SwissCovid Exposure Score Calculation

Version of 11 September 2020

Goal

SwissCovid is a proximity-based digital contact tracing system that notifies users when they have potentially been exposed to SARS-CoV-2 positive individuals. The key function of digital contact tracing systems is determining when a person is exposed and should be notified. In this document, we describe how SwissCovid estimates exposure using established epidemiological parameters and the currently available smartphone technology.

Background Information

Epidemiological

The goal of proximity-based digital contact tracing is to support traditional contact tracing. In traditional contact tracing, an index case (i.e., a person with a confirmed SARS-CoV-2 infection) is interviewed in order to identify potential contacts that the person might have infected. Contact tracers use contact definitions provided by the local health authorities. For example, in most countries, contact tracers use a cutoff of 2 meters and 15 minutes to qualify a contact as sufficiently high risk to justify quarantine.

Digital proximity tracing aims to support manual contact tracing by notifying contacts through an app, which, in addition to important speed gains, has the benefit that non-social contacts can also be notified, even those that an index case could not recall.

It is important to recognize that the distance used by traditional contact tracing is an approximation. The distance is a “best estimate” value that offers a practical guideline on which to base a decision, but it is not an absolute classifier. First, it is, of course, not the case that a contact at 1.9m would incur risk, while one at 2.1m would not. Second, people are not able to recall contact distances with high precision, and thus not all identified contacts will have been within a given radius. Bluetooth estimates should be evaluated within this context.

Moreover, traditional contact tracing for SARS-CoV-2 often results in low attack rates (percentage of people identified through contact tracing who end up being infected) of less than 15%. Thus, it is expected (and normal) in contact tracing that the majority of people in quarantine will not have been infected. Epidemiology currently lacks the predictive power to say which of the identified contacts are infected and which are not. It is thus prudent that all go into quarantine (i.e., precautionary isolation).

Bluetooth

SwissCovid measures the exchange of low-power radio packets between smartphones as a method of estimating the spatial proximity of smartphone users. It relies on Bluetooth Low Energy (BLE) beaconing that is available on most smartphones. Since BLE operates in the 2.4 GHz ISM band, it is suitable for short-range, device-to-device communication. The BLE beaconing specification does not include distance measurement. Distance can be estimated by measuring signal strength, given that radio signals naturally attenuate as they travel.

Approach

Exposure estimation predicts the degree of exposure by measuring the reception and attenuation of BLE beacons that are broadcast periodically between devices.

Epidemiologists have defined a contact to be close physical proximity with a COVID-19 positive person or people for a sufficient length of time. In Switzerland, “close” is currently defined as 1.5 meters and “sufficient” is 15 minutes.

To detect the physical proximity of people, we measure the attenuation (diminution in strength) of the radio packets that were transmitted by a COVID-19 positive person’s smartphone to the devices carried by other people in the vicinity. Attenuation is calculated as the difference between the transmission power of the COVID-19 positive user’s smartphone and the power of the signal registered at a receiving device (Received Signal Strength Indicator---RSSI). It can serve as a proxy for the physical distance between the two smartphones and therefore between the two individuals[1].

Since both transmission power and RSSI measurements differ among phone models due to different chipsets, firmware, antenna, or shielding, calibration is required for both the sending and receiving devices to correct for discrepancies and produce a uniform estimate of attenuation between any pair of phones.

The duration of exposure can be inferred from the period of time that the beacons from COVID-19 positive people’s phones are received by another user’s phone. In traditional contact tracing, where one can rely only on human memory of encounters, 15 minutes is the length of an encounter with one person. In the app, which records all encounters, we aggregate the cumulative exposure to one or more COVID-19 positive people into a total exposure to determine if the duration is sufficient.

[1] Alan Bensky, “Wireless Positioning Technologies and Applications”, Chapter 6, Artech House, 2008.

Relation between attenuation and distance

Figure 1 shows a heat map of attenuation values for individual BLE beacons measured between smartphones at various distances in several socially relevant scenarios (party, office, queue, transport, eating lunch as a group, and gym class). This figure illustrates that in real-world environments it is difficult to determine distance precisely using attenuation.

The experiment ("exp34") was conducted on 2020-07-30 in the atrium of the EPFL BC building. The scenarios followed a strict protocol in which the 20 subjects carried different phones that they occasionally used. For this experiment we evaluated the 6 different scenarios above, collecting a total of 20,719 BLE measurements during an afternoon of experiments. The data was collected by configuring phones to run our measurement app that uses the production Google/Apple Exposure Notification (GAEN) API. This ensures that beacon generation and reception is identical to the production GAEN framework. After the experiment, we dumped packet logs that were collected on our test phones, exposing the raw packet information as seen by the GAEN API. GAEN calibration was applied to the measured attenuation values. We inferred ground truth distances by recording the scene and processing the video based on a fixed grid, tracking the position of the subjects as they acted through the scripts.

The signals are rather noisy, which is well documented in the open literature: multipath and shadowing effects affect signal propagation and cause deviations from the simple, free-space radio signal propagation model. Objects, vegetation, and people attenuate signals. The latter, in particular contain a large percentage of water, which is difficult for signals in the 2.4GHz range to pass through.

It is important, however, to note that these effects almost always increase, and very seldomly decrease, attenuation. If attenuation is low (e.g., in Figure 1, <50dB), we can therefore say with very high certainty that the two devices were within a few meters of each other. Higher attenuation values offer less certainty as to distance. For example, attenuation in the 50-70 dB range (in this experiment) could in some instances result from devices that are up to 15 meters apart.

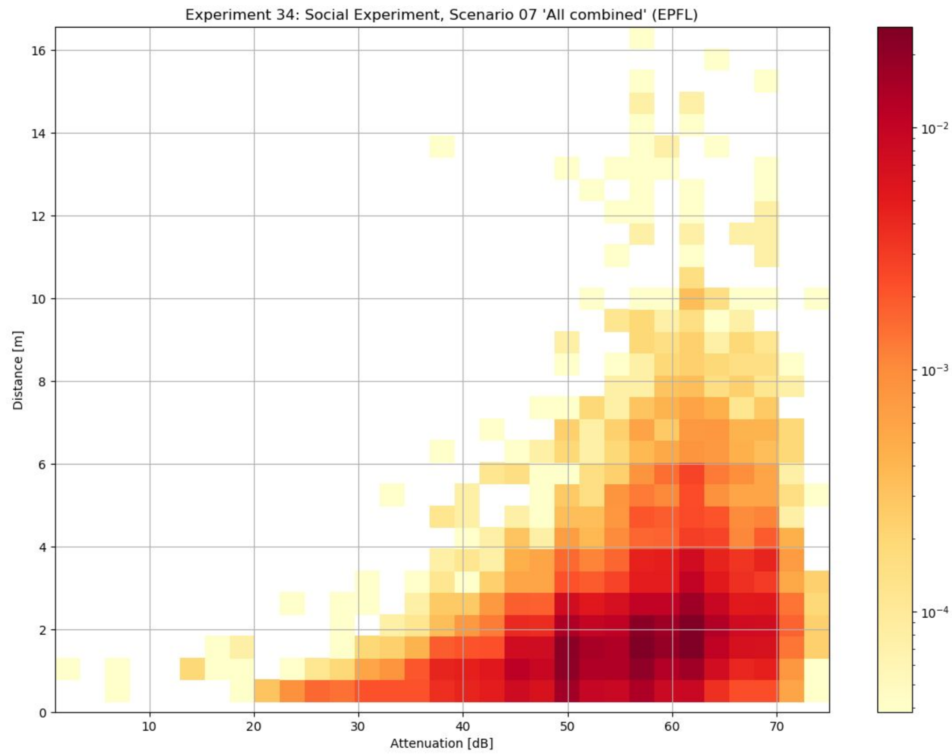

Figure 1. Heat map displaying the signal attenuation between two phones and physical distance between two subjects carrying these phones. Each square represents the number of signals received at an attenuation-distance pair (red is more frequent).

We do not attempt to use the attenuation values to precisely measure distances between devices. Considerable prior work has demonstrated that distance estimation is challenging in diverse environments, especially at the BLE frequency of 2.4GHz. Moreover, distance measurement is not the problem that contact tracing needs solved.

The epidemiologically relevant problem is to infer proximity insofar as it is thought to be relevant for viral transmission. Instead of precise distance estimation, we therefore study which attenuation thresholds both indicate that the devices are within a given distance and capture the majority of the devices that are within that distance---the concepts of precision and recall.

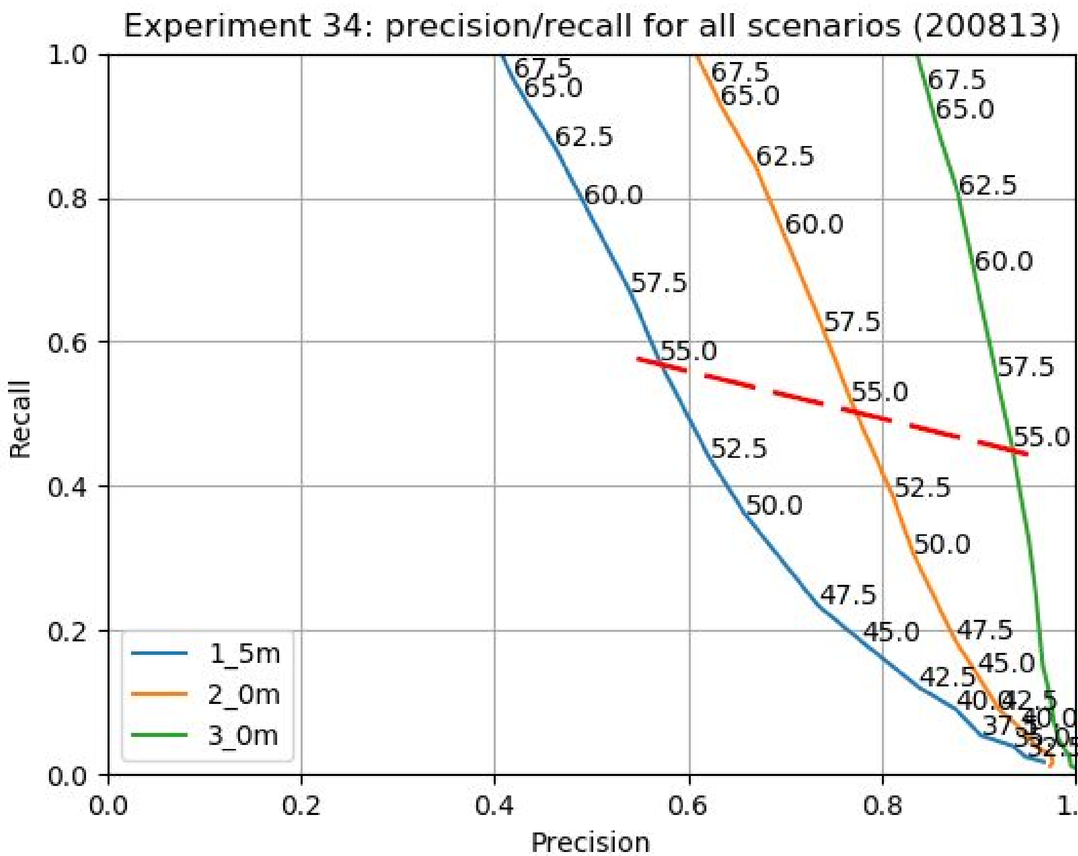

Figure 2. Precision and recall at three distances. The numbers along the curves are the attenuation values in dB. (GAEN calibration from 20-08-13).

Figure 2 shows the precision and recall for estimates that a user is closer than a given distance. These curves were generated from the data in Figure1.[2] Precision is the fraction of beacons for which an attenuation threshold correctly identified that the phone was within a given distance. Recall is the fraction of beacons from phones within that distance that had attenuation equal or smaller than the threshold.

We used the attenuation as a threshold to estimate whether two devices are within a given distance (e.g., the blue line estimates if two phones are separated by 1.5m or less). The numbers along the curves are the attenuation values, in dB, corresponding to the thresholds on which the precision-recall is calculated. For example, on the blue curve (1.5m), 57.3% of the

[2] Precision vs. recall curves require a statistical distribution of distances. For this experiment, we used the empirical distribution of distances between pairs of individuals acting in a variety of social situations, derived from our experiments.

beacons with an attenuation level of 55 dB or less came from phones that were within 1.5m, and 57.0% of the beacons from phones that were physically within 1.5m were attenuated by 55dB or less (i.e., precision≈0.570, recall≈0.573). At the same 55dB threshold, the precision at 2m and 3m increases to 0.769 and 0.935, respectively (highlighted by the red dotted line). This demonstrates that most of the beacons that were received with attenuation below 55dB and that did not originate from within 1.5m, came from devices that were within 2m and 3m.

We can use these precision-recall curves to select the attenuation values for the SwissCovid app. To achieve a high precision, we need to be selective and set the attenuation to a low value. However, at that level, many, if not most, beacons will suffer higher attenuation and be rejected. By selecting a suitable attenuation level, we can correctly identify a sizable majority of beacons corresponding to a given distance and only incorrectly reject a few.

Estimating exposure using the Google/Apple Exposure Notification API

Apps built on the Google Apple Exposure Notification (GAEN) API periodically check for exposure information of COVID-positive users. The current Google/Apple EN (GAEN) implementation receives beacons from neighboring devices every 2.5 - 5 minutes (Figure 3) and advertises beacons every 250ms. A received beacon can be interpreted as an indication of proximity for the interval between received beacons, and its attenuation level gives the probability of being within a certain distance of the device emitting the beacon.

GAEN Exposure score

GAEN v1.1 does not provide attenuation values to an application. The API instead allows the app to request duration of “exposure” to COVID-19 positive people using the ExposureSummary API**.** This API takes as input two thresholds, **t1** and **t2**, that partition the range of attenuation values into three buckets (bucket1: (0...**t1**); bucket2: (**t1**...**t2**); bucket3: (**t2**...)) and a set of keys corresponding to COVID-19-positive users. The API returns, for each of the three buckets, the joint duration of exposure to all COVID-19-positive people whose keys were provided as input. The reported duration for each bucket is limited to a maximum of 30 minutes.

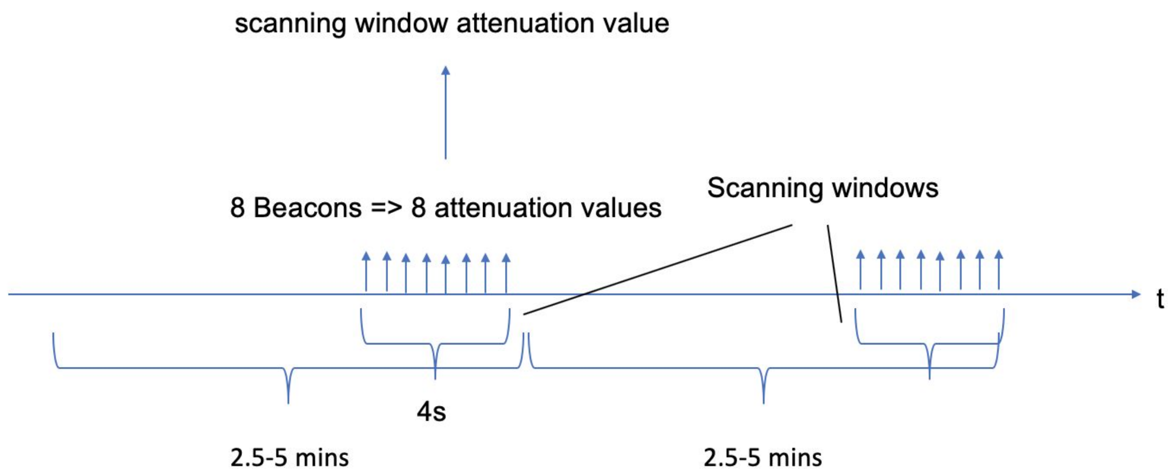

Figure 3. GAEN broadcast of EN beacons. Smartphones broadcast GAEN beacons every 250ms. The phones also listen for and record beacons from neighboring phones every 1to 3 minutes.

SwissCovid configuration

In Switzerland, an exposure notification should be shown to a person if that person has been exposed to COVID-positive individual(s) for 15 minutes or more during one day (Ordinance of 20-06-24 of the Swiss Federal Council). The Annex of the Ordinance specifies a threshold distance of 1.5m, which is lower than the 2m threshold established by the ECDC.

In the SwissCovid app, this exposure check occurs several times a day and utilizes exposures from the current day and the 9 immediately preceding days. The information from the 9 preceding days should capture the vast majority of contacts with positive cases.[3]

The SwissCovid app uses the GAEN ExposureSummary API to retrieve the duration of exposure of a user to COVID-19 positive people within one day, for each of the three attenuation buckets. The Exposure Score (ES) is an estimate of the duration of exposure at close proximity. We calculate it as a weighted sum of the duration within each of the attenuation buckets:

$$ES = \mathbf{w1}*\mathbf{B1} + \mathbf{w2}*\mathbf{B2} + \mathbf{w3}*\mathbf{B3}$$

where **B1**, **B2**, and **B3** are the durations of exposure in attenuation bucket1, bucket2, and bucket3 and **w1**, **w2**, and **w3** are the weights associated with each bucket.

[3] This recommendation is based on current knowledge of the contagious period of SARS-CoV-2, and the incubation period, i.e. the time window from infection to symptom onset (if any), following the ECDC guidelines.

SwissCovid is configured with the following settings :

t1=55dB, t2=63dB
w1=1, w2=0.5, w3=0

Setting **w3** to 0 discards exposures in the third bucket, as they correspond to large attenuation values and likely correspond to large distances between devices. Attenuations in the middle bucket correspond to likely close exposures and are given half-weight (**w2**=0.5) to contribute to the overall score. Attenuations in the first bucket correspond to likely close exposures and are given full weight (**w1**=1).

ES >= 15 minutes over a calendar day

This is computed for each day for the current and past 9 days. The exposure notification to the user is triggered if ES is greater or equal to 15min on any of these days.

SwissCovid launched on June 25, 2020 with conservative settings of **t1**=50dB and **t2**=55dB based on data from an earlier experiment ("exp05"). The thresholds were first updated on July 06, 2020 to **t1**=53dB and **t2**=60dB to increase the recall. These thresholds and weights were chosen to balance the precision and recall of exposure notification across a wide range of environments, including home, public transports, office, and public spaces. The current thresholds of **t1**=55dB and **t2**=63dB were last updated on September 11, 2020 at the request of FOPH after 2 months of field experience, and with the benefit of additional laboratory experiments and of improved attenuation calibration tables by Google and Apple. As Figures 1 and 2 illustrate, these attenuation values empirically correspond to close proximity with high probability.

The Table below provides the full precision-recall empirical probabilities for different maximum attenuations. The selected first threshold of 55dB results in a 57.0% precision within 1.5m with a 57.3% recall, and a precision of 76.9% within 2m. The selected second threshold of 63dB---associated with half-weight---has a precision of 86.9% within 3m.

The raw data set is available at https://github.com/DP-3T/bt-measurements.

	1.5m		2.0m		3.0m	
att_thr	**precision**	**recall**	**precision**	**recall**	**precision**	**recall**
40	0.876	0.091	0.943	0.065	0.983	0.049
41	0.858	0.105	0.934	0.077	0.981	0.059
42	0.838	0.121	0.922	0.089	0.979	0.069
43	0.825	0.140	0.917	0.104	0.978	0.081
44	0.794	0.166	0.905	0.127	0.976	0.099
45	0.779	0.185	0.897	0.142	0.973	0.112
46	0.752	0.209	0.883	0.164	0.968	0.131
47	0.734	0.235	0.875	0.188	0.967	0.150
48	0.715	0.266	0.866	0.215	0.966	0.174
49	0.685	0.311	0.852	0.258	0.960	0.212
50	0.659	0.361	0.833	0.306	0.959	0.256
51	0.634	0.403	0.819	0.348	0.954	0.295
52	0.622	0.440	0.812	0.384	0.952	0.327
53	0.603	0.491	0.798	0.435	0.948	0.375
54	0.590	0.522	0.788	0.466	0.944	0.405
55	0.570	0.573	0.769	0.516	0.935	0.456
56	0.556	0.626	0.755	0.568	0.926	0.506
57	0.540	0.669	0.741	0.614	0.918	0.553
58	0.526	0.707	0.730	0.655	0.914	0.597
59	0.504	0.762	0.710	0.718	0.902	0.663
60	0.493	0.791	0.699	0.750	0.895	0.698
61	0.475	0.831	0.682	0.799	0.887	0.754
62	0.462	0.870	0.669	0.844	0.879	0.805
63	0.449	0.896	0.656	0.875	0.869	0.842
64	0.440	0.916	0.646	0.899	0.862	0.872
65	0.429	0.941	0.633	0.928	0.855	0.909
66	0.424	0.954	0.627	0.944	0.850	0.929
67	0.418	0.966	0.622	0.961	0.847	0.950
68	0.413	0.979	0.615	0.976	0.842	0.970
69	0.411	0.990	0.612	0.986	0.840	0.983
70	0.409	0.994	0.610	0.993	0.838	0.990