An outbreak response tool to effectively support surveillance of suspect, probable and confirmed incidence cases while staying safe in COVID-19

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Abstract*—During the burst of the coronavirus pandemic, in early-midst 2020, public health authorities worldwide considered appropriate identification, isolation and contact tracing as the most appropriate strategy for infection containment. This work presents an outbreak response tool, designed for public health authorities to effectively track suspect, probable and confirmed incidence cases in a pandemic by means of a mobile app used by citizens to provide immediate feedback. It is developed based on an already existing personal health record app, which has been extended to properly accommodate specific needs that emerged during the crisis. The aim is to better support human tracers and should not be confused with proximity tracking apps. It respects safety and security regulations, while at the same time it conforms to international standards and widely accepted medical protocols. Issues relevant to privacy concerns, and interoperability with available patient registries and data analytics tools are also examined to better support public healthcare delivery and contain the spread of the infection.

***Keywords*—coronavirus, fast healthcare interoperability resources, mobile public health application, outbreak response tools, pandemic, personal health apps**

I. Introduction

The coronavirus disease 2019 (COVID-19) is an infectious disease which was first identified in December 2019 in Wuhan, China, and has resulted in an ongoing pandemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [1]. The confinement measures taken by governments around the world resulted in an unprecedented disruption of lives and work for millions of people, bearing significant social, economic and healthcare challenges [2]. The main focus has been the reduction of the spread of the epidemic and the minimization of the load of morbidity and mortality so that health care systems remain functional [3].

According to [4] "*Contact tracing is the process of identifying, assessing, and managing people who have been exposed to a disease to prevent onward transmission. … Contact tracing for COVID-19 requires identifying persons who may have been exposed to COVID-19 and following them up daily for 14 days from the last point of exposure.*" When applied systematically, contact tracing is in a position to break the transmission chains of an infectious disease and is therefore an essential public health tool for controlling infectious disease epidemics.

The European Centre for Disease Prevention and Control (https://www.ecdc.europa.eu/) has provided the basic principles on how to undertake conventional contact tracing, including the classification of contacts [5]. It has also published guidance on how to scale up contact tracing efforts to handle larger numbers of cases, using both additional human resources and different types of technology [6]. At the moment mobile apps can only complement and not replace regular contact tracing efforts due to several limitations and unknown efficacy.

Contact tracing, followed by treatment or isolation, is a key control measure in the battle against infectious diseases. When symptomatic, the following minimum set of data needs to be collected: date of symptom onset, referral criteria (based on clinical severity and presence of vulnerability factors), contact isolation status (at home, at the hospital, or at other

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self-isolation facility), and whether a sample has been taken (date of collection). The monitoring phase ends 14 days after the contact's last exposure to a new case, or if the contact develops COVID-19. In the latter case monitoring is still needed, not only for medical purposes but also for public health purposes so that isolation status is properly monitored, test results are directly shared with interested parties, and social patterns are analyzed.

In response to the need to rapidly perform contact monitoring, many digital tools have been developed to assist with contact tracing and case identification [7]. The pandemic mobilized the international community and several movements have been created towards connecting the civil society, innovators, partners, and investors across the globe towards the development of solutions to help the world combat the disease. Some of the most prominent ones have been COVID-19 Global Hackathon (https://covid-global-hackathon.devpost.com/), #EUvsVirus Matchathon & Hackathon (https://www.euvsvirus.org/), # The Global Hack (https://theglobalhack.com/), UNESCO CodeTheCurve Hackathon (https://en.unesco.org/news/unesco-launches-codethecurve-hackathon-develop-digital-solutions-response-covid-19), SmartDevelopmentHack (https://toolkit-digitalisierung.de/en/smartdevelopmenthack/), #HackCorona (https://hackcorona.world/), and many more.

Non-functional specifications essential for the delivery of trustworthy apps include compliance with the European Union (EU) general data protection regulation (GDPR) provisions, access to patient data depending on end-user roles, accuracy and security of data, interoperability with other applications and registries using international standards, as well as compliance with approved medical protocols.

The preliminary conception of the described work is based upon existing work on personal health record systems [8] [9] and the development of integrated care solutions to effectively support personal health management and public health [10].

II. Methods

At the time this paper was written, all governments, health organizations and other authorities were continuously focusing on identifying the cases affected by COVID-19. The Center for eHealth Applications and Services of FORTH (CeHA, https://www.ics.forth.gr/ceha/), in response to national and European calls for meaningful digital innovation against the pandemic, voluntarily developed digital tools and services based on an existing personal health record platform, in order to assist public health authorities, healthcare providers and citizens to address the current challenge.

The development of the underlying platform followed a detailed requirement elicitation process based on the official information and guidelines of (i) the National Public Health Organization of Greece (https://eody.gov.gr/), (ii) the Centers for Disease Control and Prevention (https://www.cdc.gov/) in the United States, (iii) The United Nations Public Health Unit (https://www.un.org/en/sections/issues-depth/health/), and (iv) the World Health Organization (https://www.who.int/). The modules of the Safe in COVID-19 platform were based on already existing tools and services developed in ongoing and past projects, such as BOUNCE [11], RELIEF [12], STARS [13], iManageCancer [14], as well as already existing software already developed by CeHA.

Applications for the involved stakeholders (public authorities, healthcare professionals, and patients) were built upon a common platform ensuring interoperability with existing modules and third-party systems. Safe in COVID-19 modules were incorporated into the personal health record platform to support symptoms recording and tracking, information sharing, personalized recommendations [15], communication, position tracking/ tracing, and public health visualizations. Privacy needs were considered at the very beginning of the system development following the privacy-by-design approach [16] for the modular architecture, data flow and interactions. Data protection in accordance with the European GDPR [17] was also incorporated.

III. Relevant Work

Mobile technology has been leveraged in a number of ways to control the spread of COVID-19, including to support knowledge translation. Mobile applications are accessible, acceptable, easily adopted, and have the ability to support social distancing efforts. As such, they have been widely developed during the first half of 2020 in an attempt to "flatten the curve" [18] of the increasing number of COVID-19 cases, providing information to all civilians and subsequently relieve the pressure on healthcare systems. To this direction, multiple apps and protocols have been designed to facilitate self-assessment at home, track statistics, and provide current updates.

Platforms like COVIDSafe in Australia for example, (https://www.health.gov.au/resources/apps-and-tools/covidsafe-app), offer the ability to document registered isolation, to better understand the experience of those in isolation, to create a safeguard for isolated individuals, and to allow public health to conduct appropriate analysis and research.

COVID Symptom Tracker (https://covid.joinzoe.com/us) developed in the US, helps track the onset and progression of symptoms with the goal of shedding light on the nature of the disease, to identify those at risk sooner, to pinpoint virus hot spots and to help slow the spread of the disease.

In addition, protocols like the Decentralized Privacy-Preserving Proximity Tracing (DP3T) [19], and the Apple and Google exposure notification application programming interface (API), which are currently in testing phase in Switzerland, implement a hybrid solution (https://www.google.com/covid19/exposurenotifications/) in which each participant is the sole owner of its own data until it is necessary to transmit its tokens to a central server to declare its status as "infected". Each participant generates tokens at regular intervals and then broadcasts them. The tokens generated (from seeds known exclusively by the device that emits the proximity messages) do not allow to trace the identity of the user. Only if a user is declared infected, can the tokens be retrieved to allow other users to "determine" whether or not they were in the vicinity of the infected user.

On the other hand, the Pan-European Privacy-Preserving Proximity Tracing (PEPP-PT) framework (https://www.pepp-pt.org/) defines a protocol that simplifies the recognition of users found to be infected, while at the same time is trying to ensure privacy and security. The substantial difference between PEPP-TT and DP3T lies in the fact that in the former the tokens passed on are generated from information known to a central authority which must be trusted. When a user is declared infected, he has the option to send his information to the central server to warn other users who have been in contact with him. The action is voluntary also in this case.

When the contact becomes a case, the change in status is linked, through a common identifier, to a case database (i.e. a line list). The systematic use of common identifiers linking contact tracing, case line lists, and individual laboratory results is considered to be essential. The Global Outbreak Alert and Response Network (GOARN) has developed Go.Data, a software application specifically designed to manage case-contact relationships and the follow-up of contacts (https://www.who.int/godata). Go.data has been deployed to over 35 countries in support of the COVID-19 Pandemic response.

Unfortunately, evidence-based assessment of those apps does not exist yet, even though healthcare systems rely on these as part of a toolbox of strategies to support social distancing and personal decision-making, to reduce the potential impact on overwhelmed clinical services. In addition, most of the available apps/ platforms have a single purpose, to serve either as symptom manager/ assessment tool providing news and statistics, or as information sharing/ training apps. To the best of our knowledge, none of these comprehensively includes a full range of features. Despite the fact that online analytic dashboards for tracking COVID-19 (https://app.developer.here.com/coronavirus/) are currently available, they are limited on presenting mostly recovered, and confirmed cases and deaths, without being able to present further statistics or make predictions.

IV. Safe in COVID-19

The described tool, which is named “Safe in COVID-19”, is an expandable online platform that helps:

- **Public Authorities** to have a better picture of the actual situation regarding the existence of suspect, probable and confirmed COVID-19 incidents and be able to make appropriate decisions based on the self-reported symptoms of the citizens and the relevant real time data that are available.
- **Healthcare professionals** to communicate with citizens who report COVID-19 symptoms, manage their patients, as well as to reduce direct contact with suspected cases.
- **Citizens and their families** to record data on symptoms related to COVID-19, carry out self-assessment of their health condition as well as have access to personalized information/ instructions from healthcare professionals (physicians).

A typical use case supported by "Safe in COVID-19" is the following:

- A citizen is confirmed to have a contagious disease such as COVID-19.
- The case is reported to the public health authorities and is managed by local healthcare providers.
- The citizen is being interviewed to find out who he/ she was in close contact with.
- The app is activated (voluntarily) and the citizen, is offered the option to record his/ her daily health status and to communicate on line or on demand with healthcare professionals, if needed, in order to receive further instructions and/ or alerts.
- Once the contacts are traced, workers in public health communicate with them to provide screening, testing, counselling and/ or treatment.
- The contacts traced also have now the app activated for them to monitor the progress of their own health and to support better disease control.

The information that the contact tracing teams gather on each contact should be entered into a database, such as the COVID-19 patient registry provided by national authorities, with the necessary data for the treatment and control of the pandemic being available to the involved bodies.

A. Architecture

The platform architecture is shown in Fig. 1 and consists of the Application Tier that provides front-end applications to end-users, the Business Logic Tier that offers the intelligent functionality, and the Semantic Tier that stores and processes all available data. All these layers are supported by security and integrity services.

B. Application Tier

The Safe in COVID-19 solution consists of a web application for public health authorities, a web application for healthcare professionals, and a mobile application (Android/ iOS) for citizens.

The web app for public health authorities (Fig. 2) supports the strategic planning of the involved authorities by giving a complete picture of the status regarding the spread of the disease at national level and the measures taken regarding

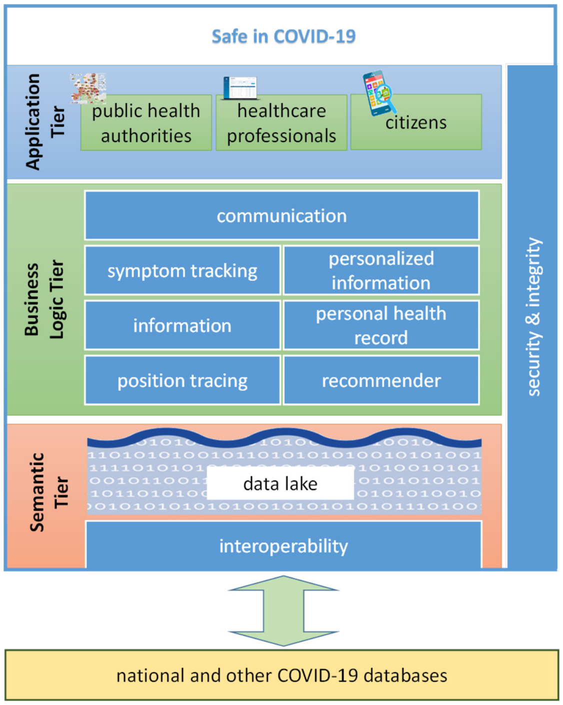

Fig. 1. Safe in COVID-19 architecture.

the provided healthcare services. The main functionalities supported are (i) monitoring the evolution of the suspected, probable and confirmed cases by accessing real-time data, (ii) filtering for more detailed information (demographics, symptoms, pre-existing conditions, etc.), and (iii) surveillance of confirmed COVID-19 cases.

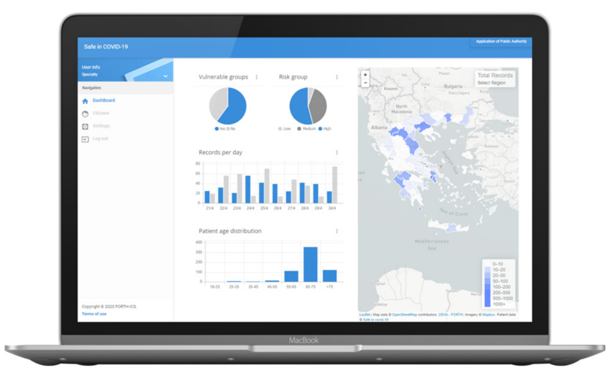

Fig. 2. Safe in COVID-19 dashboard for public health authorities.

The web app for healthcare providers (Fig. 3) supports direct, online communication with registered patients and provides instant access to patient reported symptoms, related to COVID-19 disease. The main functionalities include: (i) registration of healthcare professionals, (ii) entry of lab test results (positive/ negative for COVID-19), (iii) characterization of a citizen as a suspect, probable or confirmed case, (iv) monitoring the health status of suspect/ probable/ confirmed cases (i.e. overview of individuals' symptoms and classification into a risk group (low, middle, high) based on relevant guidelines), (v) provision of personalized information and coaching to citizens based on their health status, and (vi) synchronous or asynchronous communication with citizens who report relevant symptoms.

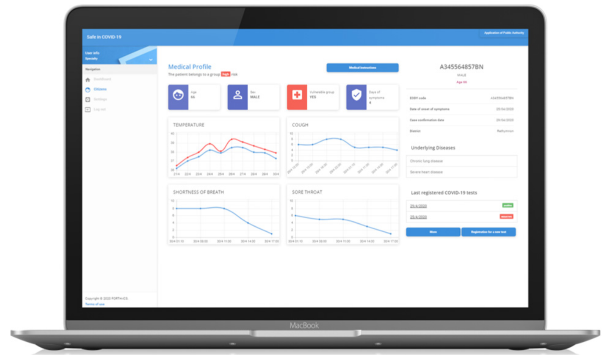

Fig. 3. Screenshot of the Safe in COVID-19 web app for healthcare professionals and contact tracers/ trackers.

The mobile application for the citizen (Fig. 4) supports the recording of health status on a daily basis and synchronous or asynchronous communication with healthcare professionals in order to receive personalized instructions for managing their health. When symptomatic, the following minimum set of data can to be collected: date of symptom onset, referral criteria (based on clinical severity and presence of vulnerability factors), contact's isolation (at home, at the hospital, or at other self-isolation facility), whether a sample has been taken (date of collection).

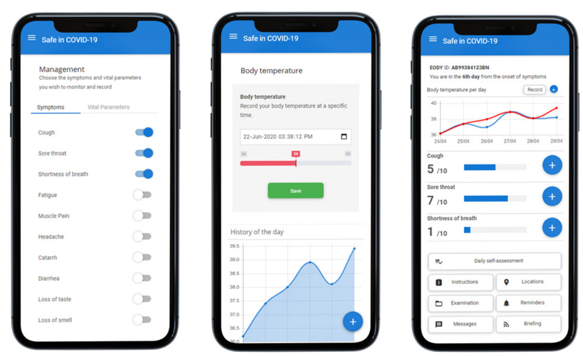

Fig. 4. Mobile app Safe in COVID-19 for the Citizen (in Android/ iOS).

Daily follow-up of signs and symptoms supported in a contact tracing form include fever (perceived or measured, and reported or observed), and other signs and symptoms: sore throat, cough, runny nose or nasal congestion, shortness of breath or difficulty breathing, muscle pain, loss of smell or taste, or diarrhea. Main functionalities supported include: (i) citizen registration, (ii) initial self-assessment based on a questionnaire for underlying diseases related to COVID-19 (this includes chronic lung disease, severe heart disease, immunosuppression, diabetes, renal failure, liver failure and morbid obesity), (iii) recording of symptoms which are related to COVID-19 and self-assessed by the citizen using a Visual Analog Scale (VAS) that include cough, sore throat, shortness of breath or difficulty of breathing, fatigue, muscle pain, headache, runny nose or nasal congestion, diarrhea, loss of taste or smell, (iv) recording of vital parameters related to COVID-19, such as body temperature, oxygen saturation (SPO2), breathing rate, systolic and diastolic blood pressure and heart beats, (v) reminders for monitoring symptoms and vital parameters based on medical history and symptomatology, (vi) automatic recording of citizen's location in order to facilitate the tracking of contact in case of confirmation of a case of COVID-19, (vii) access to the results of laboratory tests (positive for COVID-19) as well as their characterization as suspect/ probable/ confirmed cases of COVID-19, as they are registered by the healthcare professionals, (viii) display of personalized information and recommendations, prepared by healthcare professionals. The patient has access to all useful information and services related to the disease, (ix) synchronous or asynchronous communication with healthcare professionals, and (x) access to instructions, information, and other related material from reliable sources such as the national public health organization and the ministry of health.

C. *Business Logic Tier*

This tier consists of middleware services necessary for enabling communication between healthcare professionals and citizens, symptom tracking, managing personalized information and user profiles, personal health records, position tracing, and recommendations. As the Safe in COVID-19 framework is based and significantly extends a fully-fledged PHR system, state of the art communication, user profiling and personal health records come out of the box, whereas the specific COVID symptom monitoring and recommendations along with the position tracking have been implemented specifically for addressing the COVID-19 outbreak. All the services communicate with the semantic tier to retrieve, update and store data, which are further visualized and presented to the user through the application tier.

D. *Semantic Tier*

This tier includes a data lake where all available data are staged. Those include data collected by the mobile and the web apps, additional data about healthcare resources and geolocation information, as well as external open data sources and registries. The data lake currently supports relational and NoSQL databases, whereas the MHA Semantic Core Ontology [20] is also available for semantically uplifting through mapping [21] and/ or annotating available data using ontology terms.

E. *FHIR interoperability*

Fast healthcare interoperability resources (FHIR) have been used for the representation of the medical data related to COVID-19 [22]. More specifically *valueSet* for COVID-19 Patient Reported Outcome Observations, that includes the following symptoms: cough, fatigue, pain in throat, dyspnea, headache, diarrhea, nausea, loss of sense of smell, and temperature (http://build.fhir.org/ig/hl7ch/covid-19-prom/branches/master/ValueSet-covid-19-prom.html) has been adopted. This *valueSet* is used for the recording of vital parameters related to COVID-19 for the citizens' application. FHIR resources (i.e. Problem and Condition resources) are also appropriate for representation of the underlying diseases related to COVID-19. FHIR Server is the module where all the patient input coming from the citizen's application is published. The web app for public health authorities and healthcare professionals consume these data and present to the end user of each application. The citizen's app can also act as a consumer of the FHIR server, in order to retrieve the personalized recommendations that healthcare professionals published to the FHIR server through the healthcare professional web app. Safe in COVID-19 retrieves the test results from the FHIR server and present them to the end users. All the above transactions with the FHIR server follow the FHIR RESTful API specifications.

V. Security Considerations

The development of the platform was guided by privacy and data protection principles [23]. Effective cybersecurity controls have been used to protect the availability, authenticity, integrity, and confidentiality of data. Epidemiological frameworks and other safeguards have been considered. The common EU toolbox presents a detailed list of these requirements and elements [24].

Safe in COVID-19 modules do not process patient identification data but only the unique code generated pseudo-randomly by the health authority to confirm COVID-19 cases. The data processed have been minimized and encrypted in order to enhance security and privacy. Secure coding principles have applied and all network communications between the modules are encrypted. The Safe in COVID-19 app for the citizens is consent-based [25] with full information of intended processing of data.

VI. Discussion & Conclusion

This paper presented a digital platform with applications for public health authorities, healthcare professionals and citizens to support surveillance of suspect, probable and confirmed cases outside the hospital. The described tool can be used for self-reporting of symptoms by contacts and currently is not linked to proximity applications. The solution supports return to the "new normal" with less stress and more security for individuals, more direct and safer management of patients by physicians, and better possibilities for monitoring the epidemic by public health authorities.

Foreseen benefits for public health authorities include decongestion of the healthcare units (hospitals and specialized primary care centers) in situations that prevent citizens from attending health institutions (hospitals, specialized health centers) to receive the relevant diagnostic test, provision of real-time information on the evolution of suspected, candidate and confirmed cases, online monitoring of the spread of the virus, and decision-making support regarding required measures to be taken. Benefits for citizens include systematic recording of symptoms, provision of help for self-assessment of virus-related symptoms, and access to personalized information, instructions and reminders about their symptoms and health status. Benefits to healthcare professionals include support in managing the patients traced/ monitored, reduced time for direct contact with patients, and improved working conditions. In order for these benefits to be realized to their full range, it is important to have an interoperability framework such as the one already described in [26] to connect with the relevant national registries and digital health services.

The effectiveness of such a tool depends on several, interrelated factors: (i) a comprehensive national epidemiologic strategy articulating instrumental support to the public health system, (ii) an appropriate architectural, technological but also organizational model of implementation, and (iii) widespread connection with mobile devices, while acknowledging that considerable segments of the population are unable to acquire or use them, in particular high-risk groups such as the elderly.

Putting such a tool in operation requires close cooperation with public authorities for the development and deployment of the solution at a national and international level, compliance with approved medical protocols, interoperability with national registries for citizen identification and COVID-19, quality assurance, and the existence of the appropriate legal framework.

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