Privacy of COVID-19 Contact Tracing Apps

Zhiqiang Lin

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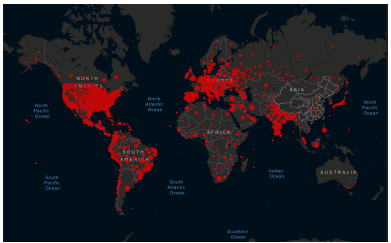
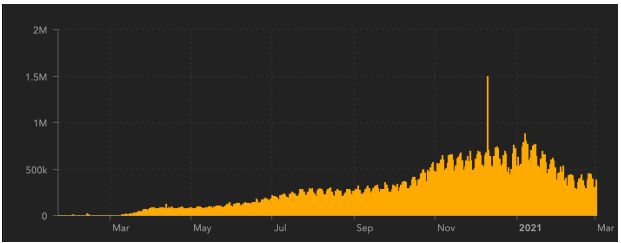
3/10/2021

Outline

Outline

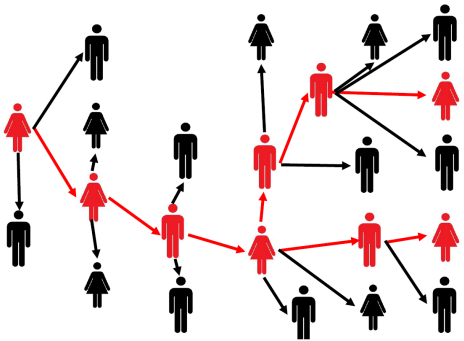
COVID-19 Pandemic





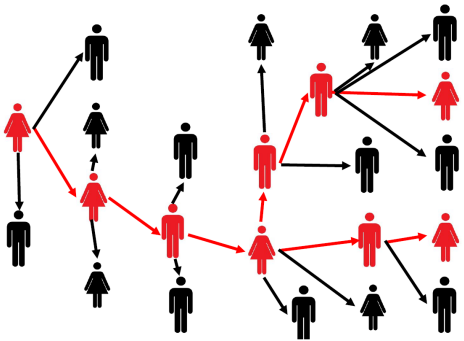
Source: https://coronavirus.jhu.edu/map.html (117 Million Global Cases, and 2.6 Million Global Death)

Contact Tracing



Source: https://www.aegis.com/contact-tracing-company/

Contact Tracing



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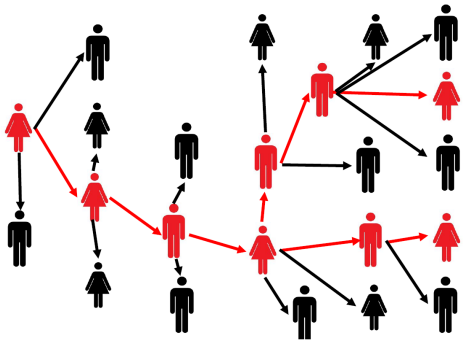
Manual Contact Tracing

- Limited Scalability
- Potential Delays

Contact Tracing



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Manual Contact Tracing

- Limited Scalability
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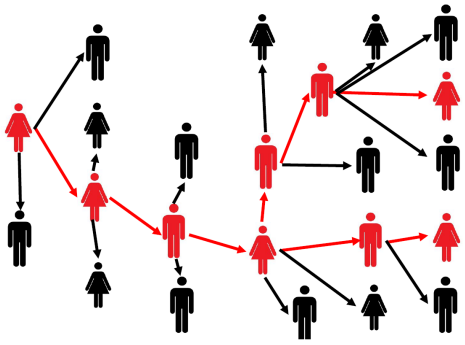
Digital Contact Tracing

- Location Tracing
  - Continuous Coordinates-based Data (e.g., GPS)
  - Discrete Places-based Data (e.g., QR code check in)

Contact Tracing



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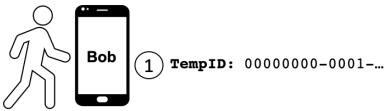
Manual Contact Tracing

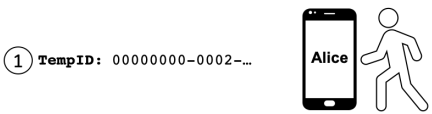
- Limited Scalability
- Potential Delays

Digital Contact Tracing

- Location Tracing
  - Continuous Coordinates-based Data (e.g., GPS)
  - Discrete Places-based Data (e.g., QR code check in)
- **Proximity Tracing** (e.g., w/ Bluetooth Low Energy)

How Does BLE-based Contact Tracing Work?

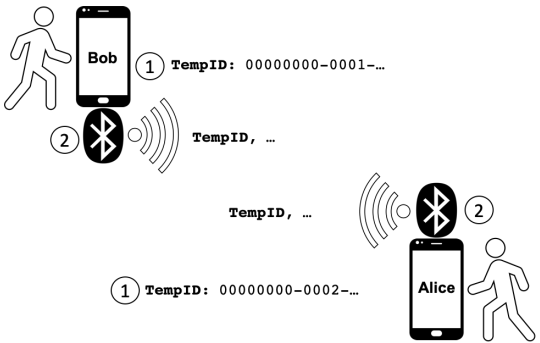




Workflow

1. App generates temp ID

How Does BLE-based Contact Tracing Work?



The Workflow

1. App generates temp ID
2. Phone broadcasts temp ID

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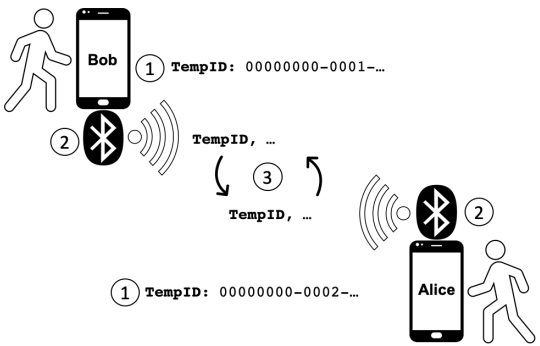

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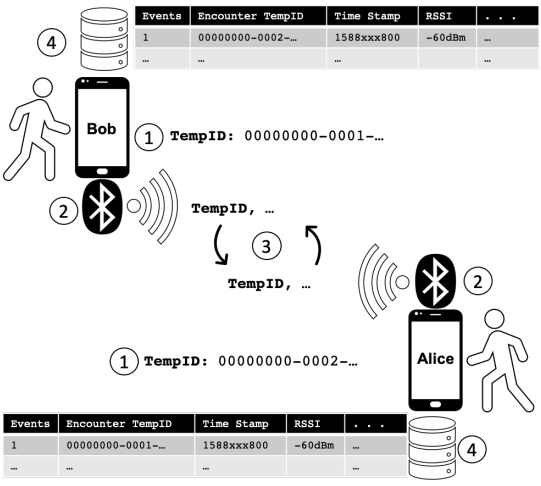
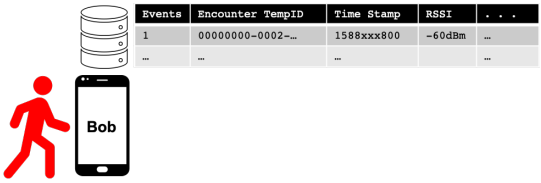


The Workflow

1. App generates temp ID
2. Phone broadcasts temp ID
3. Apps exchange temp IDs, ...
4. App stores contact event locally

Notification Mechanisms of BLE-based Contact Tracing



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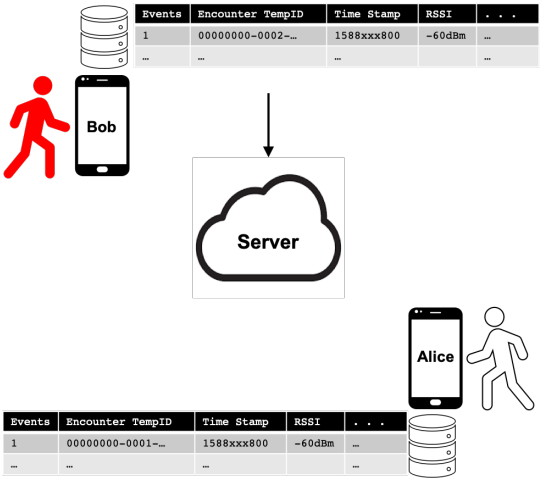

I. Centralized System

- Infected user uploads contact events

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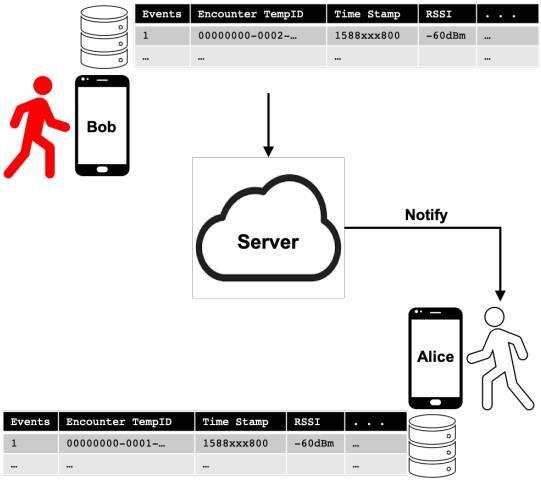

I. Centralized System

- Infected user uploads contact events
- Server notifies users with high infection risk

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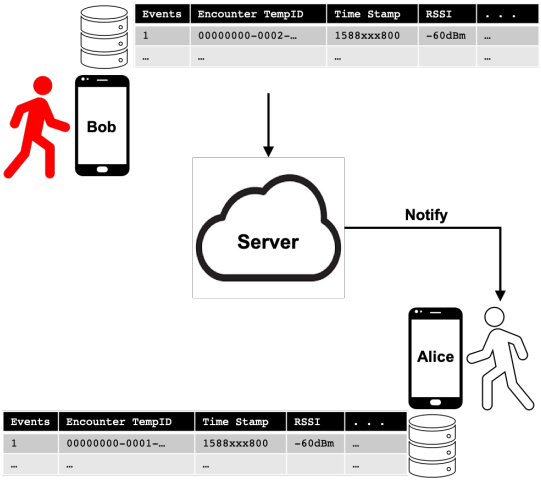

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Protocol

BlueTrace [blua]
PEPP-PT [HOM]

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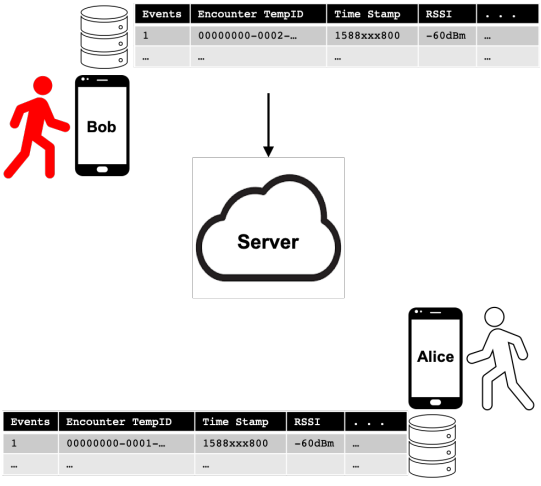

II. Decentralized System

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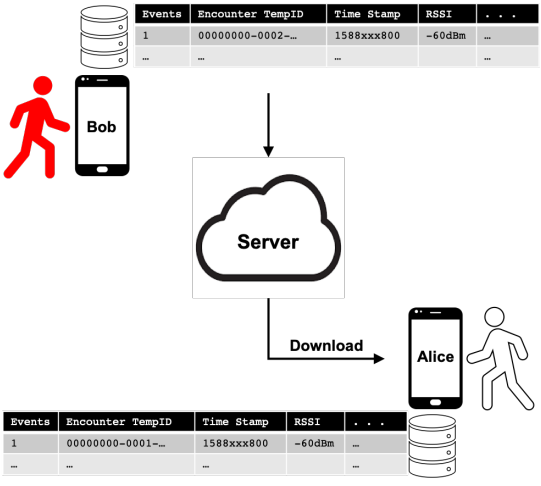

II. Decentralized System

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- All users downloads contact events of infected user periodically

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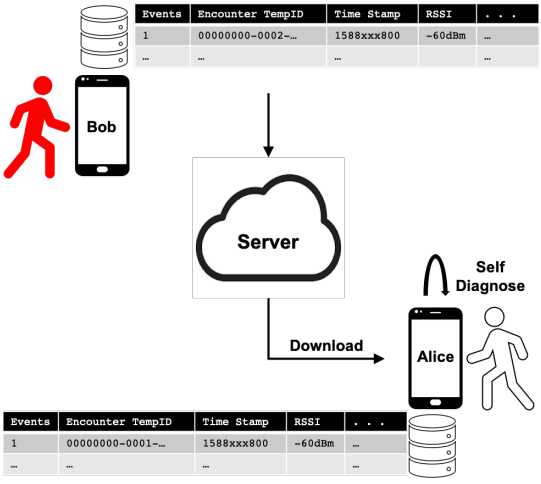

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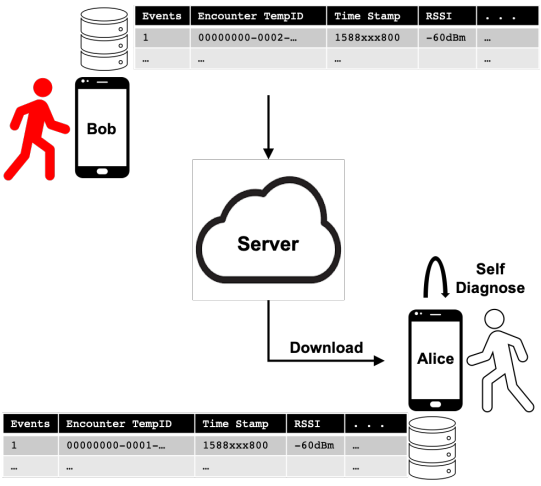

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Protocol

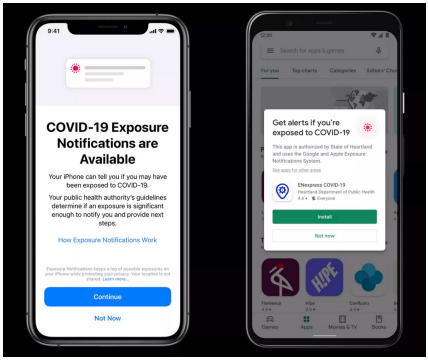
DP3T [TPH+20], TCN [NPL+]
Apple&Google [App]

Outline

Apple/Google's Exposure Notification Protocol

Exposure Notification

- A decentralized protocol

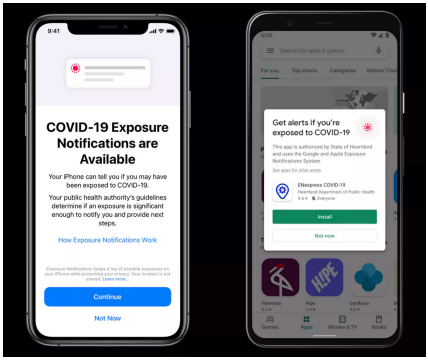


Source: [exf]

Apple/Google's Exposure Notification Protocol

Exposure Notification

- A decentralized protocol
- Implemented at the OS level



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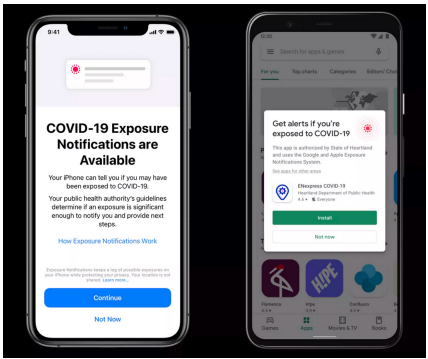
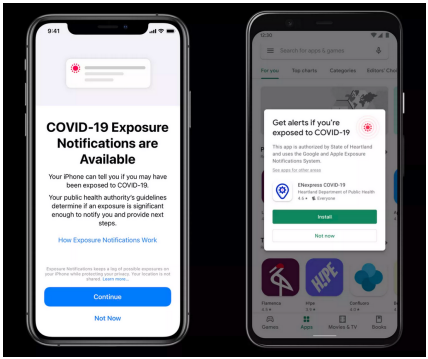


Source: [exf]

Apple/Google's Exposure Notification Protocol

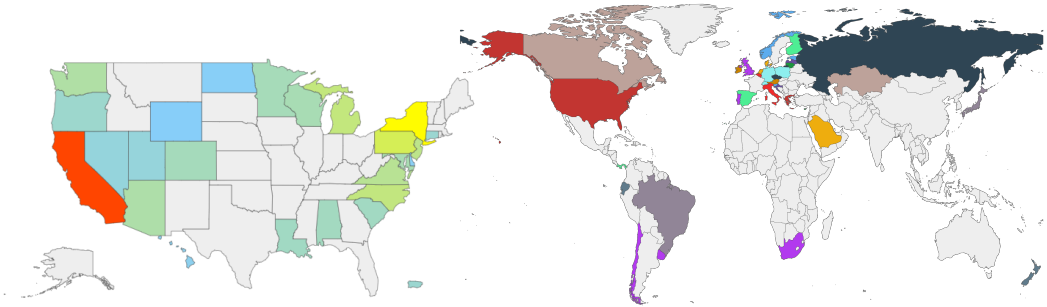
Exposure Notification

- A decentralized protocol
- Implemented at the OS level
- Released in May 2020
- Support iOS$\geq$13.5, Android$\geq$6.0



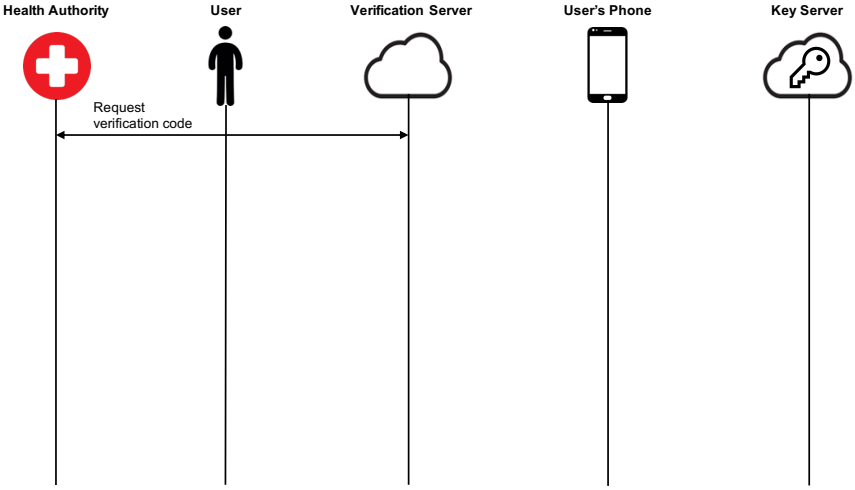
Source: [exf]

Apps Built atop Exposure Notification Protocol (38 Countries and 65 apps)



Source:https://www.xda-developers.com/google-apple-covid-19-contact-tracing-exposure-notifications-api-app-list-countries/

Exposure Notification Protocol Workflow



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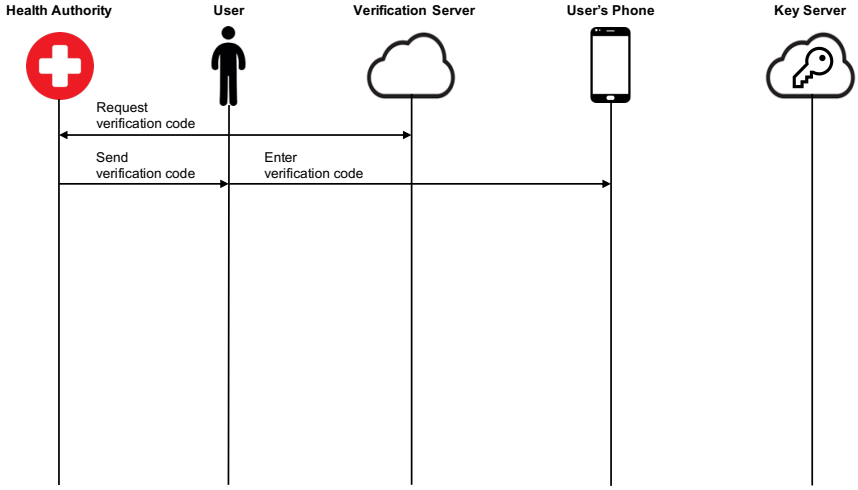

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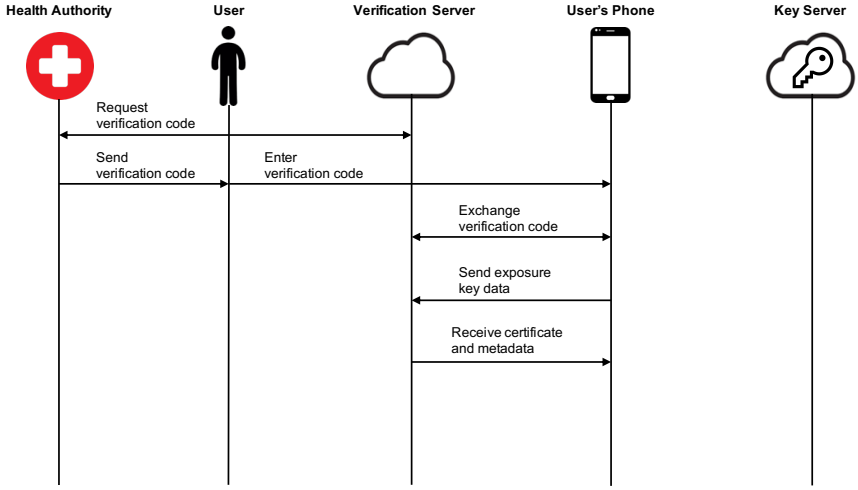

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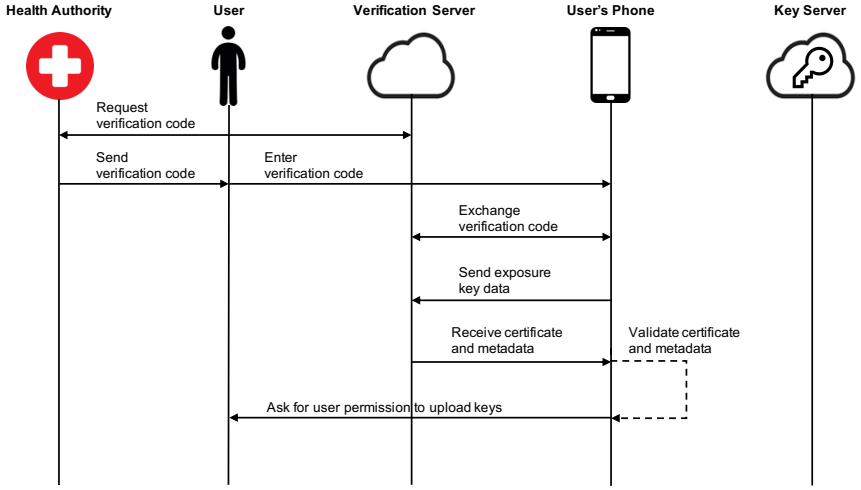

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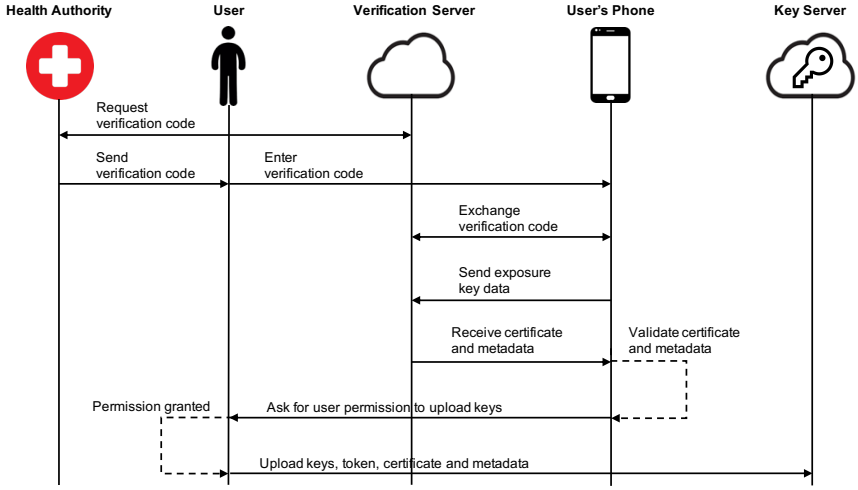

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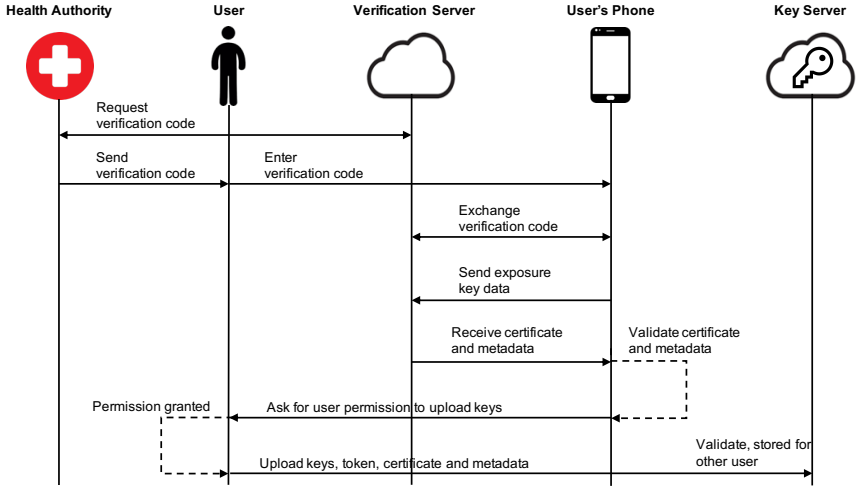

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Outline

Security Issues in BLE-based Contact Tracing Apps

(I) Security Issues

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- Cryptographic weakness [DR20]

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(I) Security Issues

- Cryptographic weakness [DR20]
- Replay attacks [Roc20]

Privacy and Accuracy Issues in BLE-based Contact Tracing Apps

(II) Privacy: Sensitive Data Leakage

- BLE Technique
  - Tracking BLE Devices
  - Fingerprinting Apps
- Contact Tracing System
  - User Identity
  - Sensitive Data Collection

(III) Accuracy: Unreliable RSSI

- Internal Affecting Factors
  - Hardware Specifications
  - Software Configurations
- External Affecting Factors
  - Invisible Radio Waves
  - Visible Physical Obstacles

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(II) Privacy: Sensitive Data Leakage

- BLE Technique
  - **Tracking BLE Devices**
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Locating BLE devices with Fingerprinted Apps [ZWLZ19]

Privacy and Accuracy Issues in BLE-based Contact Tracing Apps

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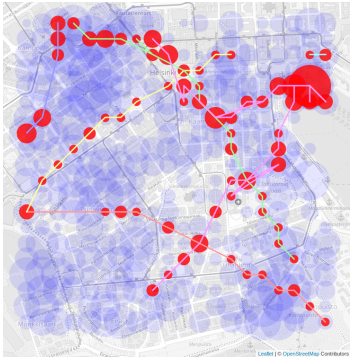
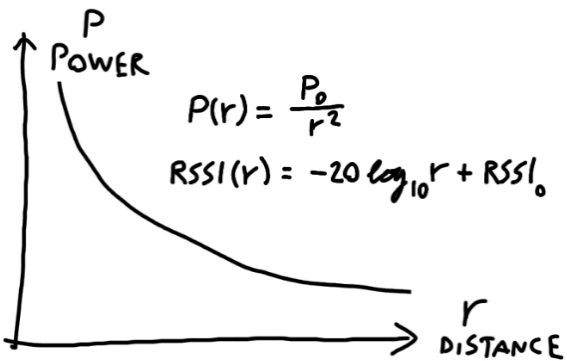


BLE contact tracing sniffer PoC [ose]

Privacy and Accuracy Issues in BLE-based Contact Tracing Apps



Source: **Why to use Bluetooth for contact tracing? [Sei]**

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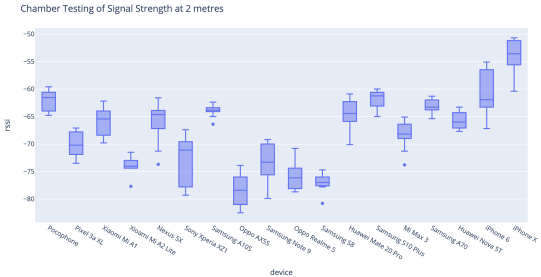

Source: **Opentrace Calibration [ope]**

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Privacy and Accuracy Issues in BLE-based Contact Tracing Apps

```
1 . . .
2 AdvertiseSettings$Builder v0 = new AdvertiseSettings$Builder()
                                     .setAdvertiseMode(1)
                                     .setConnectable(false)
                                     .setTxPowerLevel(3).build();

3 AdvertiseData$Builder v1 = new AdvertiseData$Builder()
                                 .addServiceUuid(GUUID)
                                 .addServiceData(DATAUUID, DATA)
                                 .build();
4 . . .
5 static double calculateDistance(int rssi) {
6     if(rssi != 0) {
7         double v0 = (((double)rssi)) * 1 / -69;
8         if(v0 < 1) {
9             return Math.pow(v0, 10);
10        }
11        return Math.min(
                      Math.pow(v0, 7.7095) * 0.89976 + 0.111,
                      20);
12    }
13    return 0;
14 }
15 . . .
```

(III) Accuracy: Unreliable RSSI

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  - Hardware Specifications
  - **Software Configurations**
- External Affecting Factors
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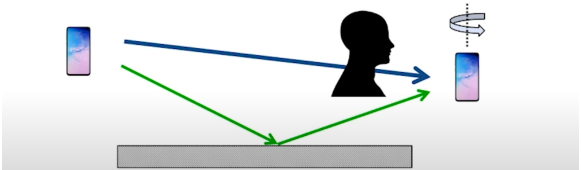
Privacy and Accuracy Issues in BLE-based Contact Tracing Apps

But lots of sources of error

- **Human Body absorbs! ~ 15 dB**
- **Signal Multipath & environmental effects ~ 10 dB**
- **Antenna Orientation & Gain ~ 5 dB**
- **Device specific behavior ~ 15 dB**



Source: **Swarun Kumar's Presentation in imPACT 2020 [imP]**

(III) Accuracy: Unreliable RSSI

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  - Hardware Specifications
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- External Affecting Factors
  - **Invisible Radio Waves**
  - **Visible Physical Obstacles**

Our Measurement Study: COVID-19 Mobile App Collection

Figure: Distribution of 41 contact tracing apps as of June 15, 2020.

Our Findings: 20 BLE-based Contact Tracing Apps

App	Country	C1	C2	C3	C4	P1	P2	F1	F2
COVIDSafe	Australia	0	✔	0	3	✔	✗	✔	Static
Stop Corona	Austria	0	✔	-	3	✗	✔	✗	Dynamic
BeAware	Bahrain	0	✔	-/-	2	-	✗	✔	Dynamic
CoronApp	Colombia	0	✔	0/1	3	✔	✗	✔	Static
eRouska	Czech	0	✗	0/0	2	✗	✗	✗	Static
Aarogya Setu	India	0	✔	1/0	0	✗	✗	✗	Static
StopKorona	North Macedonia	0	✗	-/1	3	✗	✔	✗	Static
MyTrace	Malaysia	0	✔	1	1	✗	✗	✗	Dynamic
CovidRadar	Mexico	0	✔	-/0	0	✗	✗	✗	Dynamic
Smittestopp	Norway	0	✔	0	2	✗	✗	✗	Static
ProteGO	Poland	0	✔	-/1	2	✗	✗	✗	Dynamic
Ehteraz	Qatar	0	✗	0/0	2	✗	✗	✗	Dynamic
Trace Together	Singapore	0	✔	0/1	3	✗	✗	✗	Static
MorChana	Thailand	0	✔	-	2	✗	✔	✗	Static
Hayat Eve Sigar	Turkey	0	✔	0	1	✗	✗	✗	Static
NHS COVID-19 App	UK	0	✔	1/1	2	✗	✗	✗	Static

C1: Broadcast timeout, C2: Connectable, C3: Device name, C4: TxPower, P1: Manufacture Data, P2: Service Data, F1: Manufacture ID, F2: Service UUID

Our Findings: 20 BLE-based Contact Tracing Apps

Findings

- 10 apps broadcast static UUIDs that enable app fingerprinting [ZWLZ19] [CC19].

App	Country	C1	C2	C3	C4	P1	P2	F1	F2
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CoronApp	Colombia	0	✔	0/1	3	✔	✗	✔	Static
eRouska	Czech	0	✗	0/0	2	✗	✗	✗	Static
Aarogya Setu	India	0	✔	1/0	0	✗	✗	✗	Static
StopKorona	North Macedonia	0	✗	-/1	3	✗	✔	✗	Static
MyTrace	Malaysia	0	✔	1	1	✗	✗	✗	Dynamic
CovidRadar	Mexico	0	✔	-/0	0	✗	✗	✗	Dynamic
Smittestopp	Norway	0	✔	0	2	✗	✗	✗	Static
ProteGO	Poland	0	✔	-/1	2	✗	✗	✗	Dynamic
Ehteraz	Qatar	0	✗	0/0	2	✗	✗	✗	Dynamic
Trace Together	Singapore	0	✔	0/1	3	✗	✗	✗	Static
MorChana	Thailand	0	✔	-	2	✗	✔	✗	Static
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Findings

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- Two apps store fixed user identifiers in their readable characteristics, which allows tracking of a specific user

App Name	Type	UUID	Semantics
COVIDSafe	S	Random	Monitoring Service
	C	B82AB3FC...	ID, model, version, RSSI
CoronApp	S	92959161...	Monitoring Service
	C	76FE5EB0...	ID, model, version, RSSI
eRouska	S	1440DD68...	
	C	9472FBDE...	Current ID
Aarogya Setu	S	45ED2B0C...	
	C	8D75EA37...	Unique ID
	C	91567DDF...	PinggerValue
	C	5CA2B7AE...	Device OS
StopKorona	S	0000FF01...	
Smittestopp	S	E45C1747...	
	C	64B81E3C...	
ProteGO	C	Random	ID, model, version, RSSI
Trace Together	S	B82AB3FC...	
	C	117BDD58...	ID, model, version, RSSI
MorChana	S	000086E0...	
Hayat Eve Sigar	S	D28ABA6E...	
	C	98023D4C...	Exchange Message
	C	3A8E1D5C...	User ID
NHS COVID-19 App	S	C1F5983C...	
	C	D802C645...	Keep alive
	C	85BF337C...	Identity

Our Findings: 20 BLE-based Contact Tracing Apps

Findings

- 10 apps broadcast static UUIDs that enable app fingerprinting [ZWLZ19] [CC19].
- Two apps store fixed user identifiers in their readable characteristics, which allows tracking of a specific user
- Contact tracing apps often collect other device information (e.g., system version, and phone model), possibly for increasing the estimation precision [Blub] [ZWL+20]

App	ID	SysVer.	Model	Orientation	UI Info.	Build
BeAware Bahrain	✔	✔				
CovTracer	✔	✔	✔			✔
eRouska	✔			✔		
StopCovid			✔	✔	✔	
GH COVID-19 Tracker		✔	✔	✔	✔	✔
Rakning C-19		✔	✔		✔	✔
Aarogya Setu		✔				
HaMagen	✔	✔	✔	✔	✔	
CovidRadar.mx	✔	✔	✔			
StopKorona	✔	✔	✔	✔	✔	
ProteGO	✔	✔		✔		
Trace Together		✔		✔		
NHS COVID-19 App		✔	✔			
CoronApp	✔	✔	✔			

Analysis of The Accuracy of Proximity Measurement

App Name	RSSI	Affecting Factors: Software	Affecting Factors: Hardware	Others
COVIDSafe	●	Level of TxPower	modelP; modelC	
CoronApp	●	Level of TxPower	modelP; modelC	
eRouska	●			
StopCovid	●		BuildNumber; Version Manufacturer; Model	
Aarogya Setu	●	Level of TxPower		GPS
StopKorona	●			
Smittestopp	●	Level of TxPower		GPS, Altitude Speed, Accuracy
Ehteraz	●			GPS
TraceTogether	●	Level of TxPower	modelP; modelC	
Mor Chana	●			
NHS COVID-19 App	●	Level of TxPower		
Healthy Together	●	Level of TxPower		
Bluezone	●	Level of TxPower		
CovidSafePaths	●	Level of TxPower		
Covid Community Alert	●		BuildNumber; Version Manufacturer; Model	
Coalition Network	●			

Table: Data Collected for Proximity Measurement.

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Bluezone	●	Level of TxPower		
CovidSafePaths	●	Level of TxPower		
Covid Community Alert	●		BuildNumber; Version Manufacturer; Model	
Coalition Network	●			

Table: Data Collected for Proximity Measurement.

Accuracy

- Less than half apps use TxPower

Analysis of The Accuracy of Proximity Measurement

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Coalition Network	●			

Table: Data Collected for Proximity Measurement.

Accuracy

- Less than half apps use TxPower
- Only a quarter apps may tune for limited phone models

Analysis of The Accuracy of Proximity Measurement

App Name	RSSI	Affecting Factors: Software	Affecting Factors: Hardware	Others
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Covid Community Alert	●		BuildNumber; Version Manufacturer; Model	
Coalition Network	●			

Table: Data Collected for Proximity Measurement.

Accuracy

- Less than half apps use TxPower
- Only a quarter apps may tune for limited phone models
- None environmental factors consideration

Outline

Discussion

Privacy: Sensitive Data Leakage

- BLE Technique
  - Tracking BLE Devices
  - Fingerprinting Apps
- Contact Tracing System
  - User Identity
  - Sensitive Data Collection

Accuracy: Unreliable RSSI

- Internal Affecting Factors
  - Hardware Specifications
  - Software Configurations
- External Affecting Factors
  - Invisible Radio Waves
  - Visible Physical Obstacles

Discussion

- **Privacy**
  - Centralized vs. Decentralized
  - User/Patient identity
  - Sensitive data collection

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GH COVID-19 Tracker		✔	✔	✔	✔	✔
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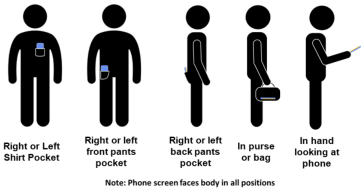
CovidRadar.mx	✔	✔	✔			
StopKorona	✔	✔	✔	✔	✔	
ProteGO	✔	✔		✔		
Trace Together		✔		✔		
NHS COVID-19 App		✔	✔			
CoronApp	✔	✔	✔			

Discussion

- **Privacy**
  - Centralized vs. Decentralized
  - User/Patient identity
  - Sensitive data collection
- **Accuracy**
  - A high rate of false positives would result in users losing trust [Imm20]
  - Duration of exposure

Discussion

- **Privacy**
  - Centralized vs. Decentralized
  - User/Patient identity
  - Sensitive data collection
- **Accuracy**
  - A high rate of false positives would result in users losing trust [Imm20]
  - Duration of exposure
  - Tuning accuracy is challenging (*e.g.*, different positions)



PACT Data Collection Protocol [PAC20]

Discussion

Optimistic Prediction [O'N20]

- Oxford University: digital contact tracing may work at much lower levels of usage, less than 60% as previous suggested

No, coronavirus apps don't need 60% adoption to be effective

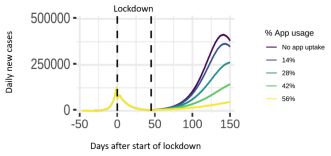
Digital contact tracing may work at much lower levels of usage than most people think, thanks to a misunderstanding of the research.

by **Patrick Howell O'Neill** June 5, 2020

MIT Technology Review

"There's been a lot of misreporting around efficacy and uptake … suggesting that the app only works at 60%—which is not the case," says Andrea Stewart, a spokeswoman for the Oxford team. In fact, she says, "it starts to have a protective effect" at "much lower levels."

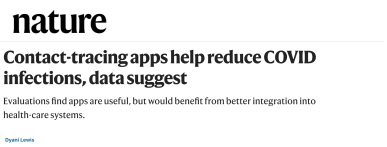
If we reduce potentially infectious contacts by 20%, and 56% of the population use the app, we can considerably slow the epidemic. The app has an effect at all levels of uptake.



Discussion

Success [Lew21, Mus21]

- Medias reported that from 10/01/2020 to 12/31/2020 in UK:
  - 4.4 notification on average from app of tested positive person
  - projected reduction: 200,000 900,000 cases



nature

Contact-tracing apps help reduce COVID infections, data suggest

Evaluations find apps are useful, but would benefit from better integration into health-care systems.

Dyani Lewis

MIT Technology Review

The UK's covid app made a serious difference during the winter surge

That's a big deal for exposure notifications, which have had a tough time proving how useful they are.

by **Lindsay Muscato** February 11, 2021

What they found: The study, by a team of Oxford researchers, modeled the impact of 1.5 million notifications that had been sent by the UK's NHS app between October 1 and December 31, when almost 2 million people were infected with covid-19. Their analysis showed that each person who tested positive and used the app to alert others sent out an average of 4.4 notifications; without this intervention, they projected, there would have been between 200,000 and 900,000 more cases.

Discussion

Failure

- Limited impacts on marginalized groups [Fer20]
  - higher dying rates
  - prefer not to use app
  - distrust the government

MIT Technology Review

Do digital contact tracing apps work? Here's what you need to know.

Health departments are using contact tracing apps and notifications to slow the spread of covid-19.

by **Cat Ferguson** November 20, 2020

Unfortunately, the promise of a smartphone solution conflicts with one of the harshest realities of the pandemic: marginalized groups around the world are contracting and dying of covid-19 at rates far higher than people with greater socioeconomic power. People in these groups are also less likely to be tested in the first place. Smartphone apps may not be as helpful in such communities, particularly if members have good reasons to distrust the government.

Discussion

Failure

- Limited impacts on marginalized groups [Fer20]:
  - higher dying rates
  - prefer not to use app
  - distrust the government
- Low accuracy: [Mar21]
  - Swiss and German: 0 potential infection
  - Italian: TP 50% and FP 50%

digitaltrends

Contact-tracing apps were the biggest tech failure of the COVID 19 pandemic

By Andrew Martonik
February 15, 2021

An excellent study out of Ireland tested the perceived location of smartphones on a tram compared to their actual locations and found the following: "In the tram, there is little correlation between received signal strength and distance between handsets." The conclusions are even more damning when the data is provided to contact tracing apps from various European countries: When the Swiss and German apps fed the data, they found zero potential infections despite being given data of people being in close proximity for an extended time. Worse yet, the Italian app "generates a true positive rate of 50% and a false positive rate of 50%." The summary is, well, damning: "Our analysis indicates that the performance of such detection rules is similar to that of triggering notifications by randomly selecting from the participants in our experiments, regardless of proximity."

Discussion

Large-scale Controlled Study (Effectiveness)

- With and without contact tracing
- Area and habits
- Age distribution
- Privacy ...

Thank You

Privacy of COVID-19 Contact Tracing Apps

Zhiqiang Lin

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3/10/2021

Outline

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