine and, unavoidably meeting a German inhabitant, is omitted in our calculation. It is obvious that

- the groups omitted cover hundreds of thousands of people, probably even millions, the residents of France commuting on a daily basis to work in Germany alone stood at 41,000 in 2012 (cf. [20], p. 7)
- it is highly unlikely that these people use the German Corona-Warn-App, which is not available in other languages than German, English and Turkish – not even planned to be available in Czech, Danish, Dutch, French or Polish [21], to mention only the languages of the neighboring countries of Germany – who have likely their own national tracing apps like France [31].

Even assuming that all app downloads are still operational, the pure likelihood in a bilateral meeting that both of the individuals have a smartphone with an active app each is .244 times .244 or 5.95 percent. So, one bilateral meeting out of 16.8 is covered by the Corona-Warn-App of the German Federal Government. Hence, 94 percent of all bilateral meetings are definitely not covered by this very app.

If we repeat our assumptions and slightly adjust them towards a more realistic scenario, the result would be like shown in the table beyond:

Table 1. Assumptions regarding the usage of the Corona-Warn-App

Assumption	Alteration	Effect
Each of the 20.3 downloads was from an inhabitant of Germany	5 % foreign downloads	minus 1m users
No multiple downloads occurred	20 % multiple downloads	minus 4.1m users
No downloaded app deinstalled nor deactivated	25 % stopped using the app	minus 5.1m users
Smartphones crashed, sold, or simply not used anymore	5 %	minus 1m users
Subtotal		**- 11.2m users**

Source: own text above

Due to the favorable assumptions it is obvious that this statistical calculation is much in favor of the app. The reality can be expected to be definitely worse; data indicates that uninstall rates vary between 26.1 percent [7] to 40.4 [8]. Hence, the real coverage ratio in bilateral meetings can be expected to be around 3 to 4 per cent.

The decision, whether to publish or not publish a positive test result is left to the individual user of the app alone [12]. The data, how many users publish positive test results, is

inconclusive and varies from 50 to 63 percent [13] [14]. This means that one third to one half of positive tests is not published, which reduces the effectiveness of the app even more – realistically we may end up with a coverage (and publication) ratio around 1 or 2 percent of all relevant meetings where the virus could have been transmitted.

In this context it is not surprising that as per 17 October 2020, four months after the app started, only 18,126 positive test results were shared with the other app users in these four months [10]. According to the Robert Koch Institute official dashboard the total number of infected in Germany stands at 464,239 with 14,964 newly infected from 27 October 2020 to 28 October 2020, when this paper was written [11]. As per today, 28 October 2020, we have 121,256 active infected with the virus [15], this equals roughly 0.14 percent of the population or one out of 685. Calculating the likelihood of two individuals meeting (0.244 squared) times the likelihood of one being infected (0.0014 percent) times optimistically two thirds sharing (times 0.67) gives 0,000055844768 percent as the likelihood that two individuals meet and one is infected, shared his test result and the other guy gets a warning. One out of 17.906 occasions results in a warning where statistically with 0.14 percent infection rate every 714th meeting is a "hit", i.e. you meet a guy who carries the virus.

So, we may conclude that only 3.98 percent of all meetings with an infected person are covered with the Corona-Warn-App as implemented and used per today under most optimistic scenario assumptions. Or roughly one out of 25, the other 24 contacts with infected persons remain undetected.

If we assume the best possible case for the German Federal Government, which were if each of the 81.7 percent of smartphone users downloads, uses and shares, the likelihood remains 0.817 squared or 66.7 percent times 0.14 percent infection rate, resulting in 0.00009 percent or one meeting in 1070. Hence 356 meetings with infected persons go without any alert, plus the meetings with non-German residents not covered in any scenario.

Note that these figures are likely even much lower, because infected persons hopefully stay at home as soon as they know their infection status, such reducing both the number of potentially dangerous meetings and the likelihood of the meeting being covered by the app. The relationship of 3.98 percent of all dangerous meetings being covered by the app should prevail for both likelihoods being reduced linear according to the number of infected people isolating.

There would be a far better indicator of the actual usage than the highly ambiguous download figures: the downloads of the updates of the app provided by the stores of Apple and Google. As per 21 October 2020 the new app version 1.5 is available [34], but no figures regarding downloads of updates are available according to our research. If someone downloads an update, the likelihood that the app is active and running is much, much higher than assuming that the persons (or machines) who downloaded itstill use it regularly.

3. How the app is designed technically

The core of the Corona-Warn-App solution is the software app on the smartphone [16] together with the Exposure Notification Framework developed by Google and Apple [17]. Note that the latter is not part of the app, but a standardized framework on an operating system level developed by the two companies. The framework applies complex cryptographic algorithms to ensure privacy and data protection [18]. A so-called Temporary Exposure Key (TEK) with a defined validity of 24 hours is generated randomly and, via a Hashed Message Authentication Code (HMAC, effectively a SHA-256 hash plus padding parameters) [19] a Rolling Proximity Identifier Key (RPIK) is generated from the TEK (cf. Figure 1). This prevents derivation of the TEK back from the RPIK. However, if the protocol ended here, one could still conclude who is behind the RPIK if a person often/permanently interacts with a TEK holder, such as a spouse. Hence, a second – time-dependent – layer needs to be added to the framework. This is done in the next step.

Every new interval of ten minutes, identified by a so called (ENIntervalNumber), the RPIK, the ENIN and other data items (padding) are forged into the Rolling Proximity Identifier, the RPI. RPIs are propagated via Bluetooth to be received by the Framework installed on other smartphones that get close. Therefore, even if a person stays in close proximity of the TEK holder, that person gets a new RPI every 10 minutes and is hence not identifiable from its TEK or RPIK.

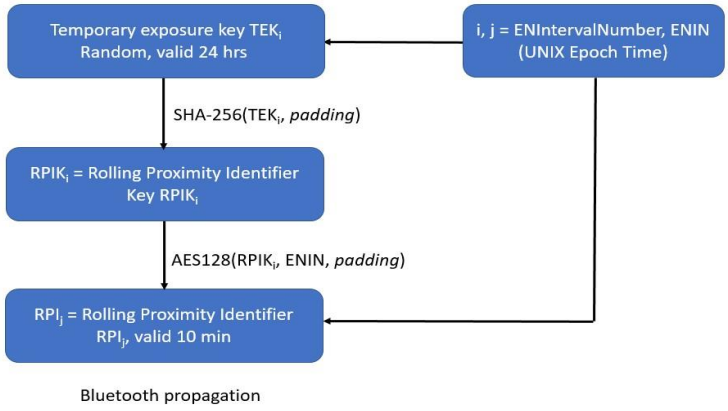

Fig. 1. Cryptographic Framework overview from the cryptographic protocol specification in [18]

This implies that it is impossible to derive the TEK from the RPI, which (i) guarantees anonymity and (ii) ensures that two persons meeting at two different ENIN time intervals have totally new RPIs, hence it is impossible to identify them via their RPIs. If a married couple meets ten times a day, they have up to ten RPI-pairs, so it is not possible to identify them for an outsider. Note that these functions are performed by the Exposure Notification Framework and are hence beyond the control of the German Federal Government and, of course not part of the app.

If the app-user is infected, i.e. receives a positive test for COVID-19, it is up to him or her to publish the TEKs together with the relevant ENIN time intervals to describe where the validity of the respective TEKs started and ended on the so-called diagnosis server (cf. [18], p. 4). These published TEKs/ENINs are downloaded by all app users (up to 20.3 m users according to [4]). The app then recalculates the RPIs according to the procedure described above and compares it to the RIPs received and stored from the meeting partners. This mechanism is covered by the app and its backend information systems.

There is a restriction that not all smartphones can use the app. According to the media [22] [35] it works only with

- iPhones using iOS 13.5[1] or higher, covering 81 percent of all iPhones (and subsequently not usable on 19 percent of all iPhones with lower versions of iOS)
- Android-based smartphones using Android 6 Marshmallow or higher, covering 92 percent of all Android-based smartphones in Germany
- Excluding popular smartphones like Huawei Mate 30, P40 Pro and Mate 40 Pro.

The app itself contained severe mistakes, above all loading the TEK of people infected was stopped by the battery-low-function of Samsung and Huawei smartphones [23].This mistake that lead to major critic in the media, together with other mistakes (cf. [23] and [24]) and, above all, a communicated price of 69 million Euros the government paid for the app mostly to SAP AG and Deutsche Telekom AG [25] lead to a very diverse echo in the media and the public. It is highly questionable whether the penetration rate of users rises to a significant part of the population and, as shown above, it will never cover more than two thirds of all meetings of two people, not even in pure theory. Based on the roughly six percent of all meetings covered under very optimistic assumptions per end of October 2020,we assume that the ceiling is around ten percent of all meetings covered, when not significantly changing the voluntarity of both usage and publication of positive test results.

4. Requirements for a Corona-Tracing- and –Warning-App

Instead of comparing the technical solutions of other countries, who did more or less the same than Germany, we would like to define requirements for such an app and, if the app itself is not considered sufficient to cover 100 percent of all people within a country's borders, additional tools and regulations.

These requirements are, in our belief:

1. The app and the additional tools must cover 100 percent of all meetings of two individuals within a state's border when there is the likelihood that one of the two is infected and can transmit the virus. Such, and this is the conclusion, the usage must be made mandatory.
2. The effectiveness is tied to a quick notification of all contacts, so the publishing of a positive test result cannot be left to the individual affected.

[1] According to the Deutsche Telekom AG, a co-producer of the app together with SAP AG, it requires even iOS 13.6 (cf. [36]).

3. Each person within the state's boundaries must be confident that he or she is warned without any unnecessary delay by authorities that he or she could carry the virus.
4. People entering, transiting and leaving the state must be covered with 100 percent accuracy. So the solution implemented must ensure that each person entering is registered and traced until exiting the state.

If we take the government of Hong Kong, who required every new arrival to download the StayHomeSafe app and gave them a paired wristband with geofencing technology (cf. [26], [27]), this seems to fulfill the requirements. Also did the Chinese response, using a Business-Government collaboration based on the frequent use and high penetration of AliPay services (cf. [28]).

Mobile phones and payment solutions, also including credit and debit cards with or without NFC function, are a good (data) basis for tracing contacts. Increased usage of cashless payment methods during the pandemic [32] provides more reliable data of e.g. visitors to bars and restaurants as the "German Way" of asking the customers to write their personal data on a sheet of paper, leading to mass visits of "Lucky Luke" and "Markus Söder"[2], i.e. visitors providing bogus data unusable for contact tracing [33].

5. Summary

Data Protection, especially after the introduction of the GDPR, is highly valued in Europe. The question underlying the German Corona-Warn-App is, whether Data Protection compliance is higher valued than effectiveness. We have mathematically shown that statements from German Government officials encouraging the usage of the app (cf. [29]) are rather symbolic, because the coverage and effectiveness of this app is very, very limited, even if a much higher number of people actually uses them. We have also shown that a share of the population lower than one quarter uses it and that it does not cover the millions of non-residents who visit Germany each day, week and month.

If COVID-19 is a serious threat to the health and lives of the Europeans, and we sincerely believe this in accordance with the WHO, who declared only 20 pandemics and epidemic diseases so far including COVID-19 [30], then Data Protection issues must have lower priority than tracing and stopping the virus.

So we defined requirements any serious and effective tracing and warning mechanism must fulfill, the most important being that it must cover 100 percent of all meetings with infected persons and notify affected persons and the health authorities without any unnecessary delay.

[2] Current Prime Minister of the Federal State of Bavaria, Germany.

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