Proximity Tracing in an Ecosystem of Surveillance Capitalism

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ABSTRACT

Proximity tracing apps have been proposed as an aide in dealing with the COVID-19 crisis. Some of those apps leverage attenuation of Bluetooth beacons from mobile devices to build a record of proximate encounters between a pair of device owners. The underlying protocols are known to suffer from false positive and re-identification attacks. We present evidence that the attacker’s difficulty in mounting such attacks has been overestimated. Indeed, an attacker leveraging a moderately successful app or SDK with Bluetooth and location access can eavesdrop and interfere with these proximity tracing systems at no hardware cost and perform these attacks against users who do not have this app or SDK installed. We describe concrete examples of actors who would be in a good position to execute such attacks. We further present a novel attack, which we call a biosurveillance attack, which allows the attacker to monitor the exposure risk of a smartphone user who installs their app or SDK but who does not use any contact tracing system and may falsely believe that they have opted out of the system.

Through traffic auditing with an instrumented testbed, we characterize precisely the behaviour of one such SDK that we found in a handful of apps—but installed on more than one hundred million mobile devices. Its behaviour is functionally indistinguishable from a re-identification or biosurveillance attack and capable of executing a false positive attack with minimal effort. We also discuss how easily an attacker could acquire a position conducive to such attacks, by leveraging the lax logic for granting permissions to apps in the Android framework: any app with some geolocation permission could acquire the necessary Bluetooth permission through an upgrade, without any additional user prompt. Finally we discuss motives for conducting such attacks.

CCS CONCEPTS

•Security and privacy → Human and societal aspects of security and privacy; Operating systems security;

KEYWORDS

proximity tracing, privacy, mobile phones

1 INTRODUCTION

Bluetooth-based proximity detection has been rapidly developed and deployed as a means to fight the public health crisis posed by COVID-19. The principle is to use mobile phones to digitally assist contagious disease contact tracing by making a digital record whenever two phones are physically proximate. Bluetooth is potentially suitable for this purpose because it is, in general, used for short-range radio communication. This is used to detect and record a proximate encounter which can be used to indicate a risk for disease exposure for one party to an encounter if the other party is later labelled as testing positive. Privacy is an immediate concern. Some protocols, including the widely deployed Google and Apple collaboration Google-Apple Exposure Notification (GAEN) [1, 2], promote themselves as being safe for users’ privacy.

The technical mechanism of Bluetooth-based proximity tracing is that users voluntarily broadcast a frequently changing pseudorandom identifier, known as an ephemeral id (Ephid). These Ephids are intended to be unlinkably anonymous, so that when a broadcaster begins to broadcast a new one, receivers are unable to associate the new broadcast with old broadcasts. In typical implementations, broadcasts are linkable to the same broadcaster with a knowledge of a trapdoor function, such as the master key used to derive them or a central authority who prescribes them. This trapdoor function is used to identify broadcasts Ephids that should be considered as high risk for exposure, and can be shared so as to make linkable the otherwise unlinkable identifiers.

Broadly speaking, there are two types of contact tracing systems: centralized and decentralized. While not the only possible implementation, centralized system involves a central authority that maintains the trapdoor functions for all users and can further associate it with an identifier such as a phone number to be able to notify them if they are at risk. This means that users’ broadcasted Ephids are verifiable to this authority, but unlinkably anonymous to others. Decentralized systems involve no central authority that knows veronyms and trapdoor functions, but instead users choose to publish their trapdoor function so that other users may derive their Ephids and determine if they have an exposure. That is, all users begin unlinkably anonymous, though some may choose to become linkably anonymous so as to publish the fact that particular Ephids should be considered as a risk for exposure.

Decentralized systems appear better for privacy. Unfortunately, there are two known attacks that have significant implications for the decentralized scheme, and we introduce a novel third one here. Note that the first two, known as false-positive attacks and de-anonymization attacks also exist for the centralized scheme, though their effectiveness and ease are reduced; we reserve a discussion for that in Section 5. The third attack we name biosurveillance attack, and it affects a non-user of a decentralized system whose device has been compromised.
All these attacks work because Bluetooth beacon broadcasts are by nature public broadcasts. Anyone else listening to broadcasted Ephlids can store information about it, such as their current location; they can also re-broadcast it elsewhere with the goal of creating false contact events in other users that may result in false positives. Proponents of decentralized systems dismiss the attacks as difficult to do and requiring specialized hardware [3], and suggest that the legal system can mitigate their risk [4].

In this work we show that this is not the case: it is easy to perform these attacks. Instead of requiring specialized hardware and physical presence to mount the attack, we show that it can be done simply by placing an SDK in a popular app. This can be by creating the app, by purchasing control over a popular app, or by paying a developer to include the SDK. Observe that this last option is standard practice in the mobile ecosystem [5]. We further found and analyze the behaviour of an SDK that already exists on hundreds of millions of Android phones and which is uploading full Bluetooth scans of nearby devices including MAC addresses as well as some Bluetooth advertising data to their central servers.

While we have no evidence of attacks against proximity tracing being conducted, the company that produced this SDK can trivially mount false-positive, de-anonymization, or biosurveillance attacks. It further gives evidence that the attacks incur little cost because a for-profit business is monetizing this data before a novel health-related purpose was added to it. That is, this type of data is already being collected in an ecosystem of surveillance capitalism [6]. This attack vector requires neither special equipment nor a physical presence in victim country. The potential adversary requires no specific abilities, powers, or access other than sufficient budget to write a few lines of code and get it included in a few modestly popular apps or one superstar app. This is well within the budget of a state-level adversary.

The contributions of this work are the following:

- We present a new attack, called a biosurveillance attack.
- We show that implementing false positive, de-anonymization and biosurveillance attacks is trivial at scale by using commodity hardware and recruiting smartphone users as confused deputies in the attack.
- We show that there exist apps installed by hundreds of millions of users that already contain an SDK that implements a substantial amount of the biosurveillance and de-anonymization attacks.
- We discuss how false-positive and de-anonymization attacks also affect centralized proximity tracing systems.

The remainder of this paper is organized as follows. In Section 2 we discuss background information including proximity tracing and the Android permissions system. In Section 3 we describe our proposed SDK-based attacks. In Section 4 we detail network transmissions from an SDK that is already deployed and collecting observed Bluetooth traffic. In Section 5 we discuss our results, including possible mitigations, similar attacks against centralized systems, and possible attackers and motivations. In Section 6 we provide future work and Section 7 draw conclusions.

2 BACKGROUND AND RELATED WORK

2.1 Nimity Slider

Goldberg’s “nimity slider” [7] is a way of thinking about user privacy that is relevant for this work. The nimity slider has four positions: unlinkably anonymous, linkably anonymous, pseudonymous, and verinymous. If a user is unlinkably anonymous, it means that each “message” that they send cannot be linked to any other message they send. If a user is linkably anonymous, it means that each message they send can be linked to other messages, but these messages do not identify the user themselves. If a user is pseudonymous, then each message they send can be linked to some assumed identity of the user’s choice, but this identity does not itself identify the user and can be dropped at any time. If a user is verinymous, then every message they send is linked to the user’s true name. Verinymous does not need to represent the user’s actual name but can instead by any type of persistent identifier, such as a MAC address, which users cannot easily discard.

Users may exist at different positions on the slider, and they lose anonymity as they go from unlinkably anonymous towards verinymous. This can happen by design, such as users intentionally revealing their identity. It can also happen as a result of a de-anonymization attack, wherein an attacker uses information to move some user on the nimity slider towards verinymous against the design of the system, i.e., in violation of the system’s privacy claims. For example, a de-anonymization attack could work by attaching a verinym to some linked identifiers; it could also simply link identifiers that were not supposed to be linked.

Users may simultaneously exist at different positions relative to different entities. For example, a user may be verinymous to a trusted third party, as well as to themselves, but be unlinkably anonymous to all others. Thus, a user’s nimity is relative to another entity and can change with time, but only towards verinymous.

2.2 Smartphone Proximity Tracing

Contact tracing in the context of infectious diseases is the practice of identifying who may be at risk of contagion by referencing the contacts that an infectious person has recently made. It works by identifying those who may have been exposed based on earlier contact with a diagnosed individual, and then warning those who may be at risk. This was typically a manual process based on personal recollection, and typically can identify friends, family, coworkers, etc.

Recollection-based contact tracing, however, is unable to identify strangers who may have unintentionally come into close contact with an infected individual, e.g., by sharing public transit. For this reason, many jurisdictions are attempting to use smartphones as an electronic aid to augment their capacity to conduct contact tracing. Smartphones assist in two complementary ways: (i) to infer a proximate encounter between two phones, and (ii) to record the details of this encounter for later contact tracing. This is appealing in places where a large segment of the population already carry such devices because it reduces the deployment cost. In a sense, this paper describes how an attacker can similarly reduce deployment costs by exploiting smartphones, this time as attack vectors.
Bluetooth-Based Proximity. Bluetooth has been used to detect and infer proximity events. Bluetooth is a commonly used technology for short-range wireless communication for many consumer electronics, such as headphones or game controllers. The observation is that Bluetooth radio can be used as a “proximity sensor” if two phones are able to “hear” each other as they broadcast. Deployments of this involve phones periodically broadcasting a short random “ephemeral ID” (EphId) that serves to identify the encounter. Any EphIds that are “heard” are recorded, i.e. by saving the EphIds to the device’s storage.

This broadcasting is done with Bluetooth Low Energy (BLE) advertisements. These are also called beacons or advertising beacons, and already serve other purposes in the world. For example, they are used for location sensing and can be used to trigger location-based functionality. They can also convey information, such as Google’s Eddystone URL beacons that broadcast a hyperlink, or Apple’s iBeacons, which broadcast device identifiers. The Google-Apple Exposure Notification (GAEN), which implements Bluetooth-based proximity for proximity tracing, uses a new type of advertising beacon to transmit EphIds with the same existing technology.

Proximity Tracing. With a Bluetooth sensor, users’ smartphones are able to record all observed EphIds, which corresponds to specific encounters with others they have had. Proximity tracing is then implemented by a separate mechanism that identifies particular EphIds that should be considered as at-risk for infection, because that EphId was broadcast at a time the person was contagious and the attenuation of Bluetooth signal strength indicates proximity. We refer to this as proximity tracing. For example, if a user tests positive for the disease, they can publish all their broadcasted EphIds over their infectiosity window and other users can determine if they are at risk.

EphIds can be implemented in different ways but existing deployments involve a trapdoor function that is able to link them. That is, the EphIds broadcasted by the same user are unlinkable unless one is aware of a trapdoor function that links them. For example, the EphIds can be the output of a cryptographically suitable pseudorandom number generator: with knowledge of the random seed, the entire sequence can then be deterministically reconstructed and therefore any two identifiers linked. The need for linkability through the trapdoor function derives from the Google/Apple implementation from bandwidth considerations.

Centralized and Decentralized Systems. A prominent dimension in proximity-based contact tracing is the characterization of them being either centralized or decentralized. While there is diversity in the specific implementations, the fundamental difference involves who is aware of the trapdoor function and whether any form of anonymity is provided.

Centralized systems involve some entity, such as a government authority, who maintains a mapping from an individual to their trapdoor function, and informs the individual what to broadcast and when. If an individual becomes ill, they report all their received EphIds to the central entity. The central entity uses the trapdoor function to de-anonymize these reported EphIds so as to notify other potentially at-risk individuals.

Decentralized systems, in contrast, involve individuals maintaining their own trapdoor function, thereby choosing what to broadcast and when. If they become ill, they may choose to publish their trapdoor function through a centralized authority. These are broadcasted to other individuals, who can then generate all EphIds that would have been sent to determine if they were witness to any. Note that the design of a decentralized system prevents linking the trapdoor function to some verinym that identifies the user.

A fundamental difference between these systems is information self-determinism. In decentralized systems, individuals—through their devices—choose their trapdoor and choose whether to publish it. Another difference is the degree of nymity: in centralized systems all individuals are verinymous to the central entity; in decentralized systems individuals are unlinkably anonymous unless they choose to become linkably anonymous—for example, to publish their trapdoor function if they become ill. That is, a centralized system has a central entity that learns a verinym for every encounter that an ill person has had in recent time, even for those who are not themselves ill, and the central authority may choose to inform at risk users. In contrast, in a decentralized system everyone learns how to link identifiers for those who report that they are ill.

We use the Alberta TraceTogether app [8] as an example of a centralized system, which we have reversed engineered. Users register with a phone number and receive an access code. This access code is then registered with a device identifier to identify the installation and the user. A central server then provides users with the list of random identifiers to be used as EphIds, along with the time interval to use them. The authority maintains a mapping from a user’s identifier (e.g., a phone number) to the trapdoor function that allows it to generate and recognize the random identifiers. Users who become sick are instructed to upload their observed encounters to the authority. The authority can then de-anonymize everyone who may be at risk, and notify them, e.g., by text message.

We use the SwissCovid app based on the Google-Apple Exposure Notification as an example of a decentralized system. Here every user picks their own trapdoor function to derive random identifiers. If they become sick, they can cooperate with a public health authority who then publishes their trapdoor function. All other users then learn the trapdoor and recompute all EphIds that are now considered to correspond to possible encounters with a contagious person. They do not reveal to anyone whether they have in fact witnessed this encounter, but instead check offline—i.e., only by looking at their own stored data—whether any EphIds associated with a risk for contagion exist among their collection of encounters.

Privacy Risks. The privacy intrusions for centralized systems are clear. First, all users are verinymous to the central authority. Second, ill users upload all their encounters, which verinously identifies both parties to the encounter to the central authority. This revelation occurs even if one of the parties is not actually ill, or, in some systems, even if the encounter was considered “at risk” [9]. Thus, the decision to reveal the fact whether a user was proximate to someone else is not under the user’s control once they have broadcasted their EphIds. Additionally, users lack control over the
data: it is the authority’s decision as to whether to alert users, instead of users being able to assess their own risks based on, for example, a heightened concern by being more vulnerable or near those who are, as well as lifestyle factors such as always wearing a mask when out of doors.

As such, the decentralized system is superficially a better solution for privacy. Users are empowered to assess their own risk based on information they collect. Only they learn about encounters they have with others. No entity knows their trapdoor function except the user unless they intentionally share it with others. There is no mapping from actual personal information to the trapdoor or broadcasted beacons aside from the user. In this work, however, we show that the privacy implications can be worse in some decentralized systems, where users who publish their trapdoor function can be made verifiable and have their geolocation tracked by an adversary with a modest budget.

2.3 Smartphone Permissions

The Android platform uses a permission system to protect access to sensitive resources based on the security principle of least privilege. Apps must request relevant permissions in order to be able to perform specific functionality. Permissions are requested statically in a “manifest” file and can thus be audited when the app is installed.

An important distinction among Android permissions are those classified as dangerous. These include access to sensors such as the camera and GPS, access to user data such as call logs, and access to actions such as sending text messages [10]. These are permissions that Android believes are dangerous if misused by apps and users are given stronger controls over them. For example, on Android 6.0 and later, users are asked the first time these permissions are used, and importantly have the ability to deny access to the app. Conversely, so-called normal permissions get granted upon installation of the app, or silently added if the app upgrades after the developer has expanded their manifest file.

Crucially, the permissions that an app has access to are also granted to any other code that runs as part of that app. This includes the prolific ads and analytics networks that are often included for monetization of apps. These can report back user data to servers and offer other features to developers. The use of such third-party code is common—it is easier and generally better to make use of existing reusable code than to rewrite everything ad hoc. Nevertheless, it means that some third-party code can find itself embedded in an app that has requested the right set of permissions to perform its desired behaviour.

For Bluetooth, there are two relevant permissions: bluetooth and bluetooth_admin. The former allows the use of Bluetooth devices, while the latter permits scanning for and connecting to new Bluetooth devices, as well as receiving and broadcasting BLE advertisings. As such, the latter is the permission of interest for proximity tracing apps and attacks against them. Examples of well-known Android apps benefiting from bluetooth and bluetooth_admin include Spotify or Uber. Despite the significance of having administrative power over Bluetooth on a device, Android considers both Bluetooth permissions “normal”.

Bluetooth has a further toggle in the system status bar. Users can disable the Bluetooth radio, as well as other radios and features on the device. For scanning to work, the Bluetooth radio must be on. Note that any use of Bluetooth, such as for headphones or car audio, requires that Bluetooth is enabled and thus passive scanning is possible for other apps. It remains enabled when not in use unless users diligently disable it when finish using a Bluetooth device.

Since Android 6.0, apps are required to hold a location permission in order to scan for nearby Bluetooth devices and nearby WiFi routers. This is because the serial numbers for these devices can act as a surrogate for location [11]. As such, collecting them is now considered to imply the collecting of location as well. The location permission is considered a “dangerous” permission. Users are prompted before allowing it the first time and can revoke it through a sequence of settings options. If an update to an app adds location access, then users are alerted to this fact before it is used.

In summary, any Android app can acquire the permissions necessary for conducting the attacks we describe here without any mention of Bluetooth in a user prompt. At best, the user will be prompted to add some location permission if the app does not already have that one, but would manage to invisibly slip in necessary Bluetooth permissions at the same time.

3 PROPOSED ATTACK

There are three attacks we consider: false-positive, de-anonymization and biosurveillance attacks. All these attacks are performed by an adversary who is capable of running code on millions of field-deployed smartphones. For example, the attack could be performed by an SDK that an app maker includes for monetization purposes, which is a standard practice. The key observation is that the attack can be mounted without specialized equipment and without a legal presence in the country being attacked. The attacker does not need to own the phones themselves, but can just leverage the existing ecosystem of mobile app monetization, where app makers are paid to include ads and analytics SDKs that run arbitrary code on users devices.

We call this SDK the attack SDK and assume that it is provided by the attacker and included in a popular smartphone app or a bevy of less popular ones. The attack SDK collects and transmits Bluetooth data and reports all received data back to the attacker. It also allows the device to broadcast arbitrary Bluetooth low energy advertisements. The attack SDK is in end users who install an app containing this SDK to act as confused deputies: they unknowingly undermine the integrity or anonymity of the contract-tracing system by contributing access to their hardware to the attacker.

Note that there is no technical obstacle to creating such an SDK: all of the functionality exists in the Android API. In the next section we show the existence of an SDK—already deployed on hundreds of millions of devices—that collects and reports back Bluetooth low energy advertising data that are “heard”. We do this not because we believe that this SDK is mounting these attacks, but rather to provide evidence that these attacks cannot be optimistically dismissed as hypothetical or unrealistic; they are well within
the budget of many types of adversaries. For the rest of this section, we assume that such an SDK exists and describe how to use it to mount false-positive, de-anonymization, and biosurveillance attacks.

3.1 False-Positive Attack

A false-positive attack works by compromising the integrity of the system by creating false contact events among users. The presumed goal is to create false positives in risk notifications and so the attacker’s goal is met if the fake contact events they generated later correspond to positive diagnoses, since this will trigger a notification. The implementation of the attack is to rebroadcast EphIds heard in one location somewhere else, in effect, a relay attack [3]. For example, the attacker may harvest beacons from a site likely to contain COVID-19 cases, such as a COVID-19 testing facility or a hospital, and relay them anywhere that the attacker wishes to cause a fake outbreak, such as at a factory for an economically vital industry, or during advanced voting to force election officials to self-quarantine and discourage citizens from voting.

In this case, the attack SDK is configured to harvest all observed Bluetooth beacons, including the EphIds. These are then uploaded to a central server as soon as they are available. The attack SDK is likely to get the user’s location: it is either running on a version of Android since 2015 that requires location permission to scan for Bluetooth, or it is not and can use surrogates to GPS-based location such as cell-phone tower triangulation or router-MAC-address-based location. Note that these surrogates work even when GPS is disabled or unavailable, and in the context of our attacks is of sufficient granularity to identify actionable location information, such as “at a hospital”.

Based on geolocation, the attacker then decides which beacons should be relayed by having other smartphone users running the attack SDK begin broadcasting them. These users are given the beacons to broadcast and they simply start advertising. This can be done by having the attacker SDK contact a control server with their location, and depending on the attacker’s goal, be given some EphIds to begin broadcasting along with a time to broadcast them.

Note that EphIds have a short range of time where they can be relayed. This is by design of the system to both prevent tracking of users and limit the effectiveness of a relay attack. The Alberta TraceTogether app uses a period of 15 minutes before switching EphIds. The SwissCovid app rotates EphIds every 10 minutes, but the GAEN framework accepts them as valid within a two-hour window. The length of the window does not change the feasibility of the relay attack, even if it is only a minute. The attacker does not need to be physically present at either the collection site or the relay site. Collected EphIds can be quickly telecommunicated from the mobile phones that first received them to a central server and onward to the devices that will rebroadcast them using the Internet. Shortening the window of time simply means that this collection and communication occurs more often.

3.2 De-anonymization Attack

A de-anonymization attack works by having an attacker gain information that is not meant to be learned by them. In our case, it refers to users “losing” positions on thenymity slider for EphIds relative to an adversary. EphIds are intended to be unlinkably anonymous, but can become linkably anonymous if users publish their trapdoor. In GAEN, this occurs by design when a user tests positive for COVID-19 so as to inform all other users of the EphIds that correspond to encounters with a risk for exposure. A de-anonymization attack is anything an adversary can do to push the nymity slider towards verinymous, against the user’s interest.

Our proposed attack involves SDKs linking broadcasted EphIds data to other available information, such as MAC address, GPS location, and persistent identifiers. For example, the SDK can centrally store all received EphIds along with the precise location where they were received. Note that these geotagged EphIds are collected by other devices, i.e., not the one emitting it.

If a user chooses to publish their trapdoor, they then allow any entity to link their emitted EphIds. Any of these EphIds that have been collected and geotagged by other nearby devices are then not only linked but further geotagged, resulting in a location history for a user who did not have the attack SDK installed on their device. This can include information about their routine such as where they sleep, work, and relax, and thus reveals a great deal about users. This occurs even if the victim user does not use any apps that collect location or even turn on their GPS.

Additionally, the EphIds are not broadcast in isolation but instead alongside the device’s Bluetooth MAC address. The key problem is to associate private data, such as a number that later is used to signal a health status, with something that never meant to be secured, such as a MAC address. Indeed, Google and Apple recognize this: they now randomize (see Bluetooth specification in [1, 2]) the broadcasted Bluetooth MAC address in tandem with the changing EphId, so that neither one can be used to bridge changes in the other. They also prevent programmatic access to the Bluetooth MAC address [12]: apps, and thus embedded SDKs, cannot determine the user’s MAC address. Despite that, the current MAC address is still broadcasted, and so privacy relies on the privacy of a value being unknown to the entity that is the one actually broadcasting it to everyone else. We describe some attacks related to this in the discussion section.

3.3 Biosurveillance Attack

This attack is novel, and in fact quite simple. It can be conducted independently of a de-anonymization attack, and concentrates on inferring the health status of the owner of a particular device. The victim need not use any contact tracing app and even have a GAEN-aware mobile device. This means that the user may believe that they have entirely opted out of participating in proximity tracing. Despite that, an attack SDK running on such a device can simply behave like the passive “listening” component of the contact-tracing system.

The attack SDK collects the observed EphIds that are broadcasted nearby—the very same ones that collected by a legitimate contact tracing app. They can use the health authority’s public information to determine which of these correspond to at-risk encounters. This allows the attacker to perform their own risk calculation about the user without the user being aware. Effectively,
the presence of ambient Ephlds creates a new “health” sensor available to mobile devices in the same way that ambient GPS signals creates a “location” sensor.

For privacy reasons, the GAEN system introduces limitations on the data it collects and makes available. Beacons that can readily be deemed to be too distant will be discarded right away. Apps using the framework will only be able to do coarse computations on beacon characteristics, and only for those beacons that are declared infected. Users will only see the end results.

On the other hand, the attack SDK is not bound by such considerations. It can observe distant and fleeting beacons as well as those never deemed infected. It can further collect the time and place for these encounters.

This provides the SDK with a better view of the ambient traffic and the prevalence of the GAEN system than the GAEN system itself. This also allows for population-level epidemiological research, such as outbreak detection.

3.4 Features of the Attacks

All these attacks can be done by an attacker with no relation, legal or otherwise, with the country in which the attack is mounted. Neither the attack SDK nor the app that includes it need to have any connection with the affected country for the attack to work. It is only the end users who unknowingly undermine the system who are physically present in the affected country.

This is not an exotic attack that requires a high-level of sophistication or domain-specific knowledge. The implementation effort of scanning and broadcasting Bluetooth signals is greatly reduced with APIs designed exactly to facilitate this kind of development. Furthermore, for the false positive and de-anonymization attacks, there is no need for the victim themselves to be the one who is also running the attack SDK—it simply needs to have a baseline presence among other mobile phone users.

4 EXISTING SURVEILLANCE OF BLUETOOTH

In this section we give evidence for the ease that these attacks could be performed by attackers with modest means. Neither the relay attack nor the de-anonymization attack are novel to this work; they are inherent to the design of GAEN. Despite that, we feel both their feasibility as well as our novel attack is not fully appreciated. For example, the Swiss National Cyber Security Centre, discussing the GAEN-based SwissCovid app, stated that: “There is no real safeguard with the current design against this [relay and de-anonymization] attack vector, however there are only few operators of such systems and they are under the Swiss jurisdiction which gives at least some protection on the legal level.” [13] This suggests a belief that the attack needs either leveraging control over already deployed specialized equipment and a physical presence to mount the attack, such as a small ground team that collects data from one location and rebroadcasts it elsewhere. The design documents of DP-3T [3] also refer to the threat of relay attacks in the context of high-energy broadcasting and high-gain antennas.

The problem with basing security on an economic argument is that attacks can become trivial if the economics change or the cost of all possible implementations of the attack are not considered. Our SDK-based attack is an example of this: it performs the same attacks without requiring expensive specialized equipment. It is mounted entirely with commodity smartphones already deployed; instead of high-gain antennas and high-energy antennas, the attacker simply uses many smartphones on the field to receive and broadcast data. We show the feasibility of this attack by detailing the behaviour of an analytics SDK that is already deployed and which harvests all Bluetooth broadcast data it observes from other users. This SDK, which exists as part of the world of surveillance capitalism, can easily perform all three attacks. We detail the SDK’s behaviour by dynamically analysing two apps that contain the SDK and recording the network traffic that it generates while executing.

We first describe our experimental method to test apps and collect data. We then describe a detailed analysis of two apps that contains the same SDK that harvests available Bluetooth data. We then list other apps in which we found this SDK and, by doing an intersection of listed third parties on the apps privacy policies, we attribute it to the company X-Mode.

4.1 Experimental Methods

We perform our dynamic analysis on a Pixel 3a (sargo) mobile phone. The phone is running an instrumented version of Android Pie, which records network traffic for later analysis, including traffic secured by TLS. Our instrumentation attributes network traffic to the specific app that is responsible for its transmission. It also logs access to permission-protected resources, such as performing Bluetooth scans. As such, we are able to observe the real-world behaviour of an app as it executes.

Our instrumented operating system further injects spurious Bluetooth scan results when an app attempts to scan for nearby devices. We use conspicuous palindromic MAC addresses in our injected results and search for them being transmitted. We format the Bluetooth advertising data to match standard beacon formats and ensure that the raw bytes are valid for the format. We inject an iBeacon (MAC address AB:B1:E6:6E:1B:BA), an AltBeacon (MAC address AB:B1:E7:7E:1B:BA), an Eddystone URL (MAC address AB:B1:E8:8E:1B:BA), and a GAEN beacon (MAC address AB:B1:E9:9E:1B:BA).

We start the app and accept its request for permissions, and then leave the app running with occasional random UI interactions through the Android “monkey” utility. We then obtain the network traffic and process it with a suite of decoders to remove standard encodings such as gzip and base64. We remove network traffic from other apps, such as system ones, and consider only that traffic being sent by the app under investigation.

4.2 App Collection

We used the following method to collect apps with Bluetooth permissions from the Google Play Store. First, we search the play store using a dictionary of 4842 English adjectives. We collected the names of apps that appear as the top results when searching these. This gave us a list of 34952 unique app package names.

We then scraped the permissions requested by each of these apps. We were able to get this information for 28270 of them. We then filtered the list to include only apps that requested both the
BLUETOOTH_ADMIN permission and a location permission, i.e., either ACCESS_FINE_LOCATION or ACCESS_COARSE_LOCATION. This left us with 1358 apps that are permissioned to perform this attack.

These 1358 represent an astounding 4.80% of random Google Play Store apps sampled by our method, nearly one in twenty. Note that the newest version of Android, which is only deployed on a small number of phones, requires strictly ACCESS_FINE_LOCATION, not ACCESS_COARSE_LOCATION. This has little impact on the prevalence of apps able to do this: of the 1358 apps, 1215 apps required the fine location permission. Recall that BLUETOOTH_ADMIN is not considered “dangerous”, meaning that apps can update to include it without alerting the user. Through our methods, we found 7835 apps with a location permission—more than one in four (27.7%).

We then ran each of the apps holding BLUETOOTH_ADMIN and a location permission on our dynamic analysis testbed based on prior published methods [14]. We examined apps to see if any transmitted our spurious Bluetooth MAC addresses. We found a prior published methods [14]. We examined apps to see if any transmitted our spurious Bluetooth MAC addresses. We found a handful of apps doing exactly this with all of the data going to one of two domains. We reversed engineered the SDK to confirm our findings and trace the Bluetooth scanning to network transmissions. We now give example transmissions for two apps containing this SDK.

### 4.3 Case Studies on Two Apps

In this section we discuss the findings for two apps, FunDevs LLC’s Video MP3 Converter (com.fundevs.app медиаконвертер) and PixelProse SARL’s Bubble level (net.androgames.level). The former app is notable as it has more than one hundred million installations and more than 600,000 reviews with an average of 4.4 out of 5. The latter app is less popular (only more than 10 million installations) but receives different configuration options and also behaves differently, which is noteworthy in itself. On June 21st, 2020, we downloaded and installed the app com.fundevs.app медиаконвертер from the Google Play Store to our instrumented Pixel 3 mobile phone and ran it with our dynamic analysis testbed. We collected all its network traffic while we ran the app and then analysed it afterwards. We confirmed our findings by repeating this on July 22nd, 2020.

The first app is to bin5y4null.execute-api.us-east-1.amazonaws.com (port 443) where the app performs a GET request for /prod/sdk-settings and provides an API key as an HTTP header (x-api-key). It returns a JSON object storing a configuration. This includes a number of parameters for Bluetooth scanning:

- "baseUrlDomain": "api.myendpoint.io"
- "beaconsEnabled": false
- "bleScanMaxPerHour": 2
- "btScanMaxPerHour": 2

This initial configuration retrieval also occurs for other apps by other developers that contain X-Mode’s SDK. The actual configurations do change, however, and it may depend on the API key that requests it. Observe the “beaconsEnabled”:false flag: for the Bubble level app this value is set to true and the resulting behaviour of the SDK changes. This shows how the attack SDK could evade detection by selectively engaging in attack behaviours only when necessary.

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There are two domains that receive transmissions of sensor data: smartechmetrics.com and myendpoint.io. Figures 1–3 show examples of these transmissions. Both domains receive the results of a scan of nearby WiFi routers and Bluetooth devices as well as precise GPS coordinates. The myendpoint.io domain only transmits precise GPS when beaconsEnabled is set to false; when it is set to true, it also sends nearby MAC addresses as well as Bluetooth LE advertising data as well.

Figure 1 presents a transmission to smartechmetrics.com. We have redacted identifying information, and observe that some of the transmissions of WiFi routers are devices that are nearby to our testbed but not actually devices owned by the authors. We see that the MAC addresses for all injected Bluetooth traffic are collected and transmitted, along with two pieces of consumer Bluetooth electronics in the same room as the testbed.

```
("multi_part":{},
  "obs": ["multi_part":{},
    "timepoint": "1592782636",
    "app:Video MP3 Converter",
    "observed": [{"mac": "AB:16:6E:65:1B:1A", "name": "null",
      "rssi": -12, "tech": "ble"},
    {... more observations ...}],
  "token": "z1+yFcmQZ2D8Q1dpJasF/te5KBhHqXT0YlT5L/eOw="}
}
```

**Figure 1:** Transmission payload from Video MP3 Converter to api.smartechmetrics.com:443. Advertising ID, precise geolocation, and nearby MAC addresses and device names have been redacted. Whitespace has been added for clarity. Observed that the first MAC addresses in the observed array correspond to our spurious traffic.

Figure 2 shows an example WiFi and Bluetooth scan being sent to api.myendpoint.io by the app net.androgames.level. We see that in addition to actual wireless devices, all our injected Bluetooth devices are included in the transmission. The corresponding transmission from com.fundevs.app медиаконвертер only sent location, which appears to be because the command and control server gave the instruction that beaconsEnabled is set to false while it was set to true for apps that sent this information.

**Figure 2:** Transmission payload from Video MP3 Converter to api.myendpoint.io by the app net.androgames.level. This includes not only precise geolocation and a result from a Bluetooth scan but it actually includes the advertising data of the Bluetooth scan itself. The list of beacons in the JSON transmission has one entry corresponding to the
injected iBeacon. The key \texttt{mnum} we believe stands for \texttt{mac uuid major minor}, because it is in fact an underscore-separated string of those four fields. We observe that the uuid, major, and minor values are exactly those that we configured to be sent as the advertised data.

From this case study of one SDK, we understand that it is already the case today that Bluetooth advertising data is being read, processed, and sent to servers on the Internet by millions of users while they go about their day. Note that Android permits this scanning to occur in the background, so users do not need to use the apps in question in order for this to be collected and uploaded. There is no technical limitation that prevents the full collection of the advertised data: a few simple lines of code could make them also upload the GAEN EphIds. These can be then sent out to other devices and rebroadcasted, or accumulated to enable de-anonymization and biosurveillance attacks.

\subsection{4.4 Prevalence of SDK}

Using our testing methods, we have found this SDK in 10 apps available on the Google Play Store. Table 1 presents the list of apps that we found, along with the number of installs, number of reviews, and a list of third parties. The MP3 converter app has more than 100 million installs; the next three have more than 10 million. They are a battleship game, an app to measure if a physical surface is level, and an Internet-speed testing app.

To determine who is responsible for this SDK, we studied the privacy policies of all these apps. In particular, we manually looked for third parties or trusted parties with whom information is shared. We found only one common entity among them and, it was present for third parties or trusted parties with whom information is shared. We observed that this includes the transmission of the advertising data from a Bluetooth beacon.

Figure 3: Data sent by \texttt{net.androgames.level} to \texttt{api.myendpoint.io}. We redacted sensor data. We added whitespace for clarity and broke the \texttt{mnum} value over two lines. Observe that this includes the transmission of the advertising data from a Bluetooth beacon.
They can eavesdrop and interfere with any communication taking place between two other devices (and even create new connections in the case of replay attacks). We have not precisely quantified the requirements for the attacks described earlier, but previous research for other real-life networks has shown that intrusions on a network originating in just one node can cause population-level privacy loss quickly [18], when a node has the capacity to observe traffic within its neighbourhood.

### 5.2 Operating System Controls

Mobile phones can prevent access to Ephids by filtering out messages meant for proximity tracing from the rest of the Bluetooth scan results and prevent broadcasting over BLE of messages that could be interpreted as an Ephid for any particular proximity tracing system. This limits the attackers ability to perform this attack because fewer devices can be enlisted to perform the attack. That is, the data is still being broadcasted publicly, but there are fewer devices that the adversary can use to collect the data.

Bluetooth permissions could be restricted. The permission could be considered dangerous and users given control with run-time prompts and the ability to restrict Bluetooth for third party apps while still getting to use Bluetooth headphones. This also prevents apps from updating to silently add administrative control over Bluetooth.

A further control is to disallow scanning for Bluetooth signals for apps running in the background. The behaviours we observed from the SDK occur even if you do not use the app, because the Android allows apps to start silently in the background and perform Bluetooth scans, as well as communicate to their servers, without any user engagement with the app. This means that apps that have been installed and stopped being used can still exhibit this behaviour. The devices that the attacker can use decreases precipitously if users are required to be actually running the app that contains the attack SDK, instead of just having once ever installed it.

All these controls should be implemented; unfortunately none will address the issue. This is because support for security fixes for mobile phones are shorter than the useful lifespan of a device.

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#### Table 1: List of apps that we found that contain the SDK that collects Bluetooth signals, along with number of installations, number of comments, and third parties listed in the privacy policy.

| App                        | Package                   | Installs | Reviews | Third Parties                      |
|----------------------------|---------------------------|----------|---------|------------------------------------|
| Video MP3 Converter        | com.fundevs.app.mediaconverter | 100M+    | 600K+   | Admob, Smaato, Mobfox, Tutela, and X-Mode |
| Fleet Battle - Sea Battle  | de.smuttlewerk.fleetbattle  | 10M+     | 130K+   | X-Mode only                        |
| Bubble Level               | net.androgames.level      | 10M+     | 200K+   | nearly one hundred including X-Mode |
| SPEEDCHECK Internet Speed Test | org.speedspot.speedanalytics | 10M+     | 484K+   | nearly forty including X-Mode       |
| Speedcheck                 | org.speedspot.speedspot   | 1M+      | 62K+    | Opensignal, Sens360, Tutela, X-Mode, HUQ, and Ogury |
| Compass                    | fr.avianey.compass        | 1M+      | 35K+    | nearly one hundred including X-Mode |
| Just a Compass (Free & No Ads) | net.androgames.compass   | 1M+      | 21K+    | nearly one hundred including X-Mode |
| Portable ORG Keyboard      | com.audiosdroid.portableorg | 500K+    | 1K+     | Opensignal and X-Mode              |
| The Sun Ephemeris          | fr.avianey.ephemeris      | 50K+     | 1K+     | nearly one hundred including X-Mode |
| Altimeter PRO              | fr.avianey.altimeter      | 50K+     | 1K+     | nearly one hundred including X-Mode |

prevention, security, anti-crime and law enforcement. They collect precise geolocation, duration of time spent in places, as well as BLE sensors and beacons, IoT signals, data sent over NFC, and persistent identifiers of users.

To be clear, we have seen no evidence that X-Mode’s SDK is performing any of the false positive, de-anonymization or biosurveillance attacks, and likewise for any of the apps listed in Table 1. Arguably, neither their collection of user data nor broadcasted Bluetooth data violate any laws as the behaviours are clearly documented on their privacy policy and users have no expectation of privacy for messages they broadcast over public radio.

Our focus on this particular SDK is to show the depth and scale of the existing state of surveillance capitalism in which proximity tracing is being added. In particular, that there already exists a field-deployed Bluetooth signals scanner and aggregator, which centralizes data from hundreds of millions of mobile devices. The owners of these hundreds of millions of devices that do the actual work may be unaware that they are doing this collection on behalf of X-Mode if they do not carefully read privacy policies. This collection is presumably profitable, as X-Mode is a for-profit company that sells this information. The consequence is that deploying an attack SDK may even pay for itself by also monetizing the data that is collected, significantly reducing the cost to perform the attacks described earlier.

### 5 DISCUSSION

#### 5.1 Coverage Requirement

The epidemiological utility of the GAEN framework roughly scales with the square $\alpha^2$ of the prevalence rate $\alpha$ of the app within the population. Since $\alpha$ is a proportion, so below 1, it is crucial these apps get significant adoption to be of any broad utility for epidemiological purposes. One might naturally anticipate a similarly prohibitive prevalence requirement for the attacking SDK. This is actually not the case. Indeed, a GAEN app is constrained by design to require both relevant devices to have the app installed, and will not do anything as long as neither of the two relevant users is infected. By opposition, an attacker does not have that constraint. They can eavesdrop and interfere with any communication taking place between two other devices (and even create new connections in the case of replay attacks). We have not precisely quantified the requirements for the attacks described earlier, but previous research for other real-life networks has shown that intrusions on a network originating in just one node can cause population-level privacy loss quickly [18], when a node has the capacity to observe traffic within its neighbourhood.
Older phones can be refurbished and repurposed, and given to people who may not be able to afford a state-of-the-art phone every three years. Privacy updates are not given the same importance as security updates because they are typically not patched but rather come with newer versions of the operating system.

According to Android’s distribution dashboard [19], data regarding distribution of Android devices can be found using the Android App making tool Android Studio [20]. When creating an app, one can specify a targeted version to determine how many devices will support that. Using this tool we found that 11.2% of devices are still using Android 6.0, a version released first in 2015 and last updated in 2017. Devices using this version do not receive security updates and it is officially unsupported. A further 7.4% of devices use versions of Android even older than 6.0. These numbers are similar to another source, StatCounter [21], which puts them it at 8.4% for version 6.0 and 6.4% for earlier.

As long as a baseline of phones in an area run versions of Android with privacy vulnerabilities, an SDK can take advantage of that fact to perform these attacks. The attacker further needs only one device in the right place to do the broadcasting. Given the great diversity in the Android ecosystem, including a variety of smartphone manufacturers with customized operating systems, the ability to entirely disable this functionality is unlikely. This is not necessarily Google’s fault for decentralizing smartphone usage instead of Apple’s model of centralizing it, but it does mean that millions of field-deployed Bluetooth sensors are easily at command for an adversary and are out of reach of security update mechanisms.

This illustrates the difficulty in adding a security or privacy purpose to a feature on a commodity device that was never meant to have it, versus building systems with security by design. If broadcasting over Bluetooth and accessing broadcasts from Bluetooth were considered dangerous from the original implementation, there would not be countless legacy devices for which it was accessible. Similarly, legacy devices may process observed BLE advertisements in irresponsible ways without realizing that it now is associated with sensitive health data.

This echo attack allows the SDK to learn the user’s Bluetooth MAC address and EphIds despite operating system controls that allow access to this information. This data can then be sent to a central service along with the user’s advertising ID or other persistent identifiers. This gives them a mapping from veronym to MAC address from the user, and a mapping from MAC address to EphId can be made by anyone listening to broadcasts. Such an echo system may even occur entirely benignly.

A more aggressive attack would broadcast a persistent identifier instead, which would then be automatically annotated with the Bluetooth MAC address—the same MAC address being used for EphIds. The same SDK running on another device can upload this data to the attacker without echoing. This gives the attacker the same pairs of mappings to de-anonymize users.

This de-anonymization attack is substantially harder than the one presented in Section 3 because it requires two phones in close proximity running the same attack SDK, and only users running the attack SDK can become victims. It would require nearly 71% (\(\frac{1}{N}\)) of the GAEN-using population to have the attack SDK such that half of encounters could be mutually de-anonymized. Privacy-conscious individuals are likely to not install closed-source apps that use surveillance capitalism for monetization and thus greatly reducing their risk. Note, however, that the attack works even if these two phones encounter each other only once during the period of relevance of the trapdoor function. If a user broadcasts their trapdoor function, the attacker needs only be able to map one EphId to a veronym through a MAC address in order to make veronymous all broadcasted EphIds.

### 5.4 Attacks against Centralized Systems

While we discussed the attacks in the context of decentralized systems, it is important to note that many of the same risks apply to centralized systems as well.

*Relay Attack.* First, the relay attack can still be executed as described. Without any additional scrutiny of reported EphIds, false positives will affect the integrity of the system by misleading the central authority, who then issues erroneous exposure alerts.

The central authority, however, has additional tools at their disposal because of their high-level view of all reported infections. For example, collecting identifiers at one site and broadcasting them widely across a geographic area may reveal the attack through manual proximity tracing efforts, *i.e.* that different individuals were in different places at the time yet still observed the same beacon. This increases the cost on operating the system by requiring extra analysis and scrutiny while having little cost for the attacker, and can erode trust in the intent of the authorities as individual users may not perceive the necessity of such monitoring. Moreover, the attacker can mitigate risk of exposure by only relaying the signals at one specific target instead of more broadly.

Even if the central server is able to correctly identify all EphIds involved in relay attacks, this opens up a *false negative* attack for centralized systems. Instead of creating fake outbreaks, the attacker relays all EphIds with the goal of getting them ignored by the central authority. This prevents users from actually receiving exposure notifications and degrades the utility of the proximity tracing app.

5.3 **MAC Address Echo Attacks**

Following on this theme is the idea that Bluetooth MAC are now considered too sensitive to allow apps to access. If the attacker records EphIds, it can also record the current randomized Bluetooth MAC addresses that is broadcasted alongside. Such an adversary needs only to associate one of these MAC addresses to a persistent identifier belonging to the user, or to know that it came from a particular phone. There is a certain irony to the fact that a value ought to remain unknown to the person who is the one intentionally broadcasting it to everyone else.

This is vulnerable to an *echo attack*, where an SDK simply repeats back everything it hears over Bluetooth, allowing the sender to learn its identity. The initial broadcast of MAC address and EphId is done by the proximity tracing app, it is received by a nearby phone and the attack SDK then echos it back using a different Bluetooth service UUID to separate it from traffic filtered out for proximity tracing apps only, and then received by the same attack SDK running on the original phone.
A central authority could also encode geographic information in EphIds. For example, different lists of EphIds could be given to the user with instructions on which set to use depending on some rough location, such as which cell phone tower is nearest. For example, a user may select an EphId from their list such that the hash of it and a nearby cell tower’s identifier have, say, four zeros at the start. Receivers will reject EphIds that do not pass this check, limiting the locations where it can be relayed. This further adds geolocation information to the data collected by the central authority.

**De-anonymization Attack.** The de-anonymization attack, however, is less effective for centralized systems. The attacker can still implement an echo attack to link broadcasted EphIds to a persistent identifier. They cannot, however, learn the specific health status of that individual because that information is not published. The attacker is also unable to “query” the database because the system works by notifying users only when they appear on other users’ submissions. Some attacks are possible. For example, the attacker could broadcast an EphId only once to a single victim; if that victim uploads their data then the attacker may get notified that they are at risk and know that it could only have come from the victim.

Another risk is an insider threat. If an attacker had access to the centralized service mapping EphIds to verinyms, then this information may get abused. Such a system also presents a single point of failure that can have enormously devastating consequences if it is accessed or published without authorization and erode public trust in similar future initiatives.

If the central authority abuses their power by using data about contacts by people for any other purposes than the intended proximity tracing, then a new attack is available: the attacker can try to frame a user by creating fake contact events. For example, the attacker collects EphIds from their target, and broadcasts it elsewhere with the goal of having other users report this fake encounter to the central authority when uploading all their encounter data. This may have consequences depending on how this data is abused by the government. For example, the encounter may represent the user in violation of a bail condition, in violation of a lockdown requirement, or simply present at an event that a politically-restrictive government has banned.

**Biosurveillance Attacks.** By design, centralized systems do not distribute any of the health status data necessary for the risk calculation. Therefore biosurveillance attacks are not possible as described here, unless the SDK learns of infected persons through other means.

### 5.5 App Stores and App Permissions

Apple and Google both have tremendous powers acting as gatekeepers for their respective mobile app marketplaces. Google is frequently criticized, particularly in academic work, but it is worth noting that Apple’s lack of criticism reflects its status as a closed society. Open societies, like democracies, invite criticism and provide transparency. Android’s open source operating system and computer control over mobile devices permits automated analysis of app at scale that results in them being criticized precisely because it is comparatively easy to do so. Anyone with an Android device can audit its security and perform large-scale analysis.

Apple, in contrast, offer a limited number of “positions” in a research and development program subject to a legal contract with Apple, an application review, and only for those who are membership account holders in the Apple Developer Program and have “a proven track record of success in finding security issues on Apple platforms, or other modern operating systems and platforms” [22]. The device remains Apple’s property and participants are required to report findings about Apple products to Apple. They stress that not all qualified applicants will be accepted due to the decision to limit manufacturing of devices that facilitate scrutiny.

Both can make many improvement on how apps are recommended to users. Apps with invasive permission requirements should not be as highly recommended as similar apps without them. Basic static analysis can detect if permission use is likely necessary only for third-party libraries. Users should be able to search for apps by specifying permissions they are unwilling to grant. Finding open-source apps that do not serve ads, collect user data, or even use the Internet, should be made much easier. Internet usage should also be considered “dangerous”, so users cannot be misled that an app that uses all their sensors is safe because—for now—it does not report it. Users should also be afforded mechanisms to deny Internet access to apps that have no legitimate need for it, even if that means only open-source apps remain as interfaces for basic sensors such as flashlight and compass.

As noted, nearly five percent of a random sample of Google Play Store apps had both access to a user’s location and administrative control over Bluetooth. We leave a deeper scrutiny of this as future work, but to give some perspective we would still like to give now a random sample of ten apps from our list of apps pulled from the Play Store (sample obtained by running the shuf command followed by head -n 10 on the whole set). In the sample are a carwash reward loyalty app; a cafe app for a particular cafe in the Detroit community, an app for an arts and craft store, a piano metronome (whose privacy policy makes no mention of Bluetooth and for which there is no associated hardware), an app for an awards ceremony, and a few games. The single app with obvious need to scan for Bluetooth was the “Happn” app, which uses Bluetooth-based proximity tracing to recommend people to date with whom you keep crossing paths. Control over the administration of Bluetooth devices should be reserved for a small number of apps that need that privilege: not compass and bubble level apps that happen to harvest this information without utility to their stated purpose. Indeed, it is exactly this type of abuse that a least-privilege-based permission system is meant to thwart.

Google should consider both Bluetooth permissions dangerous so that apps cannot add them without user warning, and that users can granularity disable access to Bluetooth on a per-app basis. The global toggle for Bluetooth is insufficient as some users may have a Bluetooth peripheral that they require using. Apps with associated hardware should have the ability to engage in user-aided pairing through operating system intents rather than requiring administrative control and thereby granting that privilege to any embedded SDK that comes with it.
5.6 Potential Adversaries and Motives

Our adversarial model has two weak assumptions: (i) they can write code or pay someone to write it, and (ii) they created a popular app, can purchase control of it, or can incentivize an app maker to include their SDK for monetization purposes. There are no technical limitations or powers that the adversary needs to mount this attack; they do not need to compromise any systems; having a budget is sufficient. The software they need to write is straightforward, with all the APIs and frameworks to implement the attack readily available. The false positive attack is the only attack described here that requires active interference with the system and has the potential to be detected and classified as malware; the other two attacks can be implemented offline by analysing data that is already being collected.

The existence of a vulnerability, however, does not imply an attack: we require a motivated attacker. To better assess the risks and thus the threat of this attack, we consider all the adversary types from Van Oorschot’s categorical schema [23]. It divides adversaries into foreign intelligence, politically-motivated adversaries and cyber terrorists, industrial espionage agents, organized criminals, lesser criminals, malicious insiders, and non-malicious employees. We do not see specific threats for the last two categories, but for the remaining ones it is clear that false positive attacks to shut down particular industries are within the motives for these attackers, whether for profit, ideology, or notoriety.

Foreign Intelligence. This adversary is motivated by allegiance to a nation and unconcerned about the law in the country where they mount their attack. They may be concerned about their domestic law but may further receive cover for their actions. They have the budget that their country deems necessary to mount their attack.

We have already seen state-sponsored disinformation campaigns regarding election interference [24]. Opportunities to selectively suppress or shutdown particular groups comes readily to the imagination: political rallies, demonstrations, voters in a particular area, the postal system during an election, military sites, and industries supporting the military.

Note that in the context of disinformation, the mere existence of a technical vulnerability can have disruptive potential in itself, as an adversary might merely hint at its knowledge of the weakness in order to erode trust. This effect is accrued for decentralized systems, as it would be harder to determine whether an attack has even taken place, which can in turn compound confusion as some would start arguing whether the attacks was triggered, with little evidence to anchor the discussion.

Cyber Terrorists or Politically-motivated Adversaries. This adversary is motivated by allegiance to a cause and may or may not be concerned about the law. Of those willing to mount an attack, they may further lack a budget. Nevertheless, they may be able to recruit others who share the same allegiance to a cause to provide the skill required. For example, one member of an organization may create the popular app that later becomes weaponized by another member without the first ever intending to weaponize it themselves.

Examples for politically motivated reasons to suppress a particular population include much from the foreign intelligence category as it relates to election interference. It also includes motives to support causes, such as disrupting the operations of slaughterhouses by those against the consumption of meat, and disruption the operations of oil refineries by those against the production of greenhouse gas emissions.

Industrial Espionage Agents. This adversary is motivated by profit and is concerned about the law. There would be no national cover or protection for their actions, though they may exist in less legally stringent nations and conduct their attacks on either foreign-owned companies or on industries in foreign nations. Any large organization will have sufficient budget to mount such an attack.

For those adversaries who face no legal repercussions the benefit of creating a false outbreak at a rival work site is that they benefit financially by continuing their own operations, and possibly reputationally depending on the specific nature of the industry, particularly if an outbreak poses a health risk to end consumers.

Organized Crime. This adversary is motivated by profit and unconcerned about the law. They have sufficient budget to mount the attack so long as the attack itself is more profitable than the cost. While they cannot write code or are unwilling to do it without remuneration, they have sufficient budget to have it made.

For these adversaries any effort in a profitable endeavour is sufficient motivation. Advanced knowledge of any sort of economic disruption is sufficient to perform criminal insider trading, hoarding then gouging, and extorting against the threat of an outbreak.

Lesser Criminals and Crackers. This adversary is motivated by notoriety or curiosity and may or may not be concerned about the law. For example, they may be a black-hat juvenile insufficiently mature to appreciate the actual consequences. This adversary is likely to lack a budget, but will have both time and skill. Were they able to create a popular app they would be able to mount the attack, and perhaps use it to create a number of fake outbreak hotspots that prints some message on a map.

6 FUTURE WORK

There is future work for this topic. Apps using Bluetooth need more careful scrutiny and auditing. SDKs that collect Bluetooth information need particular scrutiny. Our methods identified X-Mode because they did not use any obfuscation in sending their data, but many SDKs do use various types of obfuscations. We must examine whenever any app or SDK perform a Bluetooth scan and examine all the network traffic to scrutinize other SDKs that exhibit the same behaviour while obfuscating their transmissions.

Additionally, the use of BLE broadcasts can be audited more precisely. This work simply injected faked observed results, but we did not investigate whether any app or SDK actually generated their own broadcasts. The broadcasting done over BLE must be collected and analyzed. In particular, if our fake scan results are ever later broadcasted we can investigate whether it is attempting to infer MAC addresses through an echo attack.

Now that proximity tracing apps are more widely deployed, apps with Bluetooth permissions can be retested to see if their behaviours are changing. Apps that update to now include BLUETOOTH_ADMIN...
when before they did not should be retested as well to understand the purpose of the change. Furthermore, we did our testing in Alberta, Canada, which is a jurisdiction that does not have a decentralized proximity tracing system. Testing of apps in a jurisdiction may reveal different behaviours, particularly given how the command and control configuration impacts X-Mode’s SDK’s behaviour.

7 CONCLUSION

In this work, we argued that Bluetooth-based proximity tracing apps are fundamentally insecure with respect to an attacker leveraging a malevolent app or SDK. We showed that it is easier than anticipated for an attacker to gain that capability, and that once there they could launch de-anonymization, false positive or bi-surveillance attacks. While there are obvious public health benefits to proximity tracing apps for the purpose of fighting the COVID-19 pandemic which put privacy concerns to the backseat in this context, our work cautions that the existence of an ecosystem of surveillance capitalism should not be dismissed, as it is an unfortunate attack vector that threatens the security and privacy of both centralized and decentralized proximity tracing systems.

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