Digital Proximity Tracing in the COVID-19 Pandemic on Empirical Contact Networks: Controlling re-emerging outbreaks

G. Cencetti[1, †], G. Santin[1, †], A. Longa[1,2], E. Pigani[1], A. Barrat[3,4], C. Cattuto[5,6], S. Lehmann[7], M. Salathé[8], and B. Lepri[1,⋆]

[1]Fondazione Bruno Kessler, Trento, Italy
[2]University of Trento, Trento, Italy
[3]Aix Marseille Univ, Université de Toulon, CNRS, CPT, Turing Center for Living Systems, Marseille, France
[4]Tokyo Tech World Research Hub Initiative (WRHI), Tokyo Institute of Technology, Tokyo, Japan
[5]University of Turin, Turin, Italy
[6]ISI Foundation, Turin, Italy
[7]Technical University of Denmark, Copenhagen, Denmark
[8]École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland
[†]These authors contributed equally to this work.

Digital contact tracing is increasingly considered as a tool to control infectious disease outbreaks. As part of a broader test, trace, isolate, and quarantine strategy, digital contact tracing apps have been proposed to alleviate lockdowns, and to return societies to a more normal situation in the ongoing COVID-19 crisis. The efficacy of app-based contact tracing has been discussed in several recent papers.

We draw inspiration from the work by Fraser et al. [1], recently adapted to the case of Covid-19 [2]. This models the pandemic evolution using recursive equations describing the number of infected individuals in a homogeneously mixed population, taking into account the evolving infectiousness of the infected individuals. These equations include two effective parameters, ε_I and ε_T, to represent the ability to identify and isolate infected people, and to correctly trace their contacts, respectively. Assuming an exponential growth for the number of infected people (applicable in early phases of an epidemic outbreak) the authors study how the growth rate depends on these intervention parameters.

We present a work where, in order to better understand the concrete efficacy of real-world contact tracing, we expand this approach with respect to the following specific aspects.
First, we restructure and generalize the mathematical framework of the approach proposed by Fraser et al. This allows us to completely avoid assumptions regarding the functional form of the epidemic growth, making the setting applicable to any possible evolution shape and any phase of the epidemic.

Second, we provide a realistic quantification of the tracing ability by performing simulations of spreading processes and of contact tracing strategies on real-world data sets collected across different social settings (i.e., a university campus, a workplace, a high school). This allows us to numerically estimate the actual "tracing ability" ε_T as a function of the isolation efficiency ε_I and to evaluate the impact of the tracing procedure by inserting it into the mathematical model.

Third, we assume that the probability of a contagion event occurring during an interaction between a susceptible and an infected individual also depends on the duration and on the proximity of the contact.

Finally, we investigate in details the contact tracing procedure, designing appropriate policies to identify the most contagious contacts. We thus implement a system where tracing does not necessarily imply a massive preventive quarantine of the population. We make a selection on which contacts we consider at risk and which instead implicate a low probability of contagion, based on duration and proximity thresholds. Among "risky" contacts, some correspond to infections while others do not. The latter correspond to "false positives", i.e., non-infected individuals who will be quarantined. Similarly, among the contacts considered as non-risky by the contact tracing, some might actually be infected ("false negatives"). These outcomes represent crucial information to calibrate the policies for contact tracing apps. On the one hand, a low number of quarantined can unwittingly omit many potential spreaders. On the other hand, highly restrictive policies might require to quarantine large numbers of individuals, including non-infected people, with a consequent high social cost. Overall, our approach allows us to evaluate the effect of different contact tracing policies, not only on the disease spread but also in terms of their impact on the population, quantified by the fraction of quarantined individuals.

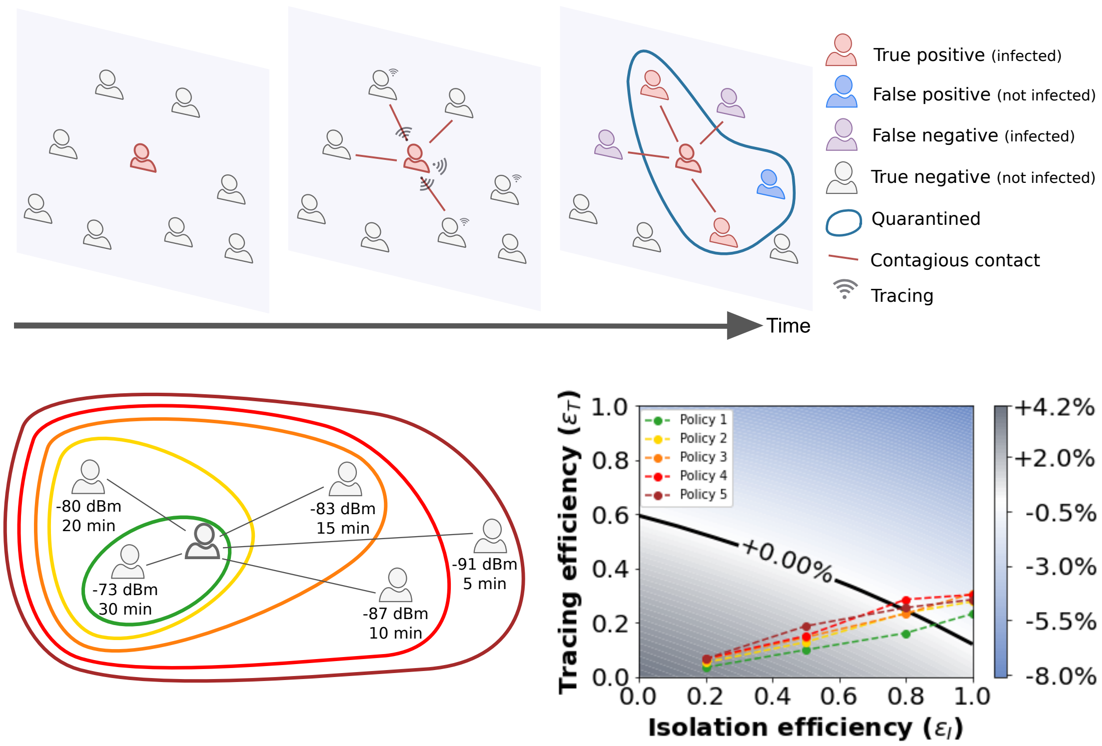

Figure 1: The upper figure shows the tracing app at work. Each interaction among users adopting the app is registered. If an individual is identified as infected, the individual is isolated, and the tracing and quarantine policy is implemented. Depending on the policy design, the number of false positives and false negatives may vary significantly. The bottom left figure graphically shows the five different policies, regarding RSSI signal strength and contact duration. Finally, the bottom right figure shows the tracing policy efficiency in containing the epidemics via the growth or decrease rate of the number of newly infected people. The points correspond to the parameter pairs such that ε_I is an input and ε_T an output of the simulations on real contact data, for the five policies. The last is obtained simulating spreading on real data, while the black line is defined by the mathematical model.

Our results show that isolation and tracing can help keep re-emerging outbreaks under control provided that other restrictive measures like face masks and social distancing limit the reproduction number to 1.5. Moreover we find that, among the tested policies, those that appear to provide the best balance between effectiveness and cost are those corresponding to considering contagious a contact longer than 15-20 minutes, with distance shorter then around 2 - 3 meters, in agreement with the European guidelines for high-risk contacts.

In conclusion, this novel combination of a well-established epidemic model with state-of-the-art, empirical interaction data collected via Bluetooth technologies or similar radio-based proximity-sensing methods allows us to understand the role played by intrinsic limitations of app-based tracing efforts, affording an unprecedented viewpoint on the ambition of achieving containment with app-based interventions. Namely, we are able to test and quantify the role that a real contact network plays both for the infectiousness of a contact and for the ability of a policy to detect it and to respond optimally.

References

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