# Cryptic COVID Contact Apps

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What is the state of the art for Coronavirus contact tracing apps?

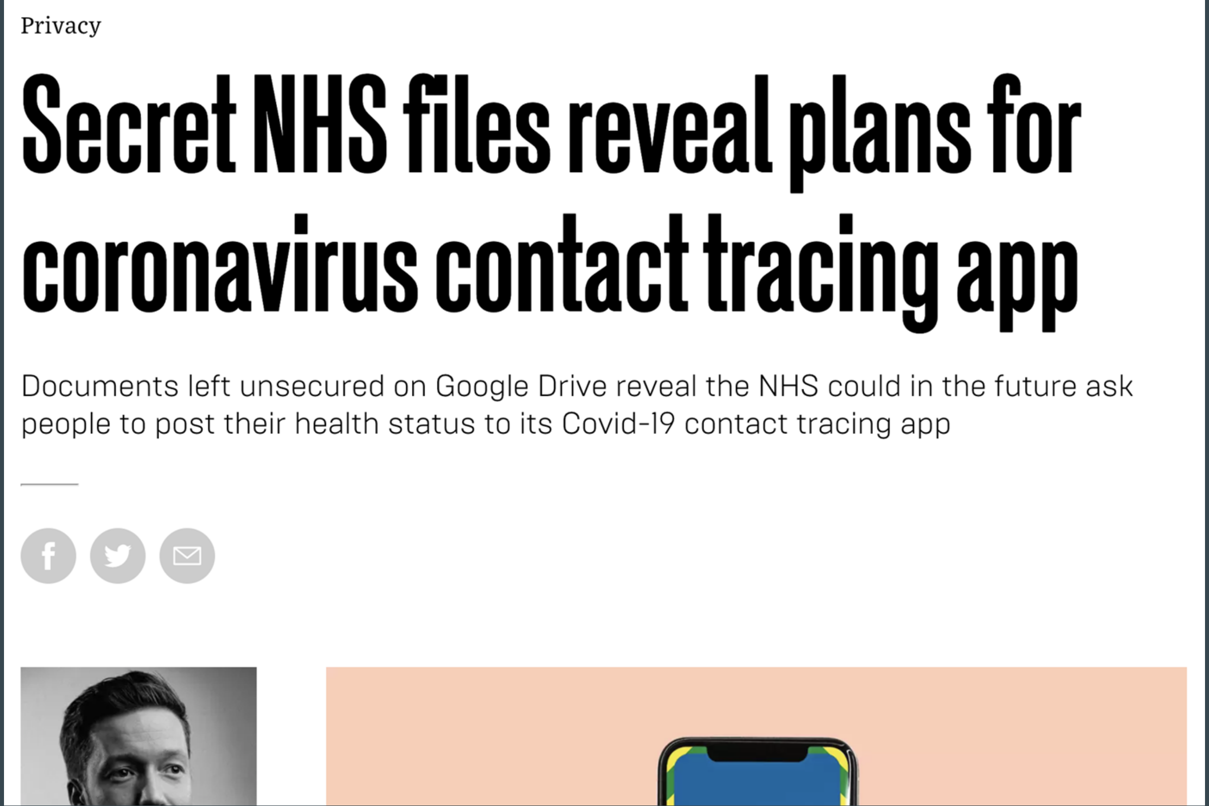
# What this talk is:

An appraisal of the current proposed methods for contact tracing apps, focusing on those utilising Bluetooth or BLE.

We focus on three main implementations:

1. NHS Colocate
2. BlueTrace
3. Apple/Google Contact Tracing

# What this talk is not:



Privacy

## Secret NHS files reveal plans for coronavirus contact tracing app

Documents left unsecured on Google Drive reveal the NHS could in the future ask people to post their health status to its Covid-19 contact tracing app

# What this talk is not:

# Central Focus of this talk - Cryptography, Privacy, and Design

We focus on the implementation of cryptography in these proposed/supplied solutions with the following focal points:

**Cryptography and protocol construction**

How are these protocols put together, and what primitives do they use?

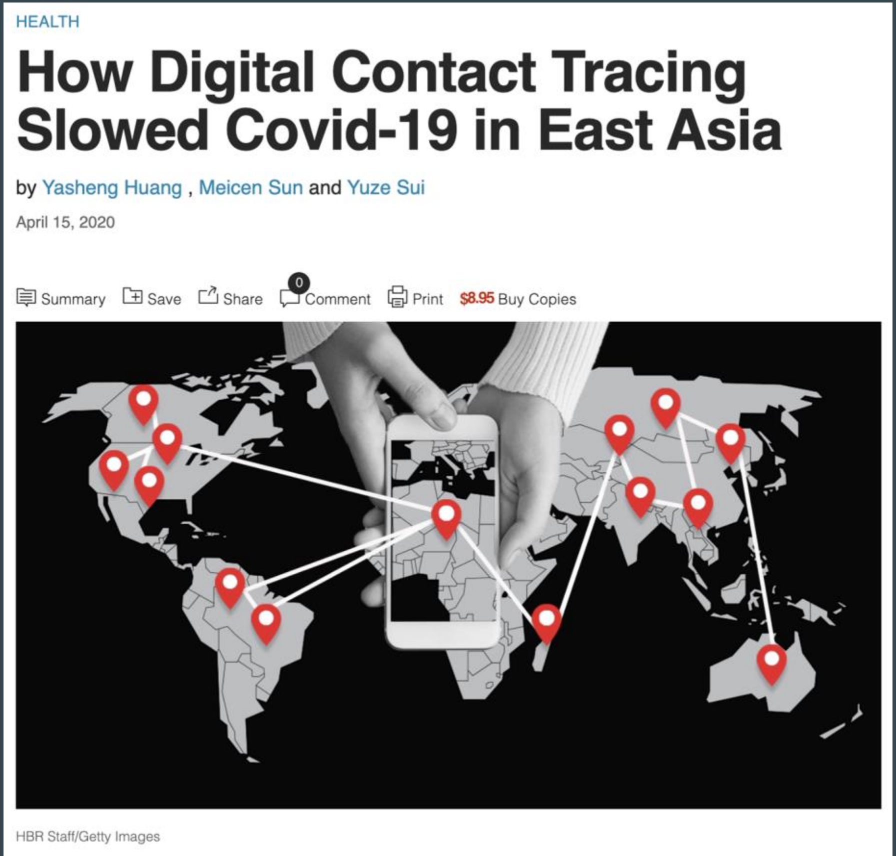
**Privacy Preservation and Considerations**

How well are privacy concerns handled? Are there areas in need improvement?

**Implementation issues and fidelity**

How faithful are the apps to their original designs, and what implementation issues are there?

# But Why are we developing these?



HEALTH

## How Digital Contact Tracing Slowed Covid-19 in East Asia

by Yasheng Huang , Meicen Sun and Yuze Sui

April 15, 2020

HBR Staff/Getty Images

https://hbr.org/2020/04/how-digital-contact-tracing-slowed-covid-19-in-east-asia

# Technology Options

## Passive Options

### GPS

Accuracy to 6ft diameter around receiver is not great for contact/proximity tracing

### SS7

The telco backbone network has capability for working out location, but to worse granularity

## Active Options

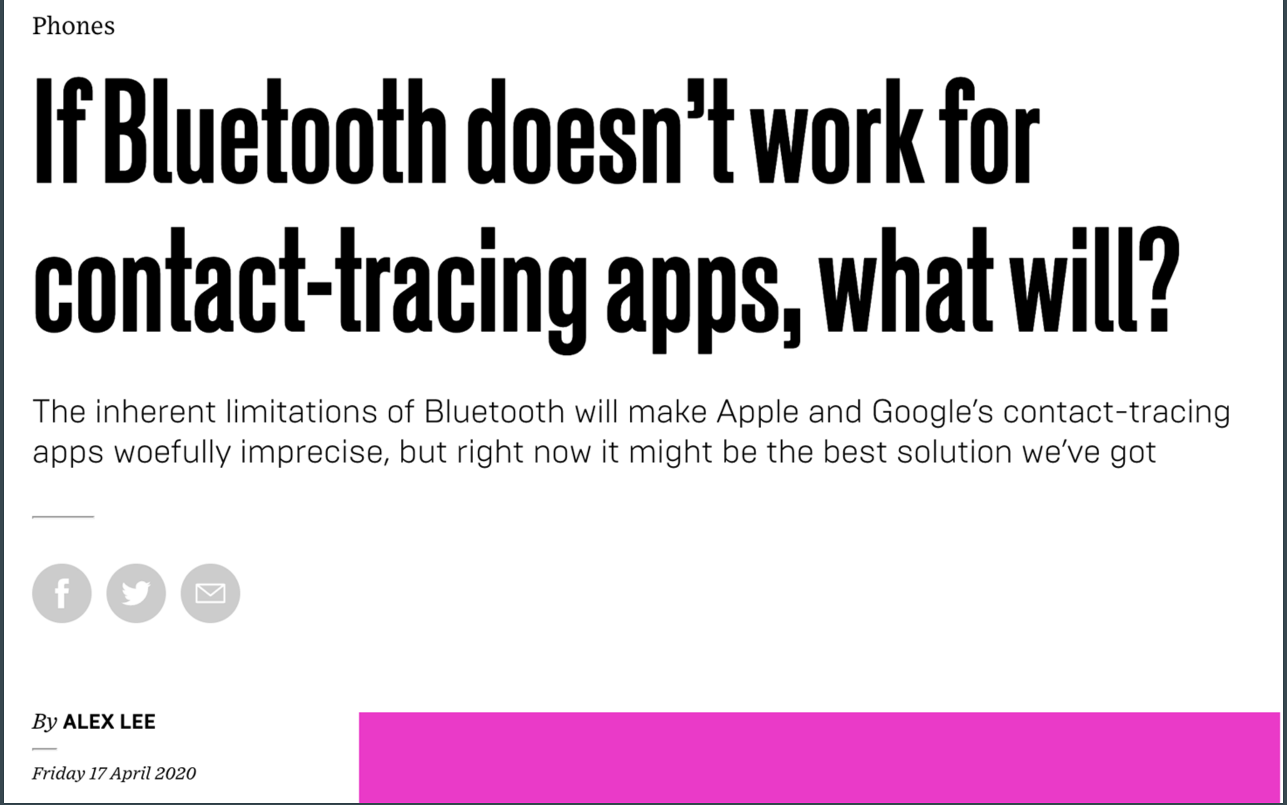
### WiFi

Consumes lots of power in AP mode, and probably too loud to be useful

### BLE

Low power and reaosnable to use, but has active privacy preserving properties (rolling MACs) to make it hard to track

# Side note: Bluetooth/BLE is not designed for this...



Phones

## If Bluetooth doesn't work for contact-tracing apps, what will?

The inherent limitations of Bluetooth will make Apple and Google's contact-tracing apps woefully imprecise, but right now it might be the best solution we've got

*By* **ALEX LEE**

*Friday 17 April 2020*

https://www.wired.co.uk/article/bluetooth-contact-tracing-apps

# There may even be some very core issues...

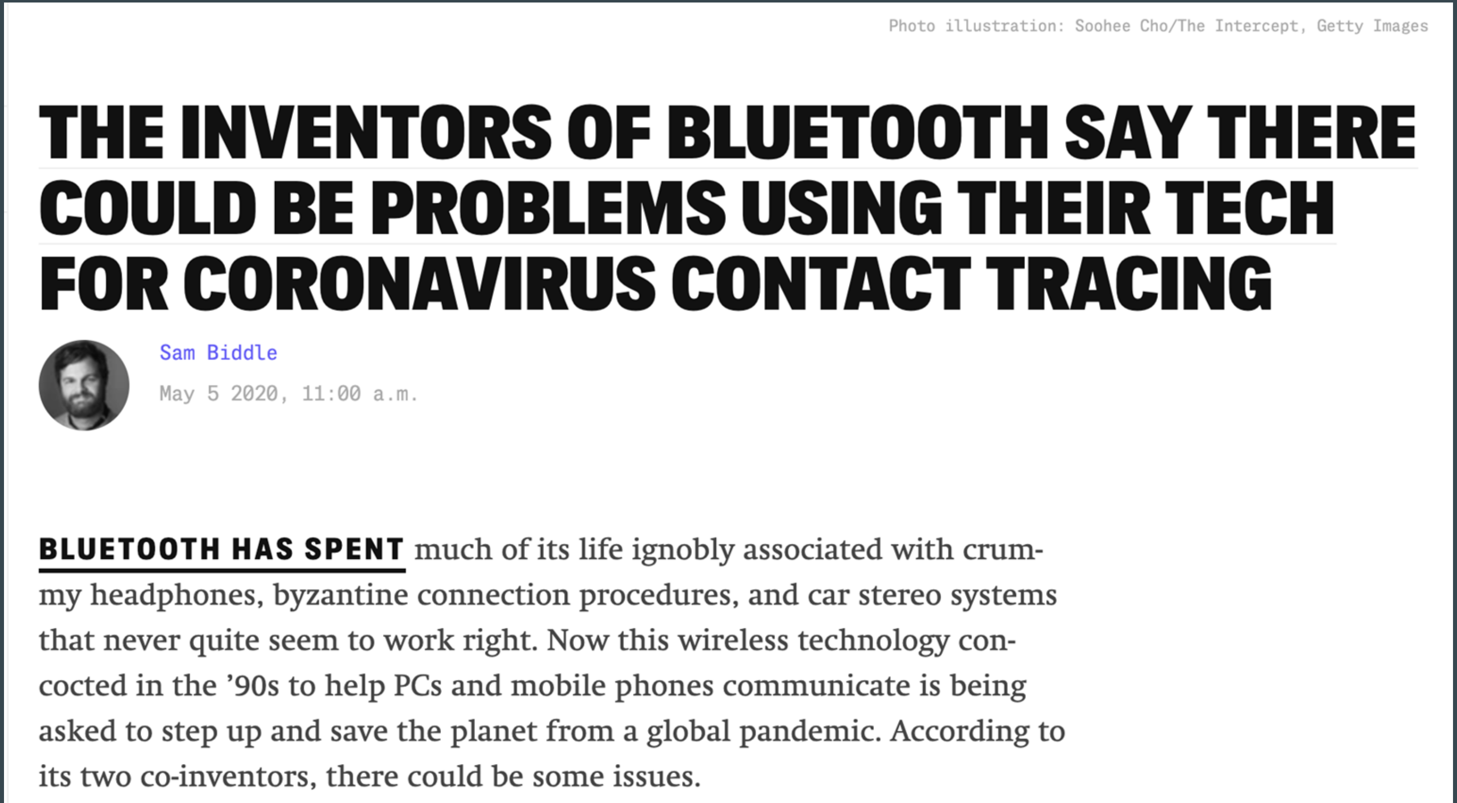


Photo illustration: Soohee Cho/The Intercept, Getty Images

## THE INVENTORS OF BLUETOOTH SAY THERE COULD BE PROBLEMS USING THEIR TECH FOR CORONAVIRUS CONTACT TRACING

Sam Biddle

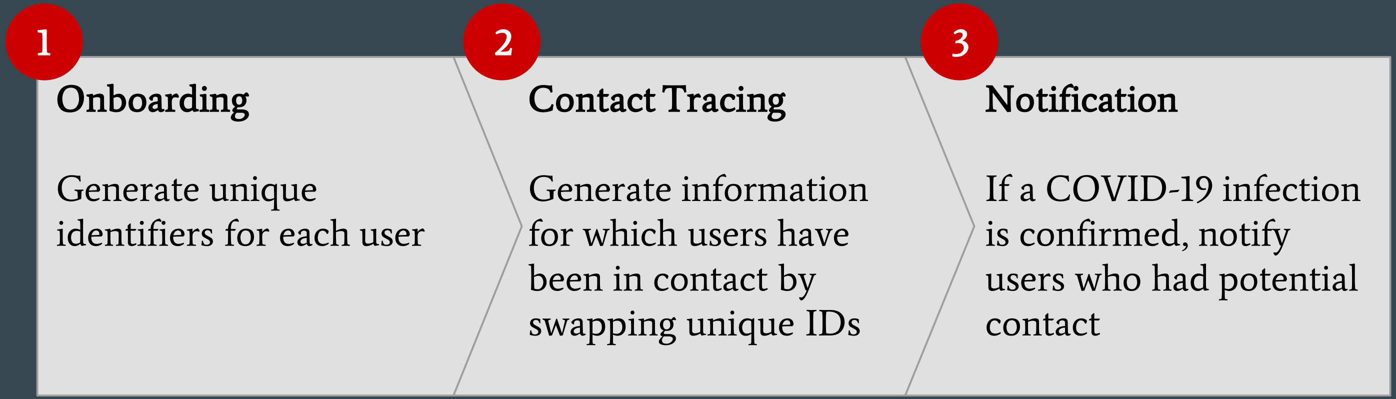
May 5 2020, 11:00 a.m.

**BLUETOOTH HAS SPENT** much of its life ignobly associated with crummy headphones, byzantine connection procedures, and car stereo systems that never quite seem to work right. Now this wireless technology concocted in the ’90s to help PCs and mobile phones communicate is being asked to step up and save the planet from a global pandemic. According to its two co-inventors, there could be some issues.

https://theintercept.com/2020/05/05/coronavirus-bluetooth-contact-tracing/

**NB** - SARS-CoV-2 can be spread by people who are asymptomatic.

# The overall workflow for a contact tracing app:



1 **Onboarding**

Generate unique identifiers for each user

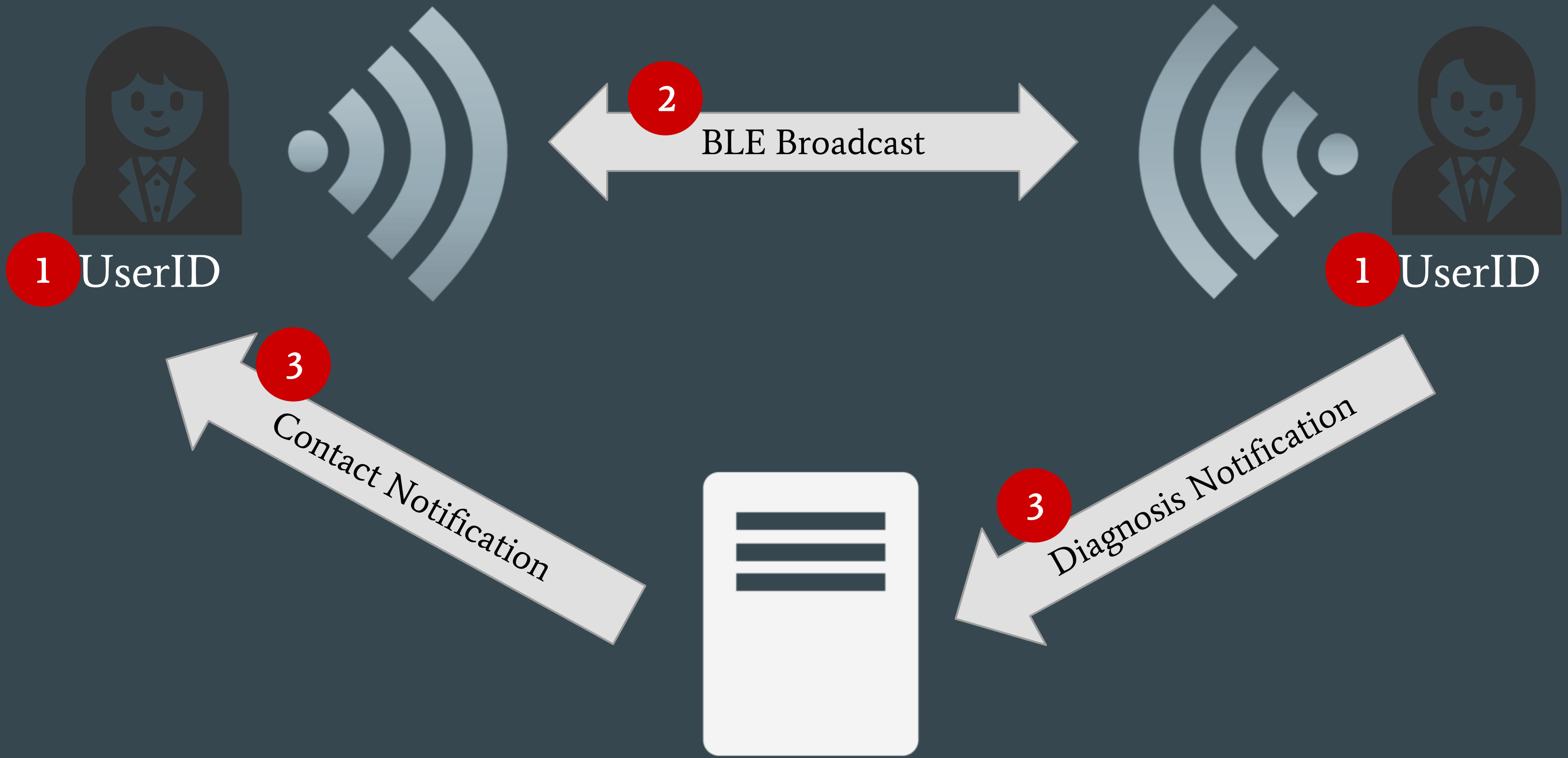
2 **Contact Tracing**

Generate information for which users have been in contact by swapping unique IDs

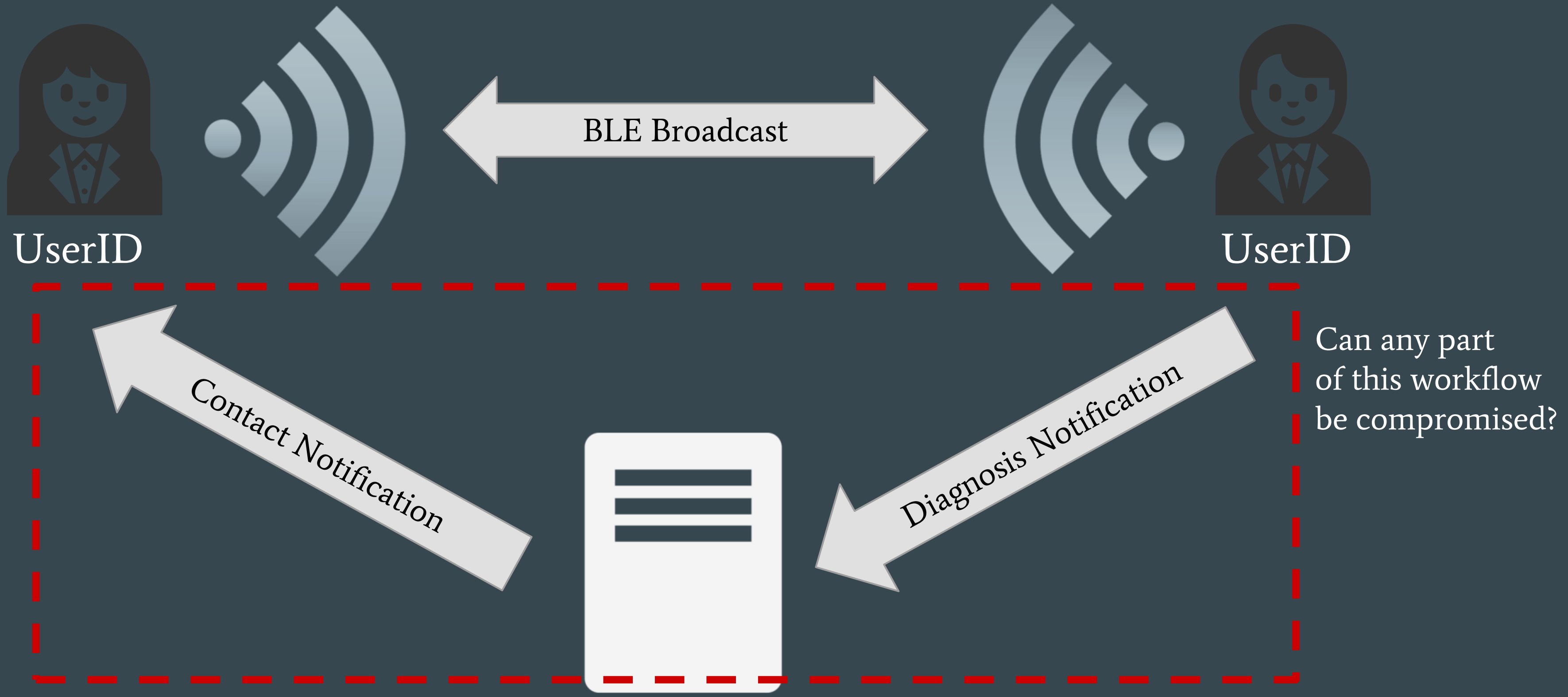
3 **Notification**

If a COVID-19 infection is confirmed, notify users who had potential contact

# General idea of BLE-based contact tracing apps



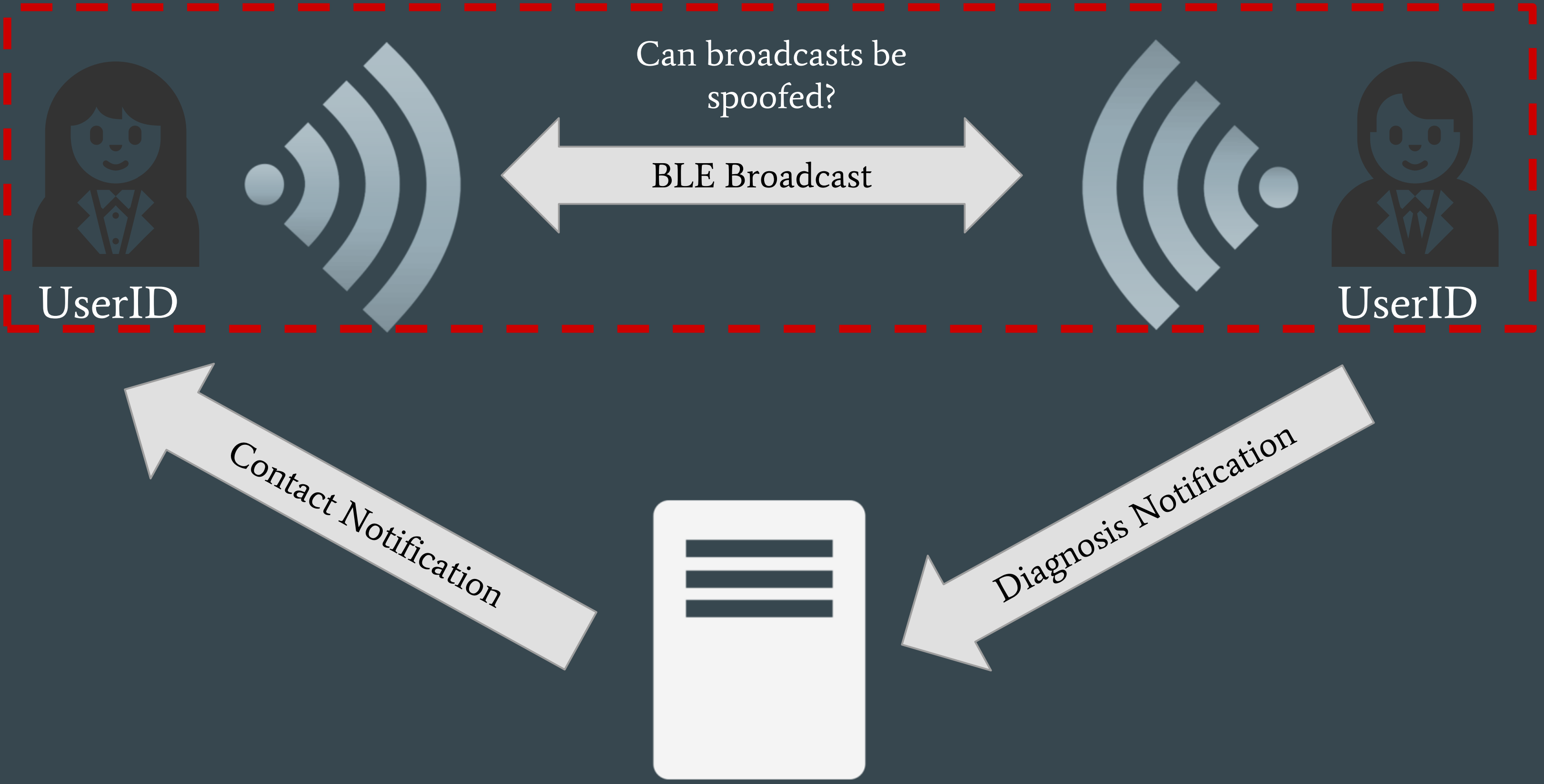
# Privacy and Security Considerations



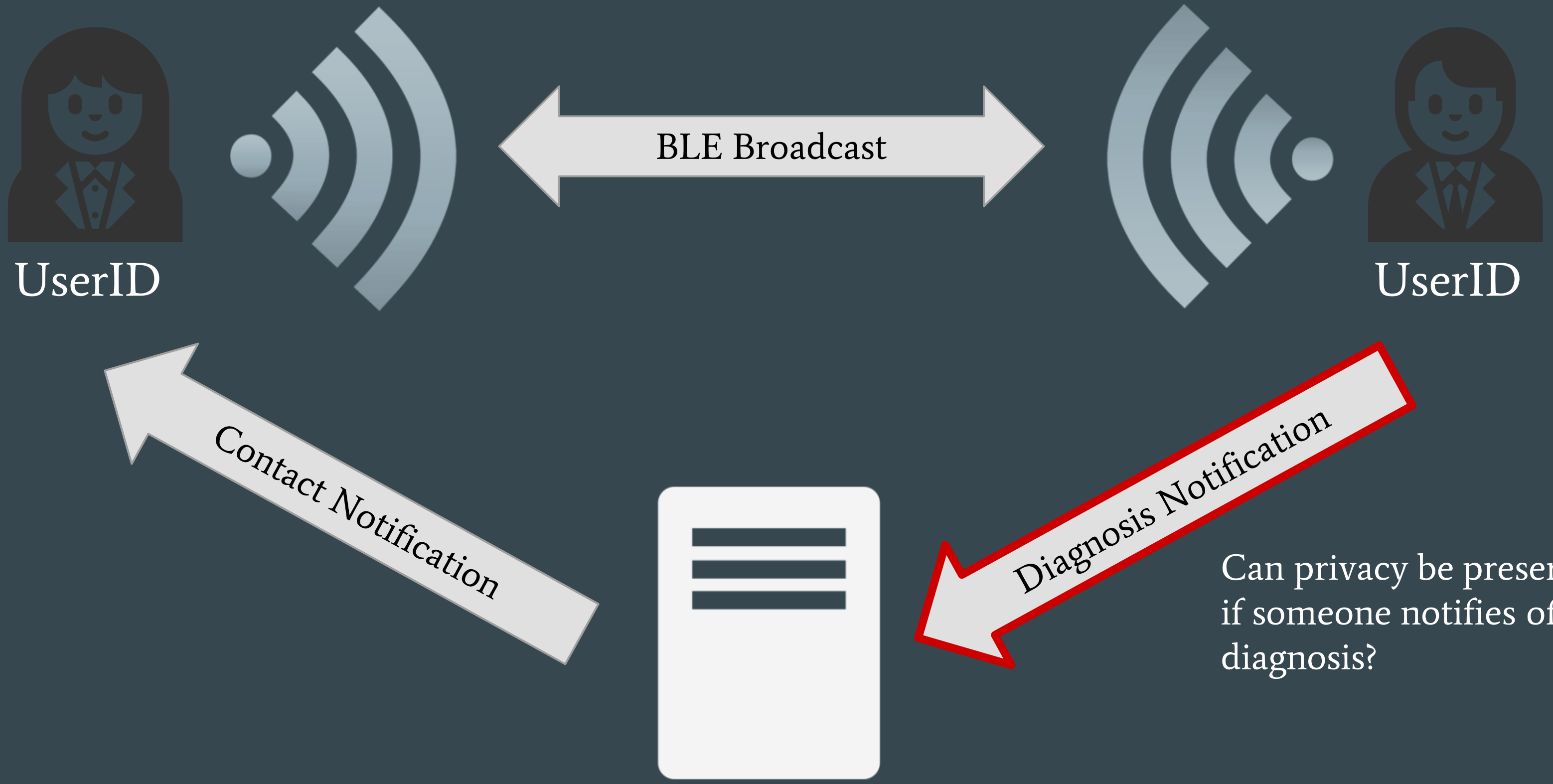
Can any part of this workflow be compromised?

# Privacy and Security Considerations

Can a malicious actor determine who is who?



# Privacy and Security Considerations



Can privacy be preserved if someone notifies of a diagnosis?

NHS Contact Tracing App (uk.nhs.nhsx.colocate version)

# Back story regarding the NHS app

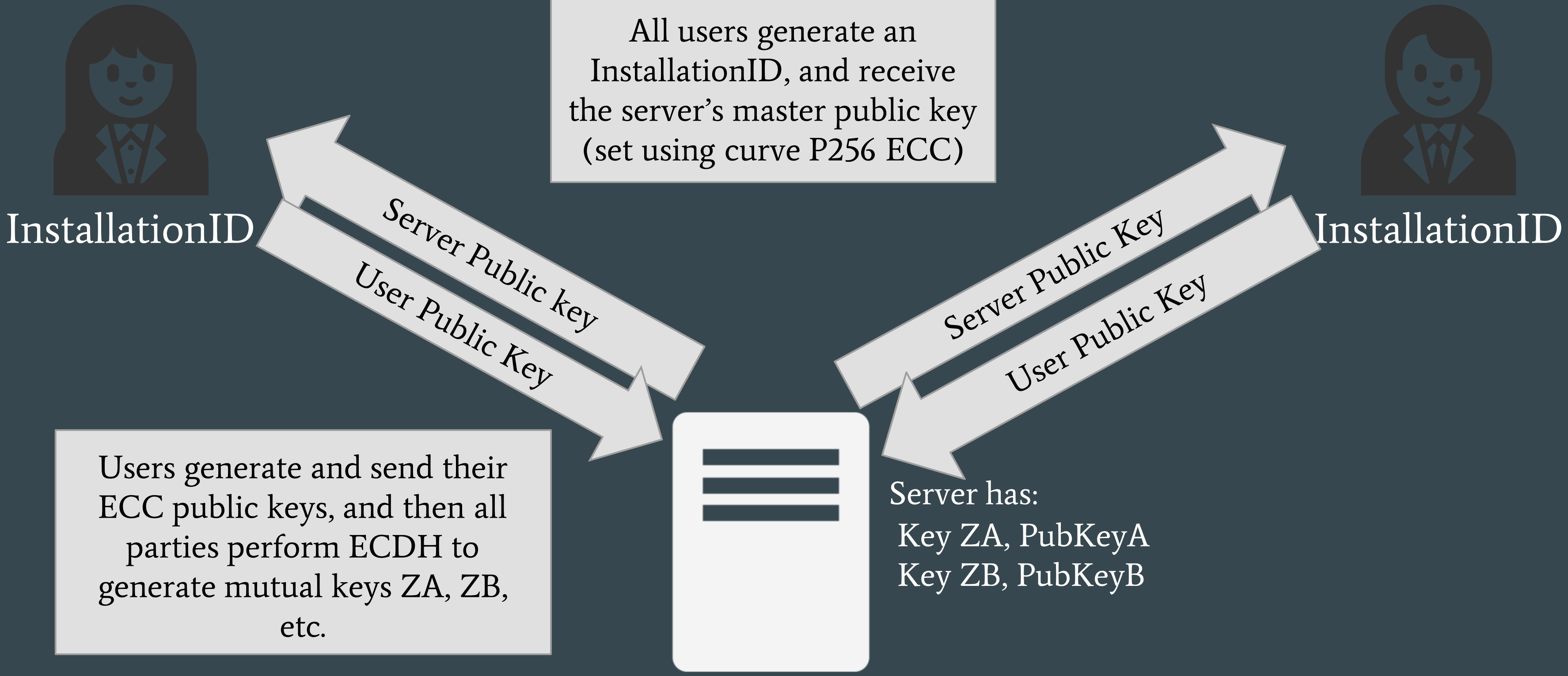
App draft design document released late April 2020

First candidate apps for Android and iOS released on 6th May 2020 for Isle of Wight users

8th May - work on second app announced, using Google-Apple model, consulted on by a Swiss cryptography firm.

# All parties get the server's master public key, generate their own keys, and perform ECDH

All users generate an InstallationID, and receive the server's master public key (set using curve P256 ECC)



Users generate and send their ECC public keys, and then all parties perform ECDH to generate mutual keys ZA, ZB, etc.

Server has:
Key ZA, PubKeyA
Key ZB, PubKeyB

# Alice derives her Broadcast Value (BV):

ZA
InstallIDA

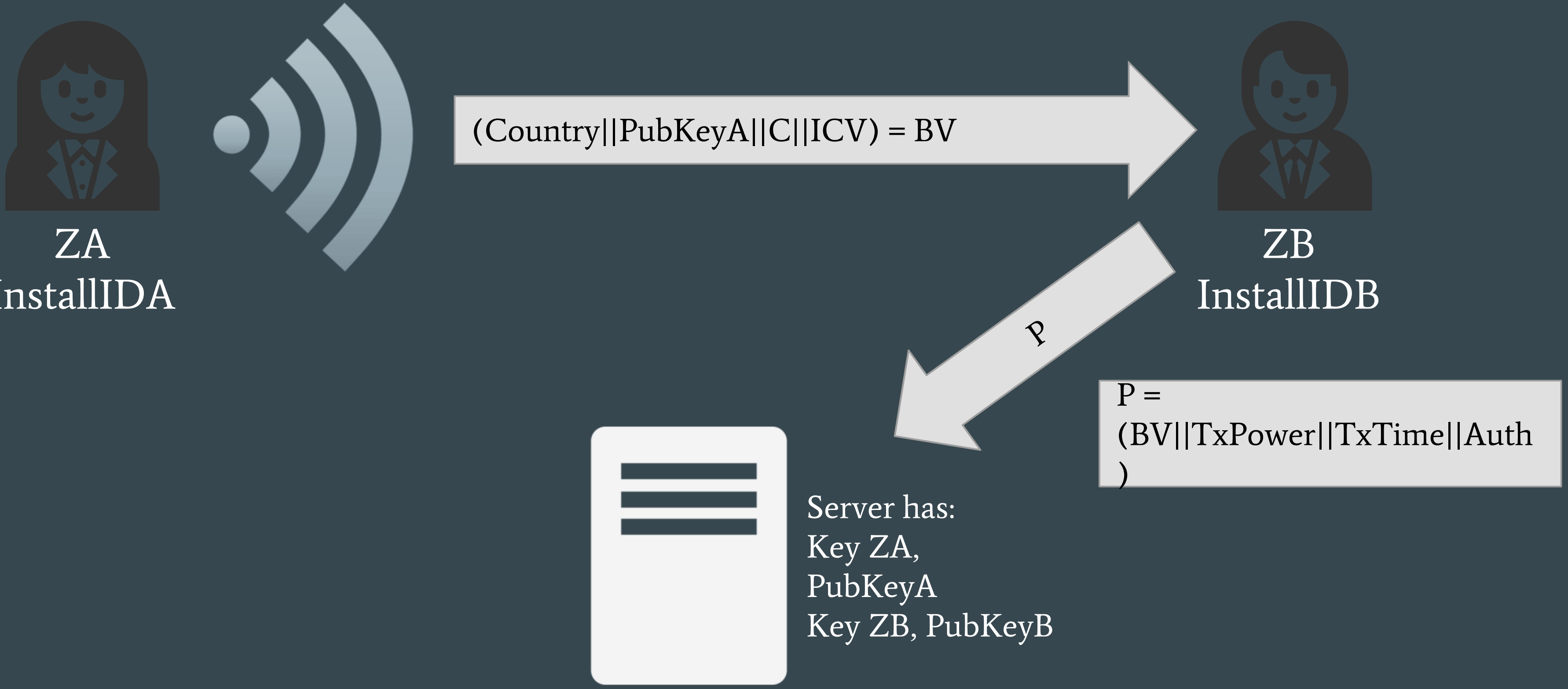
Key, IV = KDF(ZA, PubKeyA)
M = (Start||End||InstallID||Country)
Cipher,ICV=AESGCM(M, IV)
BV = (Country||PubKeyA||C||ICV)

ZB
InstallIDB

**Non-maths explanation -**
Each user generates a value BV that is their public identifier for that day.

Server has:
Key ZA,
PubKeyA
Key ZB, PubKeyB

# User derives the daily Broadcast Value and sends it out:



ZA
InstallIDA

(Country||PubKeyA||C||ICV) = BV

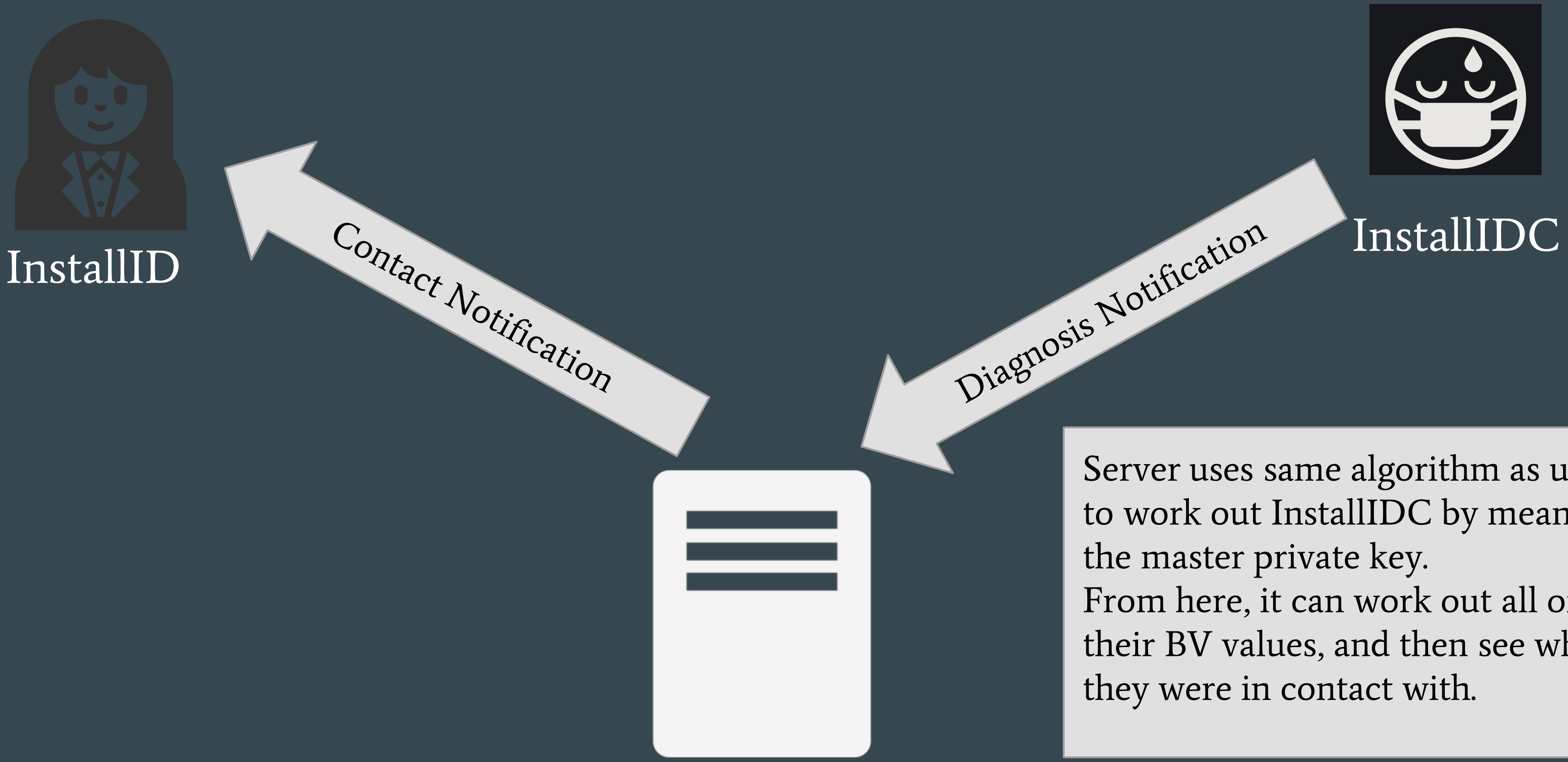
ZB
InstallIDB

P

P =
(BV||TxPower||TxTime||Auth
)

Server has:
Key ZA,
PubKeyA
Key ZB, PubKeyB

# Diagnosis Notification Workflow



InstallID

Contact Notification

Diagnosis Notification

InstallIDC

Server uses same algorithm as users to work out InstallIDC by means of the master private key.
From here, it can work out all of their BV values, and then see who they were in contact with.

# Benefits and Drawbacks of the NHSX approach

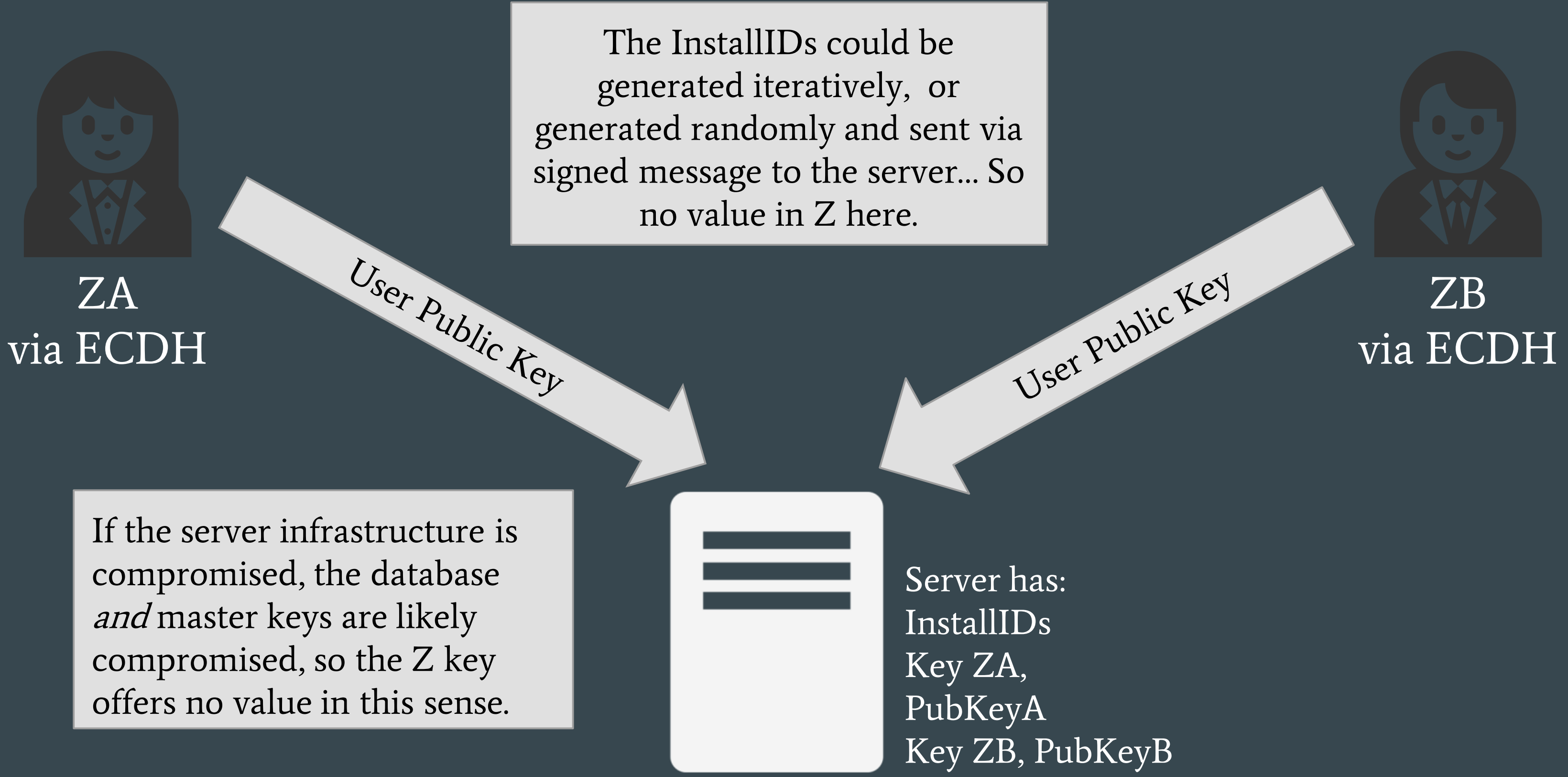
| Pros | Cons |
|---|---|
| Central management takes care of individual notifications - data isolation means no potential for delayed compromise.. | Very heavy processing required by the central services to derive and notify those who need to be after a diagnosis is declared. |
| Strong Cryptographic primitives are used (AESGCM, P256 ECC, etc.) | Single Master key for the whole system is a potential single point of failure. |
| | Much of the cryptography seems unnecessary. |
| | Broadcast Values (BVs) are static for a whole day - this could permit temporary tracking by third parties. |

The single master key design is archaic, and completely unsuitable for a modern system.

In this protocol and system, the loss of the master key would lead to total failure of the system - which is a bad design decision.

The real danger is that such a bad design could likely be replicated and copied by developers unaware of the issues, but observant that ‘it was good enough for NHSX’.

# There doesn’t seem to be any benefit of the Z key:



The InstallIDs could be generated iteratively, or generated randomly and sent via signed message to the server... So no value in Z here.

ZA
via ECDH

User Public Key

User Public Key

ZB
via ECDH

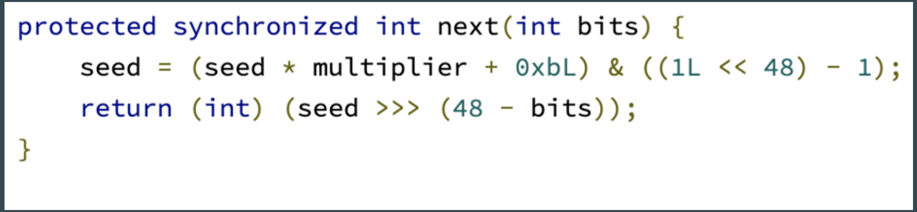
If the server infrastructure is compromised, the database *and* master keys are likely compromised, so the Z key offers no value in this sense.

Server has:
InstallIDs
Key ZA,
PubKeyA
Key ZB, PubKeyB

# Notes on the Implementation

The app makes use of the BouncyCastle cryptographic library - they claim this is for ‘point-value access to the ECC curve’.

However, the ECC implementation there makes use of java.util.Random (as opp. to java.util.SecureRandom)



```
protected synchronized int next(int bits) {
    seed = (seed * multiplier + 0xbL) & ((1L << 48) - 1);
    return (int) (seed >>> (48 - bits));
}
```

However, BouncyCastle have indicated there should be no issue. But there does not seem to be a straightforward answer as to precisely why it is used for some parts of the cryptography, when the rest of the code seems to use the better JavaX codebase for cryptography.

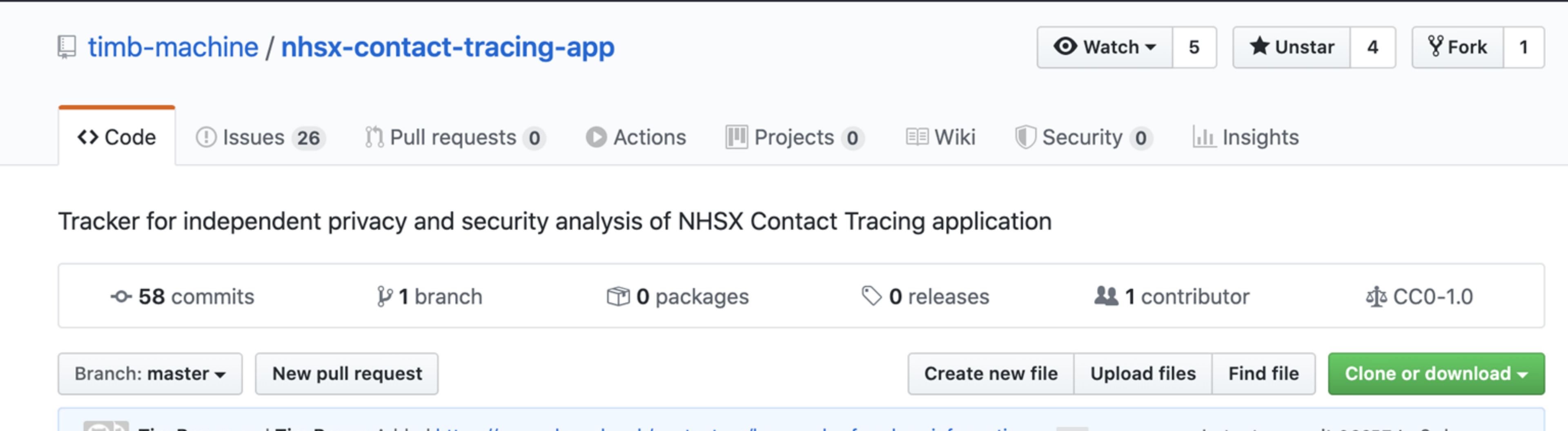
My overall assessment of the NHSX system is that it is just…

…really *odd*.

# Tim Brown’s gathering repo of resources

Tim Brown (@timb_machine) is gathering information, resources, and articles about the NHSX app(s) here:

https://github.com/timb-machine/nhsx-contact-tracing-app



Tracker for independent privacy and security analysis of NHSX Contact Tracing application

# Resources for the NHSX app

Blog posts by Prof. Bill Buchanan:

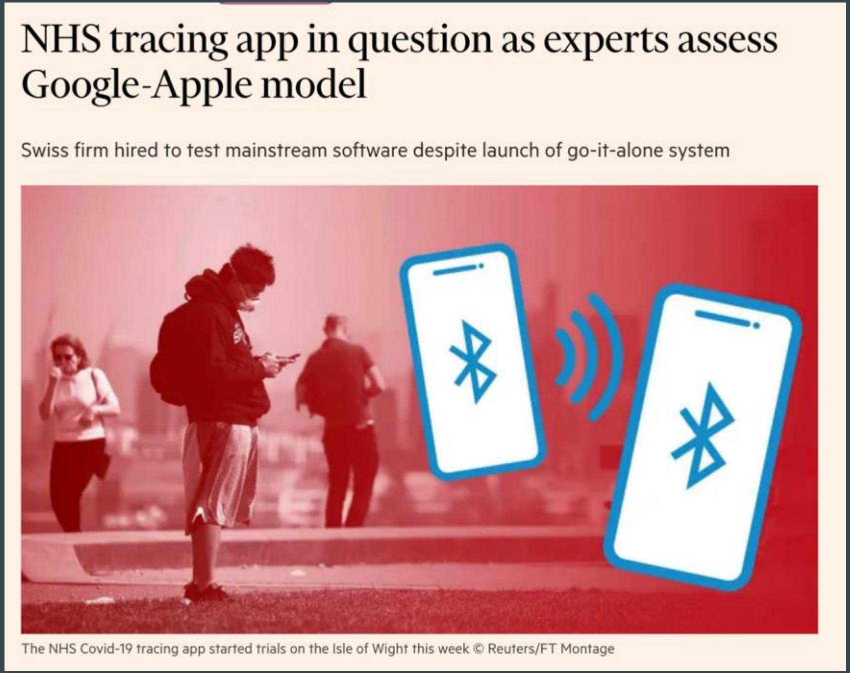
https://medium.com/@billatnapier/the-crypto-on-the-nhsx-covid-19-app-is-a-thing-of-maths-beauty-53b2434d13cb

https://medium.com/asecuritysite-when-bob-met-alice/the-uk-contact-tracing-app-version-2-69010db3394d

NCSC Documentation on the Cryptographic Security of this app:

https://www.ncsc.gov.uk/files/NHS-app-security-paper%20V0.1.pdf

Good luck to Zuhlke Engineering in working on the next version of this app - enjoy the £3.8mil.



NHS tracing app in question as experts assess Google-Apple model

Swiss firm hired to test mainstream software despite launch of go-it-alone system

The NHS Covid-19 tracing app started trials on the Isle of Wight this week © Reuters/FT Montage

BlueTrace - ref. Implementation OpenTrace

# Background to the BlueTrace Protocol

Developed by the Singaporean government for the TraceTogether coronavirus tracing app.

Works differently from the NHS app by the fact that the HA supplies each user with a traceID.

Utilises BLE in a similar way to other protocols and methods.

The open source implementation OpenTrace is not to be confused with the OpenTracing debug s/w.

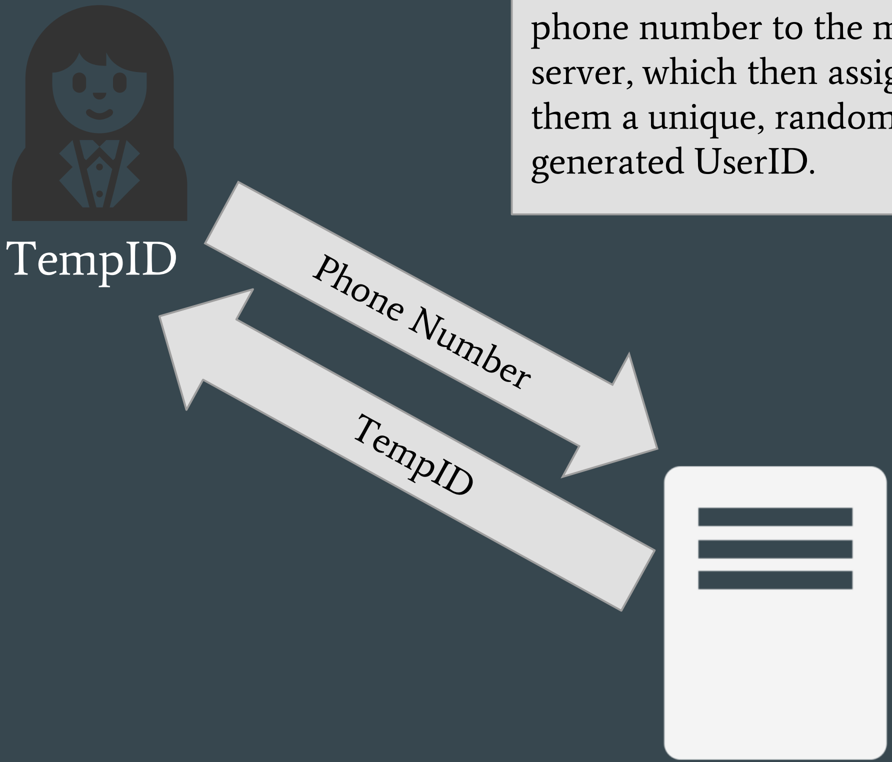
# User Registration

Each user submits their phone number to the main server, which then assigns them a unique, randomly generated UserID.

Each User is given by the server:
C,Auth =
AES256GCM(UserID||Start||End)
TempID = (C || IV || Auth)

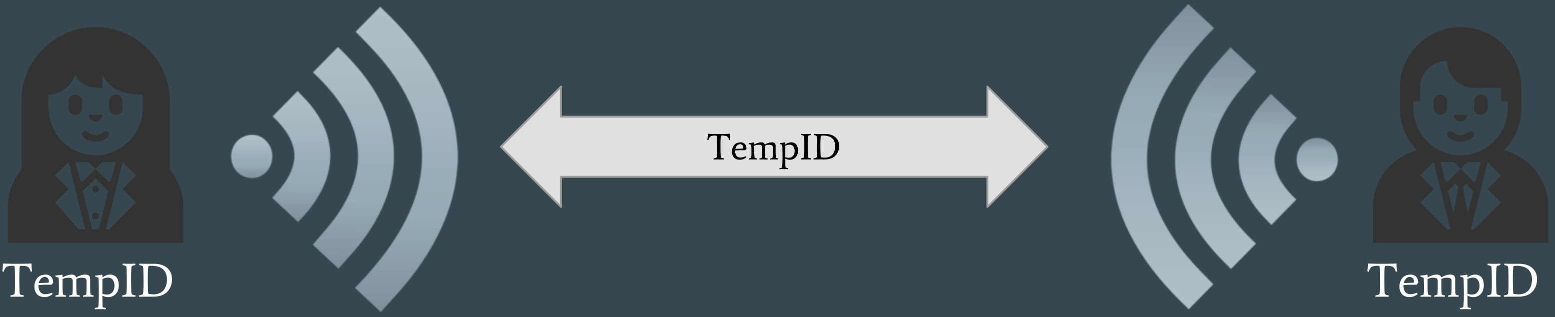
Only the HA knows the secret master AES256 key that is used to encrypt these values.

Temp IDs are time limited, as determined by the server.



Server has:
UserID
PhoneNum

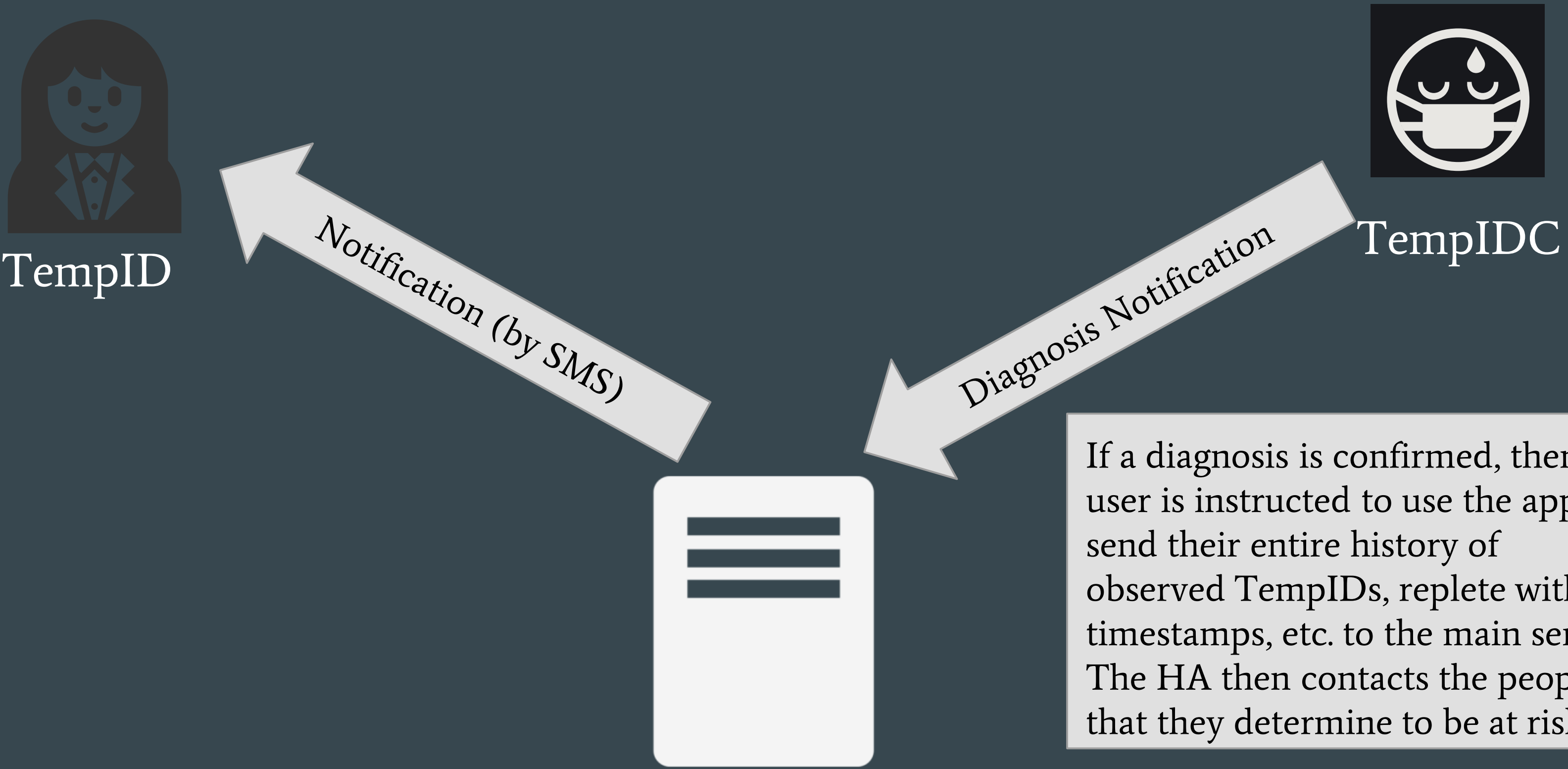
# TempIDs Recorded by Users they come into contact with



Each user logs their interactions by storing the TempIDs, the RSSI of the BLE, the make/model of the phone, timestamp, etc.

Server has:
UserID
PhoneNum
MasterAESKey

# Diagnosis Notification Workflow



If a diagnosis is confirmed, then the user is instructed to use the app to send their entire history of observed TempIDs, replete with timestamps, etc. to the main server. The HA then contacts the people that they determine to be at risk.

# Benefits and Drawbacks of the BlueTrace approach

| Pros | Cons |
|---|---|
| Complete central control make the user processing minimal - and out of band notification means the app is expendable. | Single Master key for the whole system is a potential single point of failure, as for NHSX. |
| Strong Cryptographic primitives are used (AES256GCM in particular.) | Opting out relies wholly on the central authority, which has PII for each user. |
| Users have complete control over whether they send data to the HA. (Good for privacy) | Users have complete control over whether they send data to the HA (bad for calculations and malicious activity detection). |

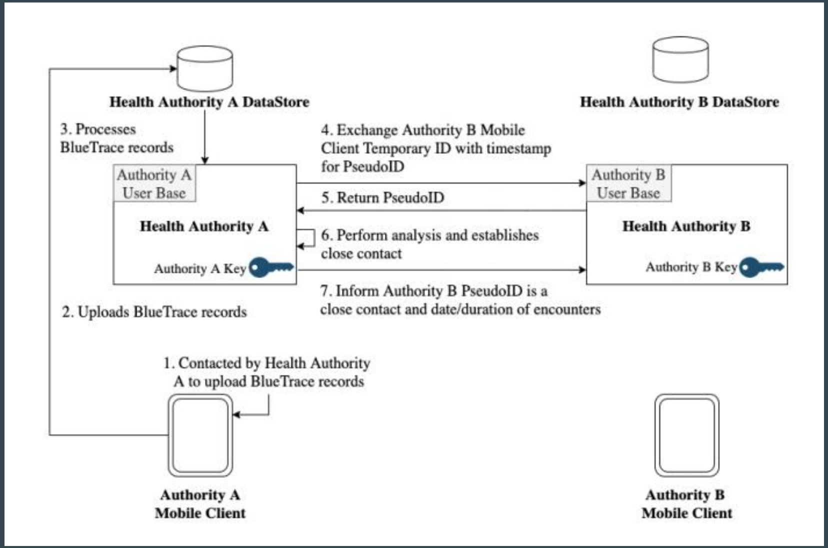
# Notes on the Implementation

The OpenTrace implementation is wholly written in Kotlin - and it should be noted that Kotlin **does not currently have** a good random number generator.

(see: https://github.com/Kotlin/KEEP/issues/184)

The Whitepaper has provision for the user to generate their UserID. At the moment they are using Java's RandomUUID through a Kotlin wrapper - this uses java.util.SecureRandom, so all is fine.

Given the centrality of storage, the whitepaper makes provision for the sharing of data between HAs.


Health Authority A DataStore
Health Authority B DataStore
3. Processes BlueTrace records
4. Exchange Authority B Mobile Client Temporary ID with timestamp for PseudoID
Authority A User Base
Health Authority A
Authority A Key
5. Return PseudoID
6. Perform analysis and establishes close contact
7. Inform Authority B PseudoID is a close contact and date/duration of encounters
Authority B User Base
Health Authority B
Authority B Key
2. Uploads BlueTrace records
1. Contacted by Health Authority A to upload BlueTrace records
Authority A Mobile Client
Authority B Mobile Client

# Resources for the BlueTrace Protocol

The BlueTrace Website:

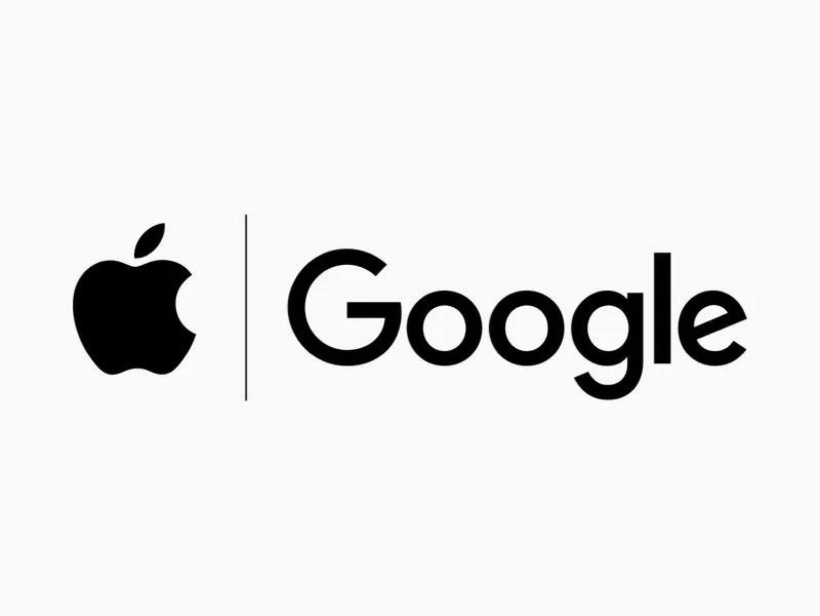
https://bluetrace.io

The BlueTrace Whitepaper:

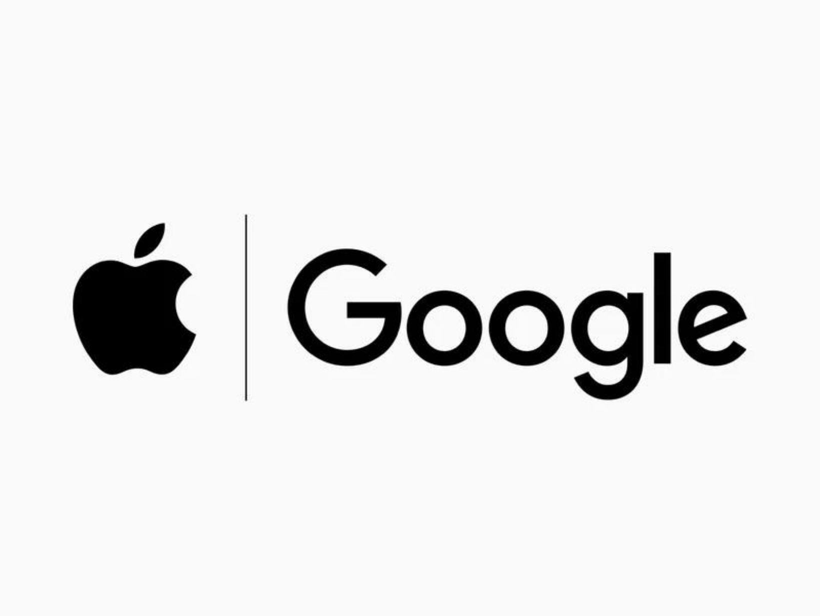
https://bluetrace.io/static/bluetrace_whitepaper-938063656596c104632def383eb33b3c.pdf

Opentrace FOSS implementation:

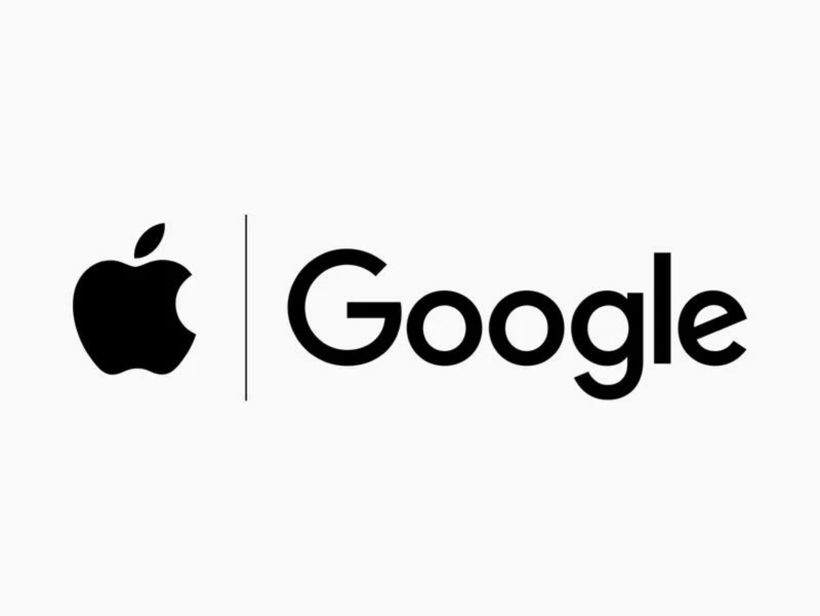
https://github.com/OpenTrace-community



# The Gapple Protocol



# The Appoogle Protocol



# The Google-Apple Protocol

# Back story regarding the Google-Apple protocol

First announced on 10th April - everyone has a little cry... https://blog.google/inside-google/company-announcements/apple-and-google-partner-covid-19-contact-tracing-technology/

Germany goes along with this technology on 26th April 2020, having been initially reticent to using it. Singapore cite this as their inspiration for their BlueTrace protocol.

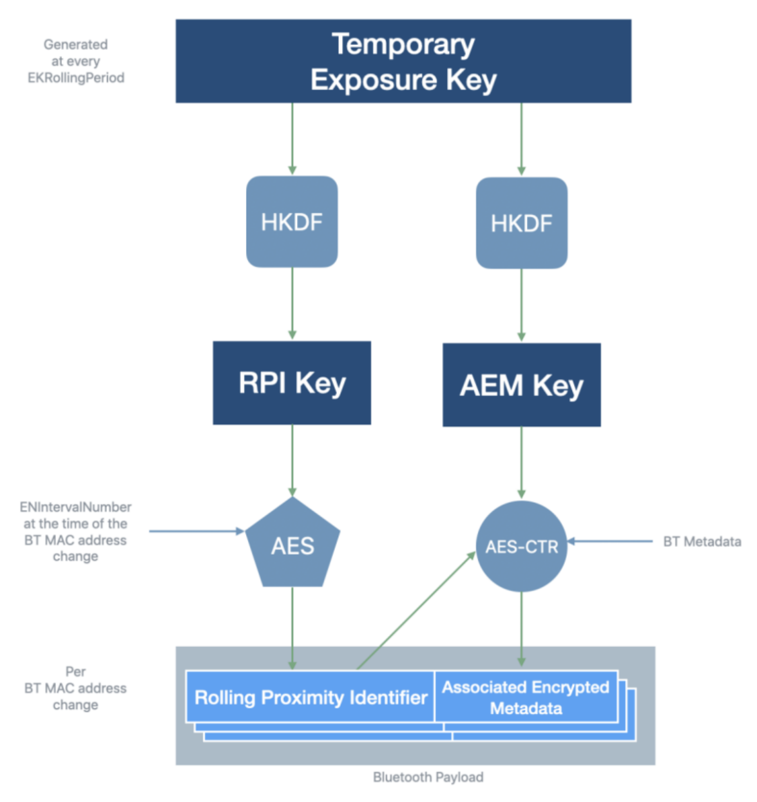
The UK sidesteps the use of the protocol on 28th April 2020 - https://healthtech.blog.gov.uk/2020/04/24/digital-contact-tracing-protecting-the-nhs-and-saving-lives/

# Overview of Key Terms

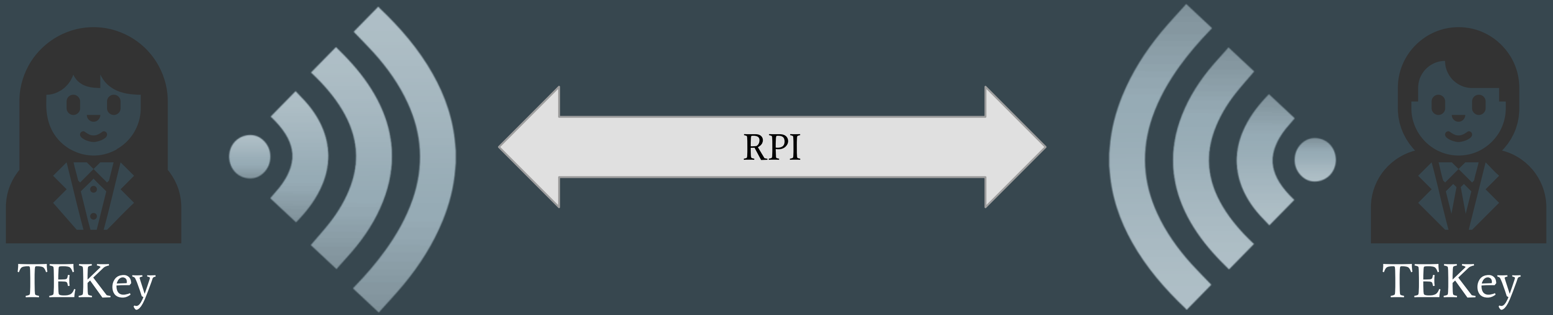
- **Exposure Notification Service** — The Bluetooth Low Energy service for detecting device proximity.
- **Temporary Exposure Key** — A key that's generated every 24 hours for privacy consideration.
- **Diagnosis Key** — The subset of Temporary Exposure Keys uploaded when the device owner is diagnosed as positive for the coronavirus.
- **Rolling Proximity Identifier** — A privacy preserving identifier derived from the Temporary Exposure Key and sent in the broadcast of the Bluetooth payload.
- **Associated Encrypted Metadata (AEM)** — A privacy preserving encrypted metadata that shall be used to carry protocol versioning and transmit (Tx) power for better distance approximation. The Associated Encrypted Metadata changes about every 15 minutes, at the same cadence as the Rolling Proximity Identifier, to prevent wireless tracking of the device.

# How Tokens are generated - fully independent of any HA Infrastructure:

The users’ devices each generate a Temporary Exposure Key (TEKey) that is fresh for each day. There is no contact with the server at all during this phase.


Generated at every EKRollingPeriod
Temporary Exposure Key
HKDF
HKDF
RPI Key
AEM Key
ENIntervalNumber at the time of the BT MAC address change
AES
AES-CTR
BT Metadata
Per BT MAC address change
Rolling Proximity Identifier
Associated Encrypted Metadata
Bluetooth Payload

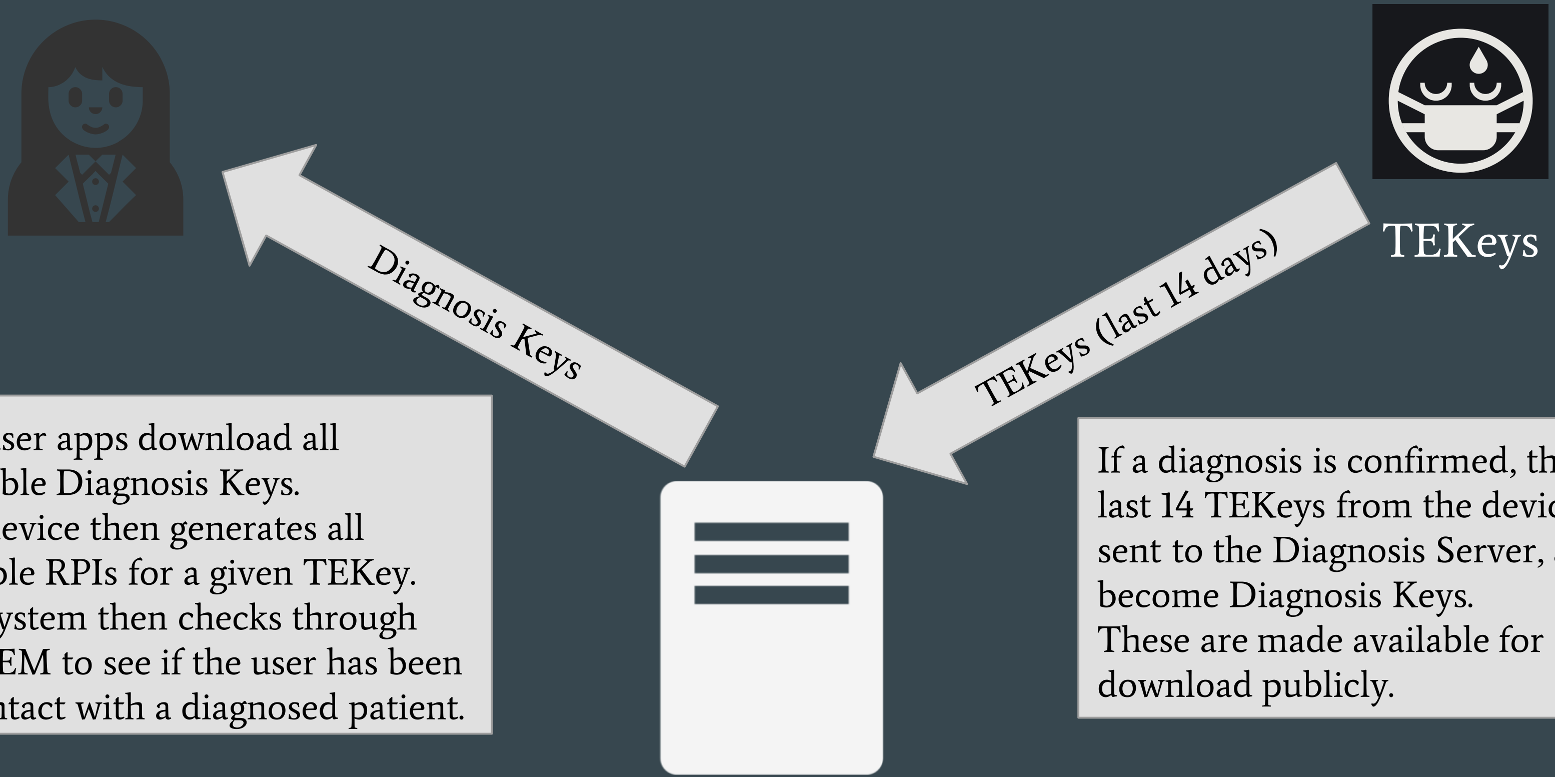
# How Tokens are generated - fully independent of any HA Infrastructure:



Each device generates Rolling Proximity Keys (RPIK) from the TEKey, which then generates a stream of Rolling Proximity Identifiers (RPI) from AES128CTM(RPIK, PaddedData)

Any detected RPIs are stored with 'Associated Encrypted Metadata', with a key that changes at the same rate as the RPIK.

# Diagnosis Notification Workflow



If a diagnosis is confirmed, then the last 14 TEKeys from the device are sent to the Diagnosis Server, and become Diagnosis Keys.
These are made available for download publicly.

The user apps download all available Diagnosis Keys.
The device then generates all possible RPIs for a given TEKey.
The system then checks through the AEM to see if the user has been in contact with a diagnosed patient.

# Benefits and Drawbacks of the BlueTrace approach

| Pros | Cons |
|---|---|
| The app relies on minimal server infrastructure. | Prone to replay attacks (but then again, so are all the others in this talk) |
| Strong privacy considerations - the app works mostly without any deliberate disclosure. | Relatively weak ciphers used (AES128-CTR) but not detrimentally so. |
| Suited for low power implementations owing to lightweight algorithms in use. | |

An interesting article about issues with this, and other, contact tracing apps:
https://eprint.iacr.org/2020/428.pdf

# Resources for the Google-Apple Protocol

Original Design Documentation site:

https://www.apple.com/covid19/contacttracing

Gavili, Yavron - “SECURITY ANALYSIS OF THE COVID-19 CONTACT TRACING SPECIFICATIONS BY APPLE INC. AND GOOGLE INC.”

https://eprint.iacr.org/2020/428.pdf

Apple-Google reference design on Github:

https://github.com/google/exposure-notifications-android

Announcement Article:

https://www.google.com/covid19/exposurenotifications/

**DP^3T** - Apple-Google protocol with more eyes and nice features

# **DP-3T:** Apple-Google 2.0? Quick overview of DP-3T

**Structurally** - the protocol is the same as the Apple-Google protocol. Users provision their own seeds that generate tokens for BLE broadcast.

**Optimised user search** - for matching observed tokens to diagnosis keys with minimal download key sizes, by means of Cuckoo filters.

**Adjustable Seed Windows** - usually set between 2-4hrs, the seeds have much shorter lives, meaning that users can choose which parts of a day's activity they with to disclose.

This preserves privacy much more effectively, whilst also helping to mitigate fake malicious retransmissions if timestamps are checked.

https://github.com/DP-3T/documents/blob/master/DP3T%20White%20Paper.pdf

# Overview of the Presented Solutions

| Criteria: | NHSX Co-locate | BlueTrace | Apple-Google | DP-3T |
|---|---|---|---|---|
| Cryptographic Primitives in Use | 😁 | 😁 | 🤨 | 😁 |
| Cryptographic Design | | | | |
| Privacy Considerations | | | | |
| Faithfulness of Implementations | | | | |

# Overview of the Presented Solutions

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| Privacy Considerations | 🤔 | 🙄 | 😊 | 😊 |
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# Overview of the Presented Solutions

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|---|---|---|---|---|
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| Cryptographic Design | 😬 | 😕 | 🙂 | 😁 |
| Privacy Considerations | 🤔 | 🙄 | 😊 | 😊 |
| Faithfulness of Implementations | 🧟‍♂️ | 💩 | 👍 | 👍 |

# Further Reading:

- **DP-3T** - https://github.com/DP-3T/documents
- **PEPP-PT NTK** - https://github.com/pepp-pt/pepp-pt-documentation
- **ROBERT** - https://github.com/ROBERT-proximity-tracing/documents
- East Cost PACT - https://pact.mit.edu/
- West Coast PACT - https://arxiv.org/abs/2004.03544
- Anonymous Collocation Discovery: Harnessing Privacy to Tame the Coronavirus - https://arxiv.org/abs/2003.13670
- Temporary Contact Numbers (TCN) - https://github.com/TCNCoalition/TCN, https://www.covid-watch.org/
- TraceSecure: Towards Privacy Preserving Contact Tracing - https://arxiv.org/abs/2004.04059

# Acknowledgements

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# Questions or Comments?