[Array 9 (2021) 100051](https://doi.org/10.1016/j.array.2020.100051)

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  | Contents lists available at ScienceDirect |  |
| Array |
| journal homepage: www.elsevier.com/journals/array/2590-0056/open-access-journal |
|  | | |

COVID-19 & privacy: Enhancing of indoor localization architectures towards effective social distancing

Paolo Barsocchia, Antonello Calabr�oa, Antonino Crivelloa, Said Daoudagha,b, Francesco Furfaria, Michele Girolamia,\*, Eda Marchettia

a ISTI-CNR, Institute of Information Science and Technologies, Pisa, Italy   
b University of Pisa, Pisa, Italy

|  |  |
| --- | --- |
| A R T I C L E I N F O | A B S T R A C T |
| Keywords:  Social distancing  COVID-19  Indoor localization system Privacy | The way people access services in indoor environments has dramatically changed in the last year. The counter-measures to the COVID-19 pandemic imposed a disruptive requirement, namely preserving social distance among people in indoor environments. We explore in this work the possibility of adopting the indoor localization technologies to measure the distance among users in indoor environments. We discuss how information about people’s contacts collected can be exploited during three stages: before, during, and after people access a service. We present a reference architecture for an Indoor Localization System (ILS), and we illustrate three representative |

use-cases. We derive some architectural requirements, and we discuss some issues that concretely cope with the real installation of an ILS in real-world settings. In particular, we explore the privacy and trust reputation of an ILS, the discovery phase, and the deployment of the ILS in real-world settings. We finally present an evaluation framework for assessing the performance of the architecture proposed.

|  |  |
| --- | --- |
| 1. Introduction | such approach is relatively easy to implement, we argue that a comple- |

mentary solution needs to be adopted on the long period; we refer to it as

The recent COVID-19 pandemic has been imposing profound changes in our daily life. Most of the affected countries adopted different coun-termeasures in order to reduce the contagious rate. Among them, an effective action is the so-called social distancing. The idea is simple as disruptive at the same time: citizens are invited to maintain at a certain physical distance from others. This recommendation applies when we interact with people out of our personal spaces, namely a restricted community of contacts.

Social distancing has become a new requirement in the way we access and provide services. In the context of the COVID-19 pandemic, policy-makers have to re-think the way we visit a supermarket, we catch a bus, or we interact with colleagues at work. We consider two possible ways of guaranteeing such a requirement: manually or automatically. The manual approach is commonly adopted in our cities, such as in a shop-ping mall. In this case, an operator observes the scene acting to limit and prevent close contacts among people; for example by managing the waiting queue, verbally distancing customers, or by optimizing the dis-placements of goods so that to reduce involuntary contacts. Although

\* Corresponding author.

automatic social distancing. In this work, we explore the possibility of automatically guarantying the social distance indoor with the adoption of a privacy-preserving Indoor Localization System (ILS). We focus on those services that are generally available indoor, such as a museum, airport facilities, or a supermarket. In these representative use cases, users roam through a sequence of points of interest such as galleries of a museum, check-in desks, or aisles of a supermarket. Our approach consists of estimating the current location of people with the ILS and to compute the personal distance among the subjects involved. Knowledge on the exis-tence of crowds can be exploited by suggesting to the customers an alternative path able to minimize gatherings with others. In the last decade, ILSs have been widely adopted [1] in different scenarios; they are based on very different technologies, ranging from Wi-Fi finger-printing [2] to solutions based on ultra-wide band radio waves [3]. We argue that the accuracy obtained from the most advanced systems is now sufficient for the purpose of the social distancing [4]. As a meaningful example, we refer to class of ultra-wide band systems able to constrain the localization error in the range of centimetres while tracking moving

E-mail addresses: [paolo.barsocchi@isti.cnr.it](mailto:paolo.barsocchi@isti.cnr.it) (P. Barsocchi), [antonello.calabro@isti.cnr.it](mailto:antonello.calabro@isti.cnr.it) (A. Calabr�o), [antonino.crivello@isti.cnr.it](mailto:antonino.crivello@isti.cnr.it) (A. Crivello), [said.daoudagh@ isti.cnr.it](mailto:said.daoudagh@isti.cnr.it) (S. Daoudagh), [francesco.furfari@isti.cnr.it](mailto:francesco.furfari@isti.cnr.it) (F. Furfari), [michele.girolami@isti.cnr.it](mailto:michele.girolami@isti.cnr.it) (M. Girolami), [eda.marchetti@isti.cnr.it](mailto:eda.marchetti@isti.cnr.it) (E. Marchetti).

<https://doi.org/10.1016/j.array.2020.100051>  
Received 24 July 2020; Received in revised form 9 November 2020; Accepted 15 December 2020   
Available online 23 January 2021   
2590-0056/© 2021 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

P. Barsocchi et al. Array 9 (2021) 100051

objects [5]. We first propose a privacy-preserving ILS architecture able to guarantee real-time user’s location and privacy of the data collected. The solution we propose in this work considers the General Data Protection Regulation (GDPR) as the grounding framework for preserving privacy through a compliant Access Control (AC) system [6–8]. The AC system ensures that only the intended users can access the protected (personal) data and get the permission levels required to accomplish their tasks. However, notwithstanding the important role of AC systems, their inte-gration inside the localization system architecture is still an emerging challenge specifically considering the enforcement of the GDPR’s re-quirements. Our solution relies on a privacy-by-design indoor positioning architecture, where purposes of data management are explicitly defined, consents collected and the rights related to privacy and data protection correctly enforced. We then discuss three use cases in which the archi-tecture proposed can be adopted, namely visits to a museum, airport access, and shopping in a supermarket. For each of the use-cases, we present the requirements for guaranteeing social distancing indoor. We also introduce some barriers currently preventing a massive adoption of ILS-based tracing systems and we conclude our paper with an evaluation framework aimed at assessing the performance.

The innovation we propose with our work mainly consists of four

Bluetooth Low Energy (BLE) [11,12], LTE [13], and Ultra-Wide Band (UWB) [14,15] signals. Wi-Fi-based solutions have the advantage of exploiting the ubiquity of Wi-Fi Access Points. The most performing Wi-Fi solutions obtain high performance in terms of localization accuracy with reduced cost of maintenance and installation [16].

In the last few years, the Bluetooth Low Energy (BLE) standard has been adopted a cheap a viable technology for indoor navigation and localization. BLE tags are cheap and easy to deploy, moreover their battery life time spans from few months to years.1Indoor localization systems based on BLE often implements a range-based technique, ac-cording to which the moving target is localized in proximity of the BLE tags with the highest Received Signal Strength of the beacons emitted ([17] explores this technique for the purpose of tracing social interac-tion). However, more advanced solutions based on the beacon’s angle or arrival and time of flight are also available with a very high accuracy level, as done with Quuppa2and the recent Bluetooth 5.1 stack.

Finally, the UWB network interface represents a recent and promising solution. Its accuracy can reach the centimeter-level with specific de-ployments. Its adoption has been increasing as Apple decided to provi-sion the iPhone 11 with the U1 chip-set. As a result, we expect that in the near future other vendors will include such technology with Android-

aspects: based smartphones. Some remarkable examples of UWB-based indoor

� we frame a reference architecture for social distancing based on an Indoor Localization System generalizing three common use-cases;

� we introduce a privacy-preserving access control system grounded on the European GDPR framework;

� we summarize three typical use cases in which the proposed archi-tecture can be adopted, by highlighting the intrinsic challenges of the

solution are the Pozyx [18] and some recent works [19–21]. Non-RF based technologies for indoor localization rely on visual/camera [22], Visible Light Communication (VLC) [23], Inertial Measurement Unit (IMU) [24], and Magnetic Field Sensor (MEMS) [25]. The visual based systems exploits images captured by surveillance camera already deployed. The performance range in the centimetre scale but, in wide and public environments, the privacy regulations might limit their adoption

social distancing; on the large scale. Differently, if the user/target is equipped with a

� finally, we discuss 4 main barriers to overcome for an effective adoption of such technologies in real-world settings.

camera sensor, a visual-based system can reach accuracy performance around a meter of error. Furthermore, the end-user is required to keep the camera in a fixed position with the side-effect of influencing the its

As recently reported by M. Zissman (MIT Lincoln Laboratory) in a natural way of moving.

recent article from J. Hsu [9], “[ …] In a perfect world, something like this would have taken a couple years to implement. There just isn’t the time [ …]”. We agree with such vision, and we consider that a great effort has to be spend for the integration of different technologies enabling the proximity detection of people both indoor and outdoor. Such effort will determine the success in fighting against the next pandemic.

The paper is organized as follows. Section 2 covers the background and related work in the field of Indoor Localization Technologies and GDPR-based Access Control. Section 3 describes our reference architec-ture for an ILS. Section 4 reports three reference use cases, namely visiting a museum, airport terminal access and shopping assistance. Section 5, we discuss some issues that we consider challenging for a real-world installation of an ILS and, finally, Section 6 describes our evalua-

The Visible Light Communication is an emerging optical technology for high-speed data transfer which uses visible light modulated and emitted by Light Emitting Diodes (LEDs). Indoor positioning systems based on VLC use light sensors (e.g. camera sensor) to measure the po-sition and direction of the LED emitters but they generally require line of sight between emitters and receivers [23].

Systems based on Micro Electro-Mechanical Systems (MEMS) exploit the distortion of the Earth’s magnetic field mainly due to structural steel elements (e.g. steel fire doors) and furniture. As an example, these dis-tortions can be a discriminating factor in environments comprised by corridors, rooms and small areas. The performances of these systems generally drops in wide and open space because the distortion are considered less meaningful [26].

tion framework. IMU based systems utilize tri-axial accelerometers and gyroscopes for

sensing the motion. The combination of gyroscope and accelerometer is

2. Background and related work

In the following, we focus on three main aspects that equally con-tributes to the proposed architecture: the related indoor localization technologies their specific characteristics 2.1; the Indoor Localization Apps 2.2 and the Access Control Systems 2.3. We discuss in particular the mobile application proposal able to deal with social distancing, exploring

used to evaluate the heading direction [27]. Unfortunately, accelerom-eters are error prone due to random movements of human motion and, the gyroscope is susceptible of magnetic fields distortion. As a conse-quence, IMU-based systems generally reach low accuracy and requires a complex calibration process to detect, for example, user’ step length and the motion speed [28]. We finally report on Table 1 a comparison of RF and non-RF based techniques, with a summary of their weaknesses and

their main strengths and weaknesses in terms of authorization to access strengths.

to the mobile resources requested to the user and their impact on user’s privacy.

2.1. Indoor localization technologies

Several localization technologies have emerged in the last years to address the demanding of location-based services. We review two cate-gories: Radio Frequency-Based (RF) and non-RF based. Among the RF technologies there exist systems based on the analysis of Wi-Fi [10],

2

P. Barsocchi et al. Array 9 (2021) 100051

Table 1 4. View network conn.: if the app can check the networks to which

A comparison between indoor localization technologies. the device has access;

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Technology | Strengths | Weaknesses | Accuracy | Scalability |
| Camera | High accuracy, | Requires dedicated | 0.5–1 m | Medium |
| low maintenance | hardware, difficult |

user identification

5. Full network access: if the app can access to any of the networks the device is connected with;   
6. Run at startup: if the app can automatic restart;   
7. Prevent device sleeping: if the app can prevent the device from

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| VLC | Potentially high | Requires line of | 0.5–1 m | High | switching in sleeping mode; |
| IMU | accuracy, easy to | sight, requires | N.A. | 8. Pair BT devices: if the app can pair with a Bluetooth device; |
| install | additional hardware |
| 1–5 m | 9. Access BT settings: if the app can initiate the device discovery or |
| No infrastructure | Requires high |
| modify the Bluetooth settings; |
| required | customization, error |
| MEMS | Ubiquity of the | prone to drift | 2–5 m | N.A. | 10. Control vibration: if the app can control the device vibration; |
| problems | 11. CRUD contents: if the app can perform CRUD operations; |
| Error prone to | 12. Take pictures or videos: if the app can take photos of record |
| signal, no | interference, costly |
| videos. |
| infrastructure | calibration process |
| Wi-Fi | required | Medium accuracy, | 2–4 m | High | Taking a glimpse as a generic user to the installation and usage of the |
| Easy to |
| BLE | implement, cost | generally require | High |
| apps analysed in the Table 2, the consent forms are very generic and |
| efficient | modifications to the |
| sometimes do not intuitively declare the purposes of data collection, the |
| 2–4 m |
| APs |
| Low energy | duration of the data retention or the possibility of future exploitation of |
| Error prone to |
| consumption, low | noise, medium | the data collected. |

cost accuracy in wide   
 environ- ment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| UWB | High accuracy in | Requires dedicated | 0.5–1 m | Low |
| small | hardware, high |
| environment | costs |

data fusion approach leads to improved performances in the same indoor environment. In [30], authors describe an extensible framework for exploring location data’s multifaceted representations and exposing a query layer. Lastly, Anyplace [31] shows a similar idea to the other ar-chitectures above mentioned by releasing an open-source architecture in order to easily deploy indoor localization functionalities in new environments.

2.2. Indoor Localization Apps

The most diffused technical solutions for guaranteeing social distance are based on mobile applications. Apps enable an easy-to-use user interface and, at the same time, a massive diffusion through the well-known app stores. Currently, there exist several applications whose features span from tracing contacts, e.g., Immuni [32] (the application build by Italian Health Minister), to the possibility of managing a waiting queue, e.g., ufirst [33].

Depending on their features, the apps require access to several entities and purposes. From a privacy-preserving point of view, unfortunately, not all the apps expose neither a clear claim about the usage of the collected personal information nor a clear description concerning the usage of such data. Consequently, we argue that the end-user might remain sceptic in daily using such apps. In order to provide a first outlook about the existing apps for social distancing or for detecting in social interactions [17], we report in Table 2 a selection of apps available on the Android Play Store and tested on a commercial smartphones. The table reports the analysis of some features and the authorizations required. In particular, the group of columns labelled Location, Others, Disk, Camera, report the name of the permissions’ classification provided by the Android Play Store for grouping the different features. Finally, for each group, we report some details concerning the permissions of each app based on the description provided by the developers. In particular, we report the following information:

1. Approx location: if the app can localize the device within a wide

For example, one application (the 2M Social distance checker) re-quests permission to access to the Call Log and Address Book without specifying how the data will be used, i.e., to enable the sharing of user experience with his/her contacts. From a technical point of view, in case of open-source applications [34] specific information about the real usage of sensors data or the procedures for managing them can be retrieved by accurate analysis of the source code. However, this opera-tion is not feasible by common users without a computer science back-ground and it is not allowed for proprietary application [35,36].

Additionally, rarely there is a clear claim on where and how the collected data will physically be stored or distributed. Indeed, depending on the country where the DB is, the rules for accessing its information could be compliant to a privacy standard different from that required by the application country. The situation could be even worse in case when the application is used by users belonging to different countries having not the same privacy rules. Consequently, there could be the risk of a personal data management not completely compliant with the consensus signed by the app users. For instance in Italian Immuni [32] (The application built by Italian Health Minister) developers clearly claims that the DB will be physically positioned in Italy and managed by the Italian Health Minister under the GDPR compliance.

Social distance can also be implemented with ad-hoc hardware components like people counter and smart bracelets [37,38]. These so-lutions have the benefit of guaranteeing reliability, since they do not dependent on the user’s device. The features offered are limited to tracing the contacts with others or alerting when a user gets too close to another. More advanced features can also be implemented with data analysis techniques but, at the current stage, we were not able to find remarkable examples in the current literature.

2.3. GDPR and Access Control Systems

We now review some techniques adopted with Indoor Localization Systems that are commonly adopted to manage the privacy of the data collected. We first review the GDPR reference framework and then we survey some recent works. The GDPR [39] defines Personal Data as any information relating to an identified or identifiable natural person called Data Subject. As a result, a data subject is a Natural Person (a living human being), whose data are managed by a Controller. The GDPR is applied to the processing of personal data, whether it is automated (even partially) or not. The GDPR defines, among others, the following prin-

area; ciples and demands: Purposes, i.e., data should only be collected for

2. Precise location GPS & net: if the app can accurately localize the determined, explicit and legitimate purposes, and should not be pro-

device; cessed later for other purposes; Accuracy, i.e., the processed data must be

3. Receive data from Internet: if the app can receive data form accurate and up-to-date regularly; Retention, i.e., data must be deleted

Internet; after a limited period; Subject explicit consent, i.e., data may be collected

3

P. Barsocchi et al. Array 9 (2021) 100051

Table 2   
Features of social distancing mobile apps.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| App name | LOCATION |  | OTHERS |  |  |  |  |  |  |  | DISK | CAMERA |
|  | Approx | Precise | Receive | View | Full | Run at | Prevent | Pair BT | Access | Control | CRUD | Take |
| location | location | data from | network | network | startup | device | devices | BT | vibration | contents | pictures |
| GPS & net | Internet | conn | access | sleeping | settings | videos |
| Social | ✓ |  |  |  |  |  |  | ✓ | ✓ | ✓ |  |  |

Distancing   
Project (Su-  
 Raksha)

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| The Social | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Distancing App

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Social | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Distance

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| REXdistance | ✓ | ✓ | ✓ | ✓ |

Social   
 Distancing

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Social | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Distance   
Alarm

|  |  |  |  |
| --- | --- | --- | --- |
| Social | ✓ | ✓ | ✓ |

Distancing

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 1point5 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Give Me Space | ✓ | ✓ | ✓ | ✓ | ✓ |

The Best Social

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| [ …]  Social distance | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Social | ✓ | ✓ |

Distancer

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Distancing | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

App

|  |  |  |  |
| --- | --- | --- | --- |
| Social | ✓ | ✓ | ✓ |

Distance

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Social | ✓ | ✓ | ✓ | ✓ | ✓ |

Distancing   
App

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pistis.io Social | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Distancing App

|  |  |  |  |
| --- | --- | --- | --- |
| Distancing | ✓ | ✓ | ✓ |

alarm

|  |  |  |
| --- | --- | --- |
| 2 M Social | ✓ | ✓ |

distance   
checker

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Social | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Distancing   
App - Wearable

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Keep Distance | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Immuni | ✓ | ✓ | ✓ | ✓ | ✓ |

and processed only if the data subject has given his explicit consent.

Concerning the design of the Access Control (AC), it is usually implemented through an Access Control Mechanism (ACM), which is the

system providing a decision to an authorization request, typically based on predefined Access Control Policy (ACP). The XACML [40] is one of the most widely used AC languages, and it provides the reference

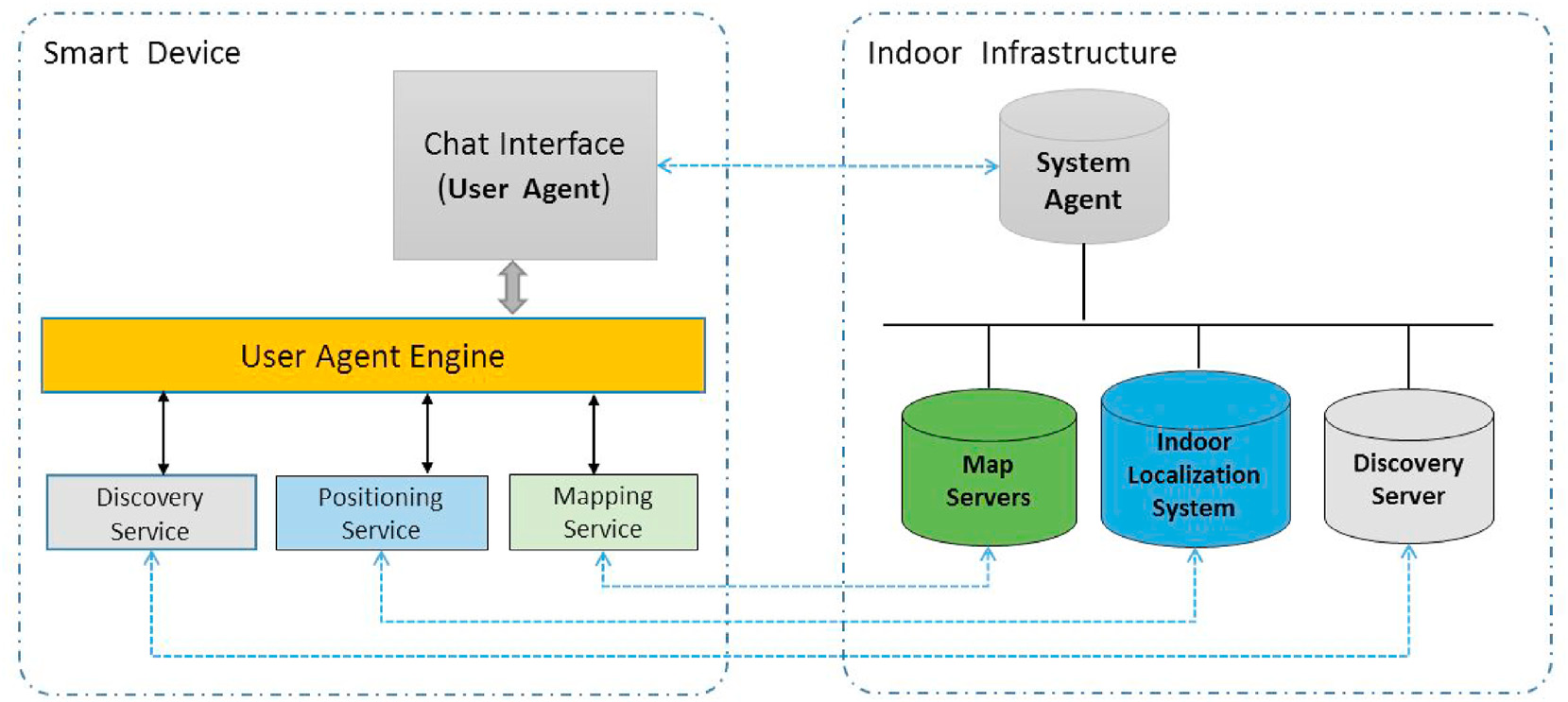


Fig. 1. Functional components of the integrated architecture.

4

P. Barsocchi et al. Array 9 (2021) 100051

architecture in the AC environment. open market, since it breaks the silos of custom and vertical solutions

We refer to [41] for a systematic review of privacy in indoor posi- available so far.

tioning systems. As emerged by this survey, recent proposals show how location and topology-aware are becoming feature for the security [42].

However, most of the research has been focused either on:

� using technology Wi-Fi and the fingerprinting methods combined with cryptography solutions [43–45];  
� using access control mechanisms for (physical) protection within virtual perimeters [46];  
� using location information to automatically authenticate customer [47];  
� specific security attributes that do not fully cover the GDPR’s re- quirements [48–50].

3. Overview of the integrated architecture

In the following, we detail the reference architecture based on an Indoor Localization System (ILS) for guaranteeing social distancing. The architecture relies on two layers: the smart device and the localization infrastructure. As detailed in Fig. 1 these layers include components such as: a User Agent for managing the interactions on behalf of the end-user, the Indoor localization system including GDPR-based Access Control subsystem and the Map server. The reference architecture extends the solution presented in [4], and it integrates the GDPR-based access control

Concerning the second benefit, we consider that the current user experience for outdoor localization systems (e.g. GPS) must be preserved also indoor. Under this context, the standardization could improve the design of systems enabling the hand-off between outdoor and indoor areas. We imagine a smooth transition from an outdoor map (e.g. pro-vided by OpenStreepMap or Google Maps) to detailed indoor maps provided by an ILS.

As first step towards such standardization process is the definition of architectural requirements to be considered. In the following, we report a list of 4 requirements that we consider mandatory:

1. To discover the available Indoor Localization System dynamically (R1)

A discovery process should be defined to enable a person to look up for services available in a specific environment [53]. The process can be triggered through the Web or based on short-range network in-frastructures. We refer to the first approach as global search, since the user queries the Web looking for an ILS available e.g. in a supermarket. In this case, the user fetches the meta-information of an ILS via the HTTP or similar protocols. Differently, the second approach is referred to as local search since the user looks up for nearby ILSs, by exploiting network interfaces such as Wi-Fi Direct, Bluetooth or LTE- Direct and the up-

described in [51,52]. coming 5G. Such interfaces allow to look up for surrounding services in

the range of few meters.

3.1. Aim and scope

2. Indoor localization systems must self-describe their features to ensure

The approach we followed with this work is to firstly framing a reference architecture to be adopted in very different scenarios. To this purpose, our effort has been mainly focused on generalizing a common architectural design of a remote ILS, based on 3 main building blocks: a map server, the ILS engine, and a discovery agent to broadcast its exis-tence. We then focus on the client side in the form of a smart device, as the primary interface to interact with the end-users. The architecture we propose has been deliberately designed without constraining to any of the common scenarios we daily experience. Differently, we tried to

interoperability with heterogeneous systems (R2).

We expect the definition of a common language for describing the features provided by an ILS. More specifically, ILS has to advertise some core information, such as: the localization technology adopted, the pri-vacy requirements, the location of the indoor map and any other resource required for a device to discover, connect and access to the ILS. The benefit of such language is the possibility of replicating the user-experience for outdoor navigation (e.g. through Google Maps or

provide the community with a modular architecture to be customized. similar) also indoor.

Furthermore, the current literature concerning the ILS does not identify a

standard de-facto for indoor localization, rather multiple and heteroge-neous solutions are available. To the best of our knowledge, this work introduces a privacy-by-design solution, mainly inspired by the European GDPR framework, as one of the most advanced regulations about privacy in force since the last decade.

3.2. Architecture requirements

Indoor localization systems are based on very different technologies. A standardization process of these systems is therefore the first objective that should be pursued in order to increase the spread and the usability of location-based services. We argue that standardized programming in-terfaces for the design of an ILS have a twofold benefit:

� to provide inter-operable location-based services to the end-users:� to integrate in a seamless way outdoor and indoor localization systems.

Concerning the first benefit, its adoption can be used not only to locate and track people, but also to measure their physical distance. Its adoption can be considered an effective counter-measure to track, pre-vent and analyse how close people are in indoor environments. We refer to Section 4 for a in-depth description of three use-cases in which we describe the adoption of an ILS in real-world scenarios. Moreover, the standardization will increase the possibility for a user-agent to discover and to bind to any of the ILS available indoor. Such aspect is crucial for an

5

P. Barsocchi et al. Array 9 (2021) 100051

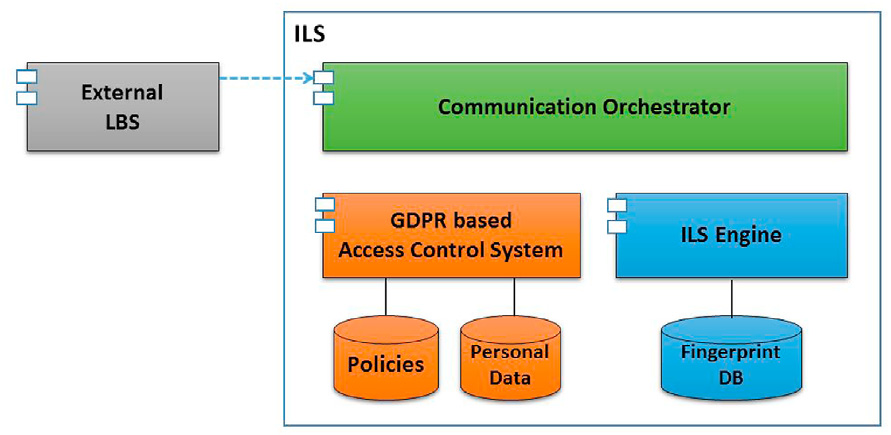
that can always be represented as a pair of coordinates in the space (e.g. lat, long as WGS84 coordinates). The same user-experience should be replicated also for indoor environment, even if a higher number of challenges are present. To this purpose, we consider mandatory to design intuitive work-flows. As for example, the end-user should be able not only to search for a location, but also to navigate toward person, to pick up a list of products in a specific order or to meet a moving target indoor. A further level of interaction is also represented by the possibility of asking to an ILS context information describing the environment, such as the existence of a crowd or the waiting time before accessing a service. Such level of interactivity can be obtained by designing multi-modal interfaces, such as the Instant Messaging (IM) paradigm. Indeed, the IM paradigm implements the best metaphor for managing the exchange of information between the end-users and a system in a intuitive way. The user can chat with the ILS in order to get the position of its target, to receive suggestions, to be notified proactively and or to be guided step-by-step toward its final destination.

3.3. Architectural components

The requirements R1 to R4 are grounding for our architectural design. We describe in this section, several functional components to be deployed in two distinct layers: those present on the user device and those made available by the indoor infrastructure. This distinction easily recalls the two methods through which the position of a user is estimated: self-positioning processed by the smartphone and remote positioning processed at the local infrastructure. We also consider the possibility of having hybrid solutions. We report in Fig. 1 an overview of the compo-nents described. For the sake of brevity, we do not consider here the possibility of other solutions that could make use of the Cloud. For example, internal maps could be downloaded from any server on the Cloud (e.g. Google Maps), as well as a route to a target calculated by a navigation service available on the cloud. We mainly focus on abstract functionalities common to all the architectures and how they are to be described. Therefore, many concrete architectures can be derived by combining the abstract components we report in Section 4.4. We report in Fig. 2 an overview of the main components.

In the first group of components, the most important is the User-Agent. It can be described as an intelligent software component that operates on behalf of the end-user. The main functions it provides are: global and local discovery (R1), to manage the privacy for the end-users (R3), to interact with the local infrastructure to estimate position of the end-user (R2), to interact with the end-user (R4). Other functional components that could be installed on the device are the Navigator and a Translator, the first of course to manage navigation, determination of the shortest routes etc, the second is increasingly adopted to facilitate vocal interaction, as done with commercial vocal assistants (Amazon Alexa, Apple Siri, Google Home) (R4).

The second group of components concern the infrastructure. In particular, the Indoor Location System and the Map Server (R2, R3). The first consists of hardware and software artifacts deployed in the environment that are functional to the estimation of the user’s position and the data protection, as detailed in Section 3.4. The second one



provides the indoor maps and features of the indoor environment useful for navigating. Other components we foresee are the Discovery Server which provides the description of the resources available by the infra-structure (R1, R2) and the System Agent which is the counter-part with which the User Agent can communicate. In particular, the System Agent can be seen as a regular chat user to which send requests for assistance or information (R4), it can be implemented by an Instant Messaging bot. Components deployed in the infrastructure are interfaced by respective services orchestrated by the User-Agent. A person trough the User-Agent interface can interact with the System-Agent of the indoor infrastructure.

3.4. Indoor localization system and data protection

We now detail the internal structure of a generic ILS. We consider it provides three main sub-components, as detailed in Fig. 2: the ILS En-gine, the GDPR-Based Access Control System (G-ACS) and the Communication and Interaction Orchestrator. Such components implement the main features of an ILS. Moreover, we expect that they rely two distinct database for collecting the information.

The ILS Engine implements the core functionality of the localization algorithm: it returns back to the User Agent the timestamped coordinates according to the map reference system (e.g. latitude and longitude as WGS84 reference system) [10,54].

Data provided by an ILS can be simultaneously accessed by multiple actors. More specifically, the end-user, the system administrator or a generic supervisor might require access to specific data. In order to manage the different grants for the actor, we consider that the ILS and the GDRP Access Control System (G-ACS) components have to cooperate (see Fig. 2). In particular, the latter is in charge of evaluating each single data access request and to allow or deny the access according to several fac-tors. They are: the consents collected, the data validity period, the spe-cific users/service rights and the access control policies established inside the overall Localization Infrastructure.

Finally the Communication and Interaction Orchestrator is the component in charge of man-aging the communication to and from the ILS. This component is exploiting publish-subscribe design pattern through extensible events. It is in charge to instantiate communication channels and manage flows of notifications and events data. Those events can be structured adopting several asynchronous messaging technologies like Java Messaging Service (JMS), Advanced Message Queueing Proto-col (AMQP), Message Queueing Telemetry Transport (MQTT) in order to decoupling not only the locations of the publishers and subscribers, but also decouple them temporally.

3.5. Components in action

The interaction among the components described in reported in Fig. 3. The indoor infrastructure periodically advertises its presence broadcasting an URI. The URI points to the meta-information of the ILS. When the end-user enables the indoor positioning on its device, the User Agent starts listening for such announces (Listen for URI activity). The Discovery phase ends when the User-agent accesses the URI in order to obtain the description of all the resources that are part of the infra-structure. The structure of the information obtained during the discovery phase represents a key-point. We report a schematic example of such information in Fig. 4. The information reported can be represented following different formats, such as JSON or XML text-based format.

The Access stage can now start. During this stage, the end-user grants or denies some consents required by the ILS to work properly (Consent evaluation). This process can also in-volve a more fine-grained assess-ment of the consents (specialized consent acceptance activity), depend-ing on the kind of services to be used. If consents are accepted, the subscription data as well as the collected consents are used by the G-ACS

Fig. 2. ILS and Data protection components. System for example:

6

P. Barsocchi et al. Array 9 (2021) 100051

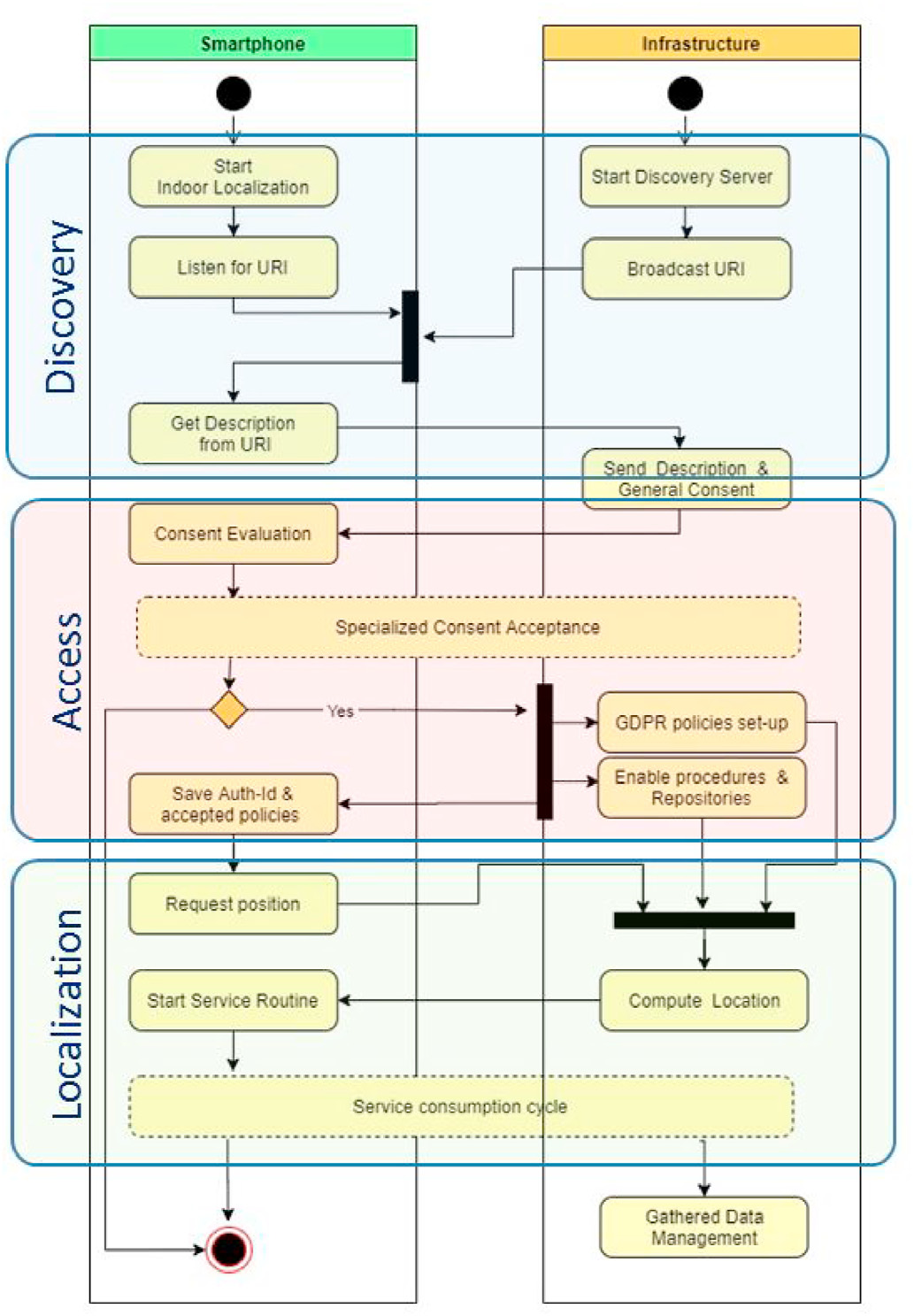


Fig. 3. Activity diagram for the system components.

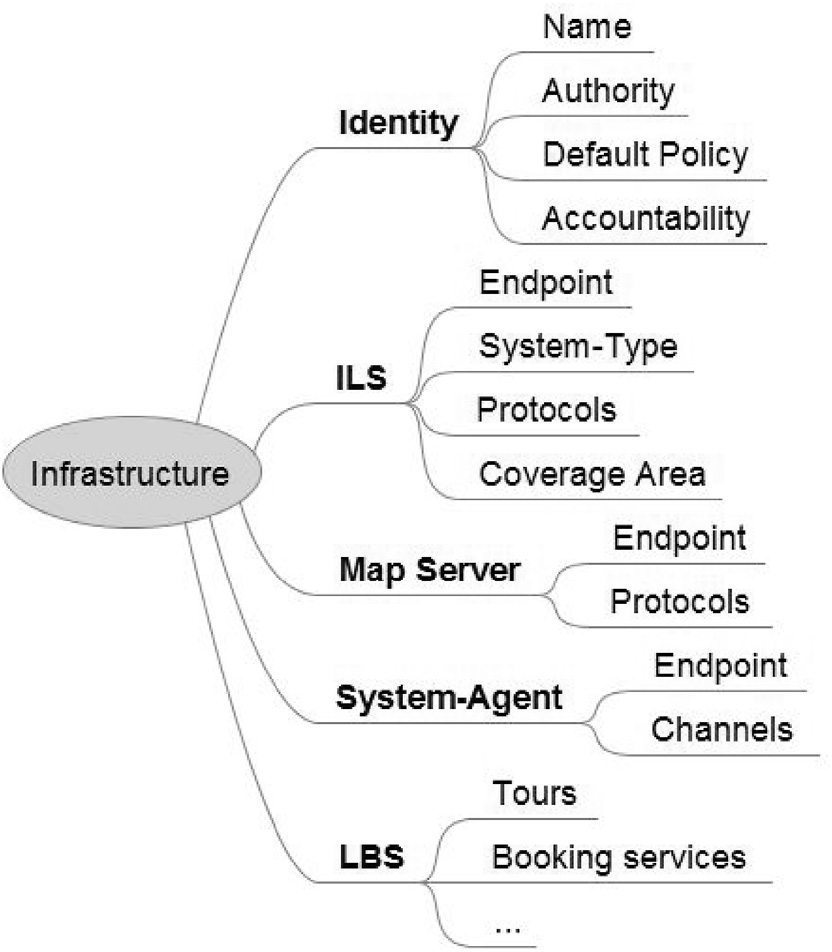


Fig. 4. Information describing an ILS through a Discovery Process.

� setting up the user specific GDPR-access control polices in order to guarantee that all the information collected and exchanged between

7

P. Barsocchi et al. Array 9 (2021) 100051

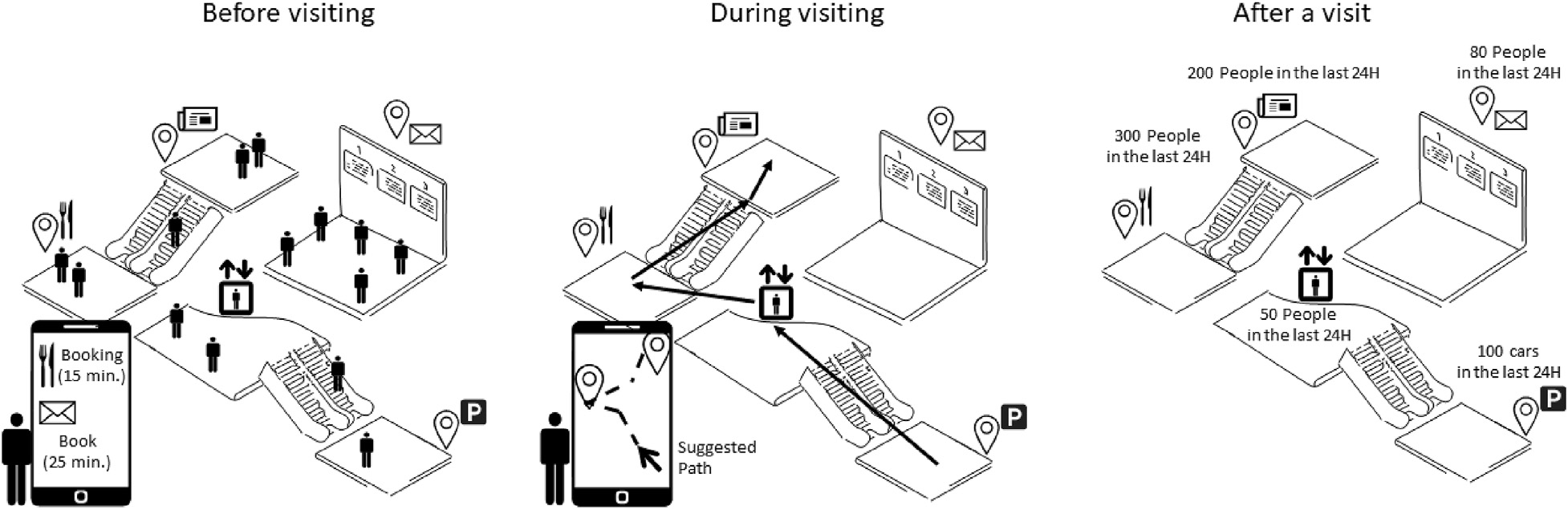


Fig. 5. How information about social distance can be used before, during and after visiting a generic indoor environment.

to follow, while others have multiple paths. Users following a path do not have any time restriction during their visits, they are free to move across the rooms and to rest. Moreover, the number of visits in a museum changes dramatically according to several factors, such as the day of the week, the hour, the scheduled holidays as well as the whether conditions. The combination of such factors determines the existence of burst of visits, as discussed in Ref. [55] that are challenging to predict.

The requirements that need to be preserved during a visit are:

� users have to be able to respect easily the distance from other visitors;� the total number of visitors has to be managed;  
� design multiple visiting paths so that to reduce the encounter prob-ability among visitors;  
� the user-experience needs to be guaranteed during a visit;  
� users can wear a wristband or install a specific app before their visit;

We consider that the adoption of an indoor localization system in a museum can support the adoption of effective countermeasures for limiting crowded areas. More specifically, the knowledge of the position of the visitors can be used for 1) observing the way visitors access the museum and 2) to manage in real-time the flow of visits. Concerning the first goal, we argue that it is highly important to measure quantitatively the way visitors access a museum. More specifically, it is possible to measure the total amount of visits, the visits during a specific time in-terval, the visiting time for each room and artwork, the existence of preferential paths during a visit and other metrics useful to describe the social attitude of the users. Such information, can be in turn used to meet the second goal, namely to plan the visits according to the requirements

in which users freely roam. An airport terminal provides several services for the end-users. Some of them are mandatory to all the passengers, others are optional and provided only for the entertainment purpose. The number of users accessing to such services changes dramatically ac-cording to the seasons and according to external factors, such as weather conditions, strikes and delays of the flights.

The requirements that need to be preserved for travellers in order to guarantee appropriate social distance are:

� the airport facilities have to be accessed with a pre-determined order. More specifically, users have to check-in, to pass through the security clearances and, finally, to step toward the destination gate. The order and the time to complete the previous steps should be orchestrated so that to consider: the amount of users, the existence of crowds and any situation leading to involuntary contacts;  
� users have to be able to respect easily the distance from other users;� the user-experience must be preserved as much as possible;

Also for this use-case, we consider beneficial the adoption of a modular indoor localization system tracking the distance among users. In particular, the indoor localization system can be used for detecting the existence of crowds in a specific location e.g. check-in desks and to prevent other passengers to stack in queue. Furthermore, such localiza-tion system can be also exploited for security tasks, such as identification and tracking of target subjects. The majority of the terminals are already equipped with Wi-Fi networks available also for traveller. Some works already address the problem of localizing users in an airport. Authors of [59] proposes a multi-modal solutions based on Wi-Fi and BLE tags.

previously reported. Through the availability of a precise map of the environment and an

Users can be localized by adopting proximity-based technologies such as Bluetooth Low Energy (BLE) or the UltraWide frequencies. Such technologies are becoming more and more popular. In particular, BLE is already available in most of the commercial smart devices, while the UltraWide technology is expect to diffuse in the near future. It is worth to notice that the iPhone 11 already provides the U1 chip-set. Bluetooth and UltraWide band allow to detect proximity not only between users but also between users and points of interests such as artworks or furniture. Moreover, such technologies can be easily integrated with personal de-vices such as smartphones or an audio guides without the need of a complex network infrastructure. Some remarkable works already addressed the problem of localizing people in a museum, we refer to Refs. [56–58] for further details.

4.2. Use case 2: airport access

The layout of an airport is generally a combination of indoor/outdoor multi-floor environments with restricted areas. Except for shops, gener-ally the airports offer multi-storey buildings within wide and open spaces

8

P. Barsocchi et al. Array 9 (2021) 100051

distance between customers are:

� specific products need to be booked in advance so that to reduce the number customers waiting in the same location;  
� users should be able to easily respect the distance from other users;� the user-experience must be preserved as much as possible.

A shopping mall equipped with an indoor localization system can provide several services for customers. We foresee the possibility of optimizing the path to follow in order to completing the shopping list. Moreover, the supermarket can provide a queue management service that notifies the customers when to approach to a specific desk. Finally, a supermarket can provide services for personalized advertising to the end-users. In fact, indoor positioning systems shall make available a set of personal data which can be exploit to promote sales products or to pro-mote temporary offers.

In the last decade, supermarkets have been equipped with internet access, throughout Wi-Fi Access Points deployed in the environment. These APs can be exploited also to provide an indoor localization ser-vices. The more promising technique in this environment is the finger-printing technique, where the RSSI previously collected together with the position of the user is leveraged to infer the current user position [61]. In fact, the accuracy of this technique ranges in the order of few meters and, exploiting also inertial sensors of the smartphone, ILSs are generally able to localize users accurately. A distributed ILS can provide meaningful information before, during and after shopping. For example, before shopping, users can use the aggregated information about the number of current buyers to plan the purchases or not. During shopping, the user is reassured about the use of the ILS which can provide a “safe route” as described before. After shopping, information related to all the routes followed by customers can be used to thoroughly sanitize the most fre-

Finally, in relation to the Smart Device we found several client in-terfaces that can be customized. Among them, we consider that Telegram app5is a valuable alternative since it offers the possibility of customizing the popular chat-based application by reusing most of features available. Such choice allows to include specific features enabling the localization, the discovery and the map rendering in a chat box. We finally remark that guidelines for choosing the proper technical solution are out of the scope for this paper but, it is worth to remark that these design decisions strongly depend on the considered use cases.

5. Towards social distancing through ILS

We now discuss some issues related to the concrete possibility of adopting an indoor localization system for the purpose of measuring the distance among users. This section covers different aspects of its adop-tion. In particular, in subsection 5.1 we discuss the impact on the privacy and trust reputation of the ILS. Subsection 5.2 focuses on the discovery phase of ILS. Subsection 5.3 presents two alternatives for the social distancing, namely a manual and automatic approach and, lastly, sub-section 5.4 concludes with a description of some challenges of the deployment phase of an ILS in real-world settings.

5.1. Privacy and trust reputation

Our first consideration faces with the problem of how to guarantee privacy of data collected by an ILS. We refer to [63] for complete survey also covering the following issues.

Privacy by design encompasses seven principles that should be fol-lowed [64]: proactive privacy protection instead of remedial action after privacy violations have happened; privacy as the default setting; privacy embedded into the design; full functionality with full privacy protection;

quented spaces. privacy protection through the entire life-cycle of the data; visibility and

transparency; and respect for user privacy. Solutions for incorporating

4.4. A reference architecture for different use cases

Although our goal is not to define a reference implementation of the architecture described in Section 3, we consider that some of the com-ponents in Fig. 2 can be implemented with existing software artifacts available in the current literature. We report in this section some meaningful examples both for the Indoor Infrastructure and for the Smart Device.

Concerning the Indoor Infrastructure, the Map Server is responsible for managing the indoor map. In particular, it provides the base maps or a tile set covering a specific area. The Map Server couples with the client side, in charge or downloading (possibly, with parallel connections) and rendering the map on a e.g. 5-inch screen. Both modules are available in literature and can be re-used as third-party black boxes. As for example, the open source map-view solutions, open layers and leaflet are available. According to the specific needs, it is also possible to adopt different Map Server such as mapbox, Google Maps and AcrGis.3   
 Concerning the ILS engine the literature also offers some interesting and open source solutions that can be deployed as off-the-shelf products, among them we refer to Anyplace as a complete framework for indoor localization comprising API, Viewer, Navigator and Logger components.4 We finally mention some existing discovery protocols that can be embedded with the Indoor Infrastructure to discover the server in a seamless way. In particular, the SLP, UPnP, ZeroConf and WS-Discovery are old-but-robust valuables candidates for discovering networked re-sources [62]. Moreover, if the goal is to implement a local discovery then the Bluetooth beaconing and the Wi-Fi probing also represent two interesting protocols that can be used to broadcast small chunk of information.

3 <http://openlayers.org>, [https://leaf](https://leafletjs.com/)l[etjs.com/](https://leafletjs.com/). 4 [www.indoorlocation.io](http://www.indoorlocation.io/)[/](https://leafletjs.com/).

9

P. Barsocchi et al. Array 9 (2021) 100051

5.2. Discovering an ILS with local and global interfaces

The capability of discovering an ILS automatically is a central aspect. We consider two possible approaches for the discovery phase: local and global. The local discovery is based on the analysis of local signals when entering a new environment. In this case, the user exploits short-range network interfaces looking up for nearby signals. However, we consider that a global search is required as well. In this last case, a standard search through a web-browser allows to query and to connect with the ILS. We recall the well-known user experience though which users look for services on a search engine. The search engine summarizes to the user a box with key information about the service, such as the street address, the opening hours, the popularity of the service (e.g. Google Popular Times). We expect to extend such list, by also reporting the information of the Indoor Localization System, e.g. showing an URL

respect to a range-based approach, fusing data together allows to over-come issues such as body attenuation, indoor reflections and multi-path fading. The side-effect of an Indoor Localization System is the mostly represented by its installation costs.

The current trend is to adopt solutions for preserving the social dis-tance that are based on apps for smartphones. We consider that such approach might fail on the large-scale and on the long-term. We consider necessary to understand those practicable alternatives and how to gradually move from the use of apps to the use of infrastructures, such as an Indoor Localization System.

If we consider that people are well predisposed for social distancing through the use of sight, a first discriminating factor is the type of environment. In open spaces, such as a supermarket, people will have greater ease of self-determination if a situation is risky or not. Differently, in indoor and constrained environments people need to be supported

with the meta-information reported in Fig. 4. with automatic tools.

Mobility in multiple indoor environments increases privacy issues. Continuing on the example of the outdoor navigation services offered by Google, we know that the people who activate the history of their posi-tions are tracked by Google, which, through the user account, allows you to view your movements and possibly eliminate them entirely. In the case of indoor navigation, this information will be collected by multiple subjects who must make it accessible to the owners of the data both for consultation and for modification. The task of the User Agent in this case becomes essential, because it must be capable of maintaining a history of the indoor sites visited. In particular, it must keep track of the policies and consents signed by the user, as well as links to the various interfaces to access the consultation and modification services of personal data. Nevertheless, much of this information must be conveyed during the Discovery process (Figure JSON file) Privacy management in general is more complex than the use case presented here, de-pending on whether the localization techniques used are Self-positioning or Remote posi-tioning based. Systems that intrinsically guarantee privacy should be favoured, in which the position is estimated by the user agent (self-positioning) and is not known by other subjects, such systems are also more scalable. However, with respect to social distancing, you must in any case give up your rights and reveal your position even if used only anonymously, therefore defining an access control based on GDPR is always an indispensable step.

The transition from manual to automatic systems for social distancing requires bridging technologies able to reduce the deployment costs. As a remarkable example, we mention those systems designed to count the number of people in each room. Once a certain density has been reached, the system warns incoming people, in order to limit the access to such places. In any case, even if a precise localization system is not used, common interfaces must be studied through which to communicate to all end-users. Other aspect to consider is that the turnout of people could be estimated from the reservations that are made to visit a certain envi-ronment. This practice is currently used by the most visited museums, where you can buy tickets online and avoid long queues to buy tickets. In other environments such as airports, by integrating the various infor-mation systems of the airline companies, the number of people at a certain time can be determined on the basis of the scheduling of flights departing and arriving. Obviously, this is an alternative to preparing new infrastructures for localization, but it is an estimate that can be affected by various random factors, lost reservations, flight delays, random congestion. But even in this case, an interface to people who access the environment/system is necessary to allow it to check the crowding status and possibly receive notifications.

5.4. Deploying an ILS in real-world environments

We now discuss some deployment issues of an ILS that at realistic

5.3. A dichotomy of manual and automatic social distancing conditions.

Deploying an ILS requires to accomplish at least the following two

Another crucial aspect is the safety distance among people (usually fixed in the range of 1–2 m) which is normally perceivable on sight. People in favour of using automatic tools to support social distancing are already well prepared to keep the right distance from others. We observe two conflicting requirements: firstly, service providers e.g. a shopping centre, aim to increase the number of customers while, secondly, cus-tomers are interested to access a service scarcely populated. Therefore, a service obeying to the current prescriptions will grant the access to the maximum number of admitted customers. Such situation is generally perceived by the final users as potentially unhealthy, even if customers stay 1–2 m away from others. Such consideration is predominantly of psychological nature. However, we argue that also the adoption of apps for preserving the social distance do not resolve the dichotomy between number of customers and distance among them. In fact, the false posi-tive/negative alerts of such app, combined with the privacy issues pre-viously mentioned, discourage their use in the daily basis.

Under this respect, the technology adopted by the apps is determinant for their successful adoption on the large scale. More specifically, range-based applications (i.e. based on Wi-Fi/Bluetooth signal strength) often fail in crowded scenarios or in those environments characterized by barriers and obstacles. Differently, the adoption of indoor localization system based on the data-fusion techniques are more reliable in such circumstances. Data-fusion allows to gather and to combine heteroge-neous sensing and context information. Although more complexity with

10

Table 3   
Evaluation framework of the reference architecture.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| End-user | KPI | Objective | Measuring tool | Unit | Issues |
| Personalized | To measure the overall impression of the final | questionnaire, survey | Statistics with the reported answers | 1. Share the questionnaire |
| Smart-Device | feedbacks | users (feel of protection, motivation is using | users feedback: average number of scores | Statistics with the reported answers | 2. Bias of the answers caused by |
| the app) | frustration and anxiety emotional states |
| User acceptance |
| The success of ILS depends on the way the user | none |
| Energy consumption | interacts with it | received | (Milli) Watts consumed by the app | none |
| To measure the impact of the app to the | Reporting APIs provided by iOS and |
| App usage | battery life-cycle | Android SDKs | 1. Average usage time | To manage appropriately any sensitive |
| To estimate the usage of the app and the | Reporting APIs provided by iOS and |
| voluntary/involuntary stops of thew app | Android SDKs | 2. Number of crash | information collected |

3. Number of stops of the app

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Discovery and Access | To measure the time required by the app to | Profiling APIs available for iOS and | Milliseconds | none |
| latency | discovery and access to the Indoor | Android SDK |

infrastructure

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Initial localization | To measure the time required by the app to | Custom reporting APIs profiling. | Milliseconds | none |

compute the initial localization of the device

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Maps Data transferred | To measure the amount of data transferred for | Profiling APIs available for iOS and | #byte | none |
| rendering indoor maps | Android |

SDK or Custom reporting APIs profiling

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Indoor | location latency | To measure the time required by the | Custom profiling API server-side | Milliseconds | none |
| infrastructure | ILS load | infrastructure to localize the smart device. | Performance profiling tools (e.g. Java JMX, | 1. CPU load | Overhead of the profiling tool |
| To measure the computational load of the |
| Map Server load | ILS to estimate the position of all the devices | Python DataDog client, Visual Studio | 2. RAM allocated | Overhead of the profiling tool |
| connected | profiler) | 3. Data structure inspection |
| To measure the computational load of the Map | Performance profiling tools (e.g. Java JMX | 1. CPU load |
| Server to provide maps to the clients | interface, Python DataDog client, Visual | 2. RAM allocated |
| Studio) | 3. Data structure inspection |

4. Data transfer rate

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| performance of the | To measure the correct detection of devices in | Custom reporting API | Confusion matrix from which extract: | To compare the results obtained with a |
| proximity detection | proximity | Accuracy, Precision, F1, k-Statistics etc. metrics | reliable ground-truth to build the |

confusion matrix

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| update location | To measures the system’s capacity to re- | Custom reporting API | Ratio between the number of received samples and | none |
| frequency | compute the user’s locations seamlessly | the number of expected samples (for instance one |

every second).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Service- | Installation complexity | To measure the technical issues behind a | Custom reporting tool maintenance effort | Time of installation and of configuration, | none |
| provider | correct deployment the indoor infrastructure |

P. Barsocchi et al. Array 9 (2021) 100051

settings. As a meaningful example, we refer to the fingerprint-based techniques (see subsection 2.1). In this case, the localization system re-quires a database mapping the quality of the radio signals (e.g. Received Signal Strength Indicator) with a number of locations. Such database is generally built only after the hardware installation and it can be obtained with a data collection campaign often achieved manually by an expert. Another representative example of configuration is represented by all the algorithm settings of the ILS it-self. Such settings, very often, model features of the environment and they can be tuned only after the installation of the system in the target environment. Nevertheless, the configuration of a ILS is not one-shot task. Rather, real-world localization systems configured and re-configured multiple times during their life-cycle. Some factors that require a new round of configuration are: envi-ronmental changes such as new obstacles or a new layout of the envi-ronment, new areas to be covered or modifications due to hardware

Conceptualization, Methodology, Investigation, Supervision, Visualiza-

tion, Writing – review & editing. Antonino Crivello: Conceptualization,

Methodology, Investigation, Supervision, Visualization, Writing – review

& editing. Said Daoudagh: Conceptualization, Methodology, Investiga-

tion, Supervision, Visualization, Writing – review & editing. Francesco

Furfari: Conceptualization, Methodology, Investigation, Supervision,

Visualization, Writing – review & editing. Michele Girolami: Conceptu-

alization, Methodology, Investigation, Supervision, Visualization,

Writing – review & editing. Eda Marchetti: Conceptualization, Method-

ology, Investigation, Supervision, Visualization, Writing – review &

editing.

Declaration of competing interest

replacement. The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence

|  |  |
| --- | --- |
| 6. Measuring the performance of the integrated architecture We finally focus on the assessment of the performance of the inte-grated architecture as a crucial part of applicability of the solution we | the work reported in this paper. Acknowledgment |

propose in this work. Our goal is to frame a reference architecture based on localization techniques for the purpose of measuring quantitatively the distance among people roaming in an indoor environment. In this

This work is partially supported by CyberSec4Europe project grant agreement n. 830929.

|  |  |
| --- | --- |
| picture, both the user experience and the hardware/software compo-nents can be measured to understand the effectiveness and its real | References |

applicability in real-world scenarios. To this purpose, we consider a set of measurable KPIs addressed to the 4 main players: the End-Users, the Smart Device, the Indoor Infrastructure and the Service Providers. We detail the motivation behind the such choices, how to measure the KPIs, the unit of measurement and any critical issue arising from the KPI. Table 3 summarizes the KPIs we propose.

7. Conclusions

Computing the inter-personal distance among people in real-time represents a challenging task. However, the recent COVID-19 pandemic imposes such requirement to the way people interacts and to the way people access services in indoor environments. Countries affected by such pandemic reacted to the emergency in different ways by adopting counter-measures that, in some circumstances, might be not effective after the lock-down phase. In particular, we focus on exploitable tech-nologies for guaranteeing social distance among people that are generally employed in the field of indoor localization. In this work, we describe the adoption of an Indoor Localization System (ILS) with a twofold goal. On one hand, the ILS can be adopted to localize people and, on the other hand, for measuring the in-between physical distance. We first present some functional requirements for an ILS and a reference architecture. Then, we present three significant use-cases where an ILS can be adopted for measuring distance among users. We discuss how information describing the distance among people can be used during three stages: before, during and after accessing a service. We also discuss some issues and new possible new lines of investigation concerning the design of an ILS for the purpose of the social distance. In particular, our attention moves towards the design of discovery protocol able to identify available ILSs indoor and to the adoption of privacy mechanisms for the treatment of sensitive information collected about end-users. The letter point is, in our opinion, one of the most important barrier to the adoption and diffusion location-based services. We argue that a more transparent approach for the data treatment would benefit the adoption of such location-based services offered by ILSs.

Credit author statement

Paolo Barsocchi: Conceptualization, Methodology, Investigation, Su-pervision, Visualization, Writing – review & editing. Antonello Calabr�o:

12

P. Barsocchi et al. Array 9 (2021) 100051

[Pervasive computing and communications workshops (PerCom workshops); 2018.](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref17)

[18] Barral V, Sua0rez-Casal P, Escudero CJ, Garc0ıa-Naya JA. Multi-sensor accurate [p. 125](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref17)–[30](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref17).

forklift location and tracking simulation in industrial indoor environments.

Electronics 2019;8(10):1152. <https://doi.org/10.3390/electronics8101152>.

[19] [Xu Y, Shmaliy YS, Li Y, Chen X. Uwb-based indoor human localization with time-](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref19)

[20] [Bregar K, Mohorcic M. Improving indoor localization using convolutional neural](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref20) [delayed data using f](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref19)i[ltering. IEEE Access 2017;5:16676](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref19)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref20)[83](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref19).

[21] [You W, Li F, Liao L, Huang M. Data fusion of uwb and imu based on unscented](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref21) [networks on computationally restricted devices. IEEE Access 2018;6:17429](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref20)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref21)[41](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref20).

[kalman f](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref21)i[lter for indoor localization of quadrotor uav. IEEE Access 2020;8:](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref21)

[22] [Van Opdenbosch D, Schroth G, Huitl R, Hilsenbeck S, Garcea A, Steinbach E.](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref22) [64971](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref21)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref22)[81](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref21).

[Camera-based indoor position- ing using scalable streaming of compressed binary image signatures. In: 2014 IEEE international conference on image processing](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref22)

[23] [Zhang W, Kavehrad M. Comparison of vlc-based indoor positioning techniques. In:](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref23) [(ICIP). IEEE; 2014. p. 2804](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref22)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref23)[8](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref22).

[Broadband access communi- cation technologies VII, vol. 8645. International Society for Optics and Photonics; 2013. 86450M](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref23).

[24] [Shao W, Luo H, Zhao F, Wang C, Crivello A, Tunio MZ. Depedo: anti periodic](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref24)  [negative-step movement pedometer with deep convolutional neural networks. In:](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref24)

[25] [Kim S-E, Kim Y, Yoon J, Kim ES. Indoor positioning system using geomagnetic](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref25) [2018 IEEE international conference on communications (ICC). IEEE; 2018. p. 1](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref24)–[6](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref24).

[anomalies for smartphones. In: 2012 International conference on indoor positioning and indoor navigation (IPIN). IEEE; 2012. p. 1](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref25)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref26)[5](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref25).

[26] [Shao W, Luo H, Zhao F, Crivello A. Toward improving indoor magnetic f](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref26)i[eld–based positioning system using pedestrian motion models. Int J Distributed Sens Netw](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref26)  [2018;14(9). 1550147718803072](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref26).

[27] [Lu C, Uchiyama H, Thomas D, Shimada A, Taniguchi R-i. Indoor positioning system](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref27)  [based on chest-mounted imu. Sensors 2019;19(2):420](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref27).

[28] [Shao W, Luo H, Zhao F, Wang C, Crivello A, Tunio MZ. Mass-centered weight](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref28)  [update scheme for particle f](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref28)i[lter based indoor pedestrian positioning. In: 2018 IEEE](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref28)

[29] [Lemic F, Handziski V, Mor N, Rabaey J, Wawrzynek J, Wolisz A. Toward](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref29) [wireless communications and networking conference (WCNC). IEEE; 2018. p. 1](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref28)–6.

[standardized localization service. In: 2016 international conference on indoor](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref29)

[30] [Stevenson G, Ye J, Dobson S, Nixon P. Loc8: a location model and extensible](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref30) [positioning and indoor navigation (IPIN). IEEE; 2016. p. 1](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref29)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref30)[8](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref29).

[framework for programming with location. IEEE Pervasive Comput 2009;9(1):](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref30)

[31] Zeinalipour-Yazti D, Laoudias C. The anatomy of the anyplace indoor navigation [28](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref30)–[37](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref30).

service. SIGSPATIAL Spec 2017;9(2):3. [https://doi.org/10.1145/](https://doi.org/10.1145/3151123.3151125)

[43] [J](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref43)€a[rvinen K, Lepp](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref43)€a[koski H, Lohan E, Richter P, Schneider T, Tkachenko O, Yang Z.](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref43)

[PILOT: practical privacy- preserving indoor localization using outsourcing. In: 2019](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref43) [44] R. Nieminen, K. Jarvinen, Practical privacy-preserving indoor localization based on [IEEE European symposium on security and privacy (EuroS P); 2019. p. 448](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref43)–[63](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref43).

secure two-party computation, IEEE Trans Mobile Comput (01) (5555) 1–1. doi: 10.1109/TMC.2020.2990871.

[45] [Yang Z, J](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref45)€a[rvinen K. The death and rebirth of privacy-preserving wifi](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref45) fi[ngerprint](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref45)  [localization with paillier encryption. In: IEEE INFOCOM 2018 - IEEE conference on](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref45) [46] [Greaves B, Coetzee M, Leung WS. Access control requirements for physical spaces](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref46) [computer communications; 2018. p. 1223](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref45)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref46)[31](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref45).

[protected by virtual perime- ters. In: Furnell S, Mouratidis H, Pernul G, editors.](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref46)

[Trust, privacy and security in digital business. Cham: Springer International](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref46) [47] [Haofeng J, Xiaorui G. Wi-f](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref47)i [secure access control system based on geo-fence. In:](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref47) [Publishing; 2018. p. 182](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref46)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref47)[97](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref46).

[48] [Jensen CD, Geneser K, Willemoes-Wissing IC. Sensor enhanced access control:](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref48) [Proceedings of ISCC 2019; 2019. p. 1](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref47)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref48)[6](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref47).

[extending traditional access control models with context-awareness. In: Ferna](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref48)0[ndez-](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref48) [Gago C, Martinelli F, Pearson S, Agudo I, editors. Trust management VII. Berlin,](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref48) [49] [Barsocchi P, Calabr](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref49)�o [A, Ferro E, Gennaro C, Marchetti E, Vairo C. Boosting a low-](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref49)[Heidelberg: Springer Berlin Heidelberg; 2013. p. 177](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref48)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref49)[92](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref48).

[cost smart home environment with usage and access control rules. Sensors 2018; 18(6):1886](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref49).

[50] [Calabr](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref50)�o [A, Marchetti E, Moroni D, Pieri G. A dynamic and scalable solution for](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref50) [51] [Daoudagh S, Marchetti E. A life cycle for authorization systems development in the](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref51) [improving daily life safety. In: Proceedings of APPIS 2019; 2019. p. 1](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref50)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref51)[6](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref50).

[gdpr perspective. In: Proceedings of the fourth Italian conference on cyber security, Ancona, Italy, February 4-7, 2020; 2020](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref51).

[52] [Bartolini C, Daoudagh S, Lenzini G, Marchetti E. Towards a lawful authorized](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref52)  [access: a preliminary gdpr- based authorized access. In: Proceedings of ICSOFT](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref52)  [2019, Prague, Czech Republic, july 26-28, 2019; 2019. p. 331](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref52)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref53)[8](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref52). [53] [Girolami M, Barsocchi P, Chessa S, Furfari F. A social-based service discovery](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref53)  [protocol for mobile ad hoc networks. In: 2013 12th annual mediterranean ad hoc](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref53) [54] Crivello F Potortì A, Girolami M, Traficante E, Barsocchi P. Wi-fi probes as digital [networking workshop (MED-HOC-NET); 2013. p. 103](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref53)–[10](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref53).

crumbs for crowd localisation. In: 2016 international conference on indoor positioning and indoor navigation (IPIN); 2016. p. 1–8. [https://doi.org/10.1109/ IPIN.2016.7743599](https://doi.org/10.1109/IPIN.2016.7743599).

crowd? analysis of face-to-face behavioral networks. J Theor Biol 2011;271(1): [55] Isella L, Stehle0J, Barrat A, Cattuto C, Pinton J-F, den Broeck] WV. What’s in a [56] [Alletto S, Cucchiara R, Del Fiore G, Mainetti L, Mighali V, Patrono L, Serra G. An](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref56) 166[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref56)80. <https://doi.org/10.1016/j.jtbi.2010.11.033>.

[3151123.3151125](https://doi.org/10.1145/3151123.3151125). [indoor location-aware system for an iot-based smart museum. IEEE Internet Things](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref56)

[32] Immuni, uno strumento in piu’ contro l[’](https://www.ufirst.com/)epidemia. <https://www.immuni.italia.it/>. [33] ufirst, risparmia tempo con ufirst. URL <https://www.ufirst.com/>.

[34] Kunai. URL <https://github.com/kunai-consulting/OpenTrace>.

[35] Skyook <https://syook.com/the-social-distancing-app/>.

[36] Who has access to your smartphone data? [https://cacm.acm.org/magazines/202](https://cacm.acm.org/magazines/2020/10/247585-who-has-access-to-your-smartphone-data/fulltext)  [0/10/247585-who-has-access-to-your-smartphone-data/fulltext](https://cacm.acm.org/magazines/2020/10/247585-who-has-access-to-your-smartphone-data/fulltext).

[37] ifeel-you bracelet. <https://www.iit.it/iit-vs-covid-19/ifeel-you-bracelet>.

[38] [Nguyen QH, Johnson P, Nguyen TT, Randles M. A novel architecture using ibeacons](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref38)  [for localization and tracking of people within healthcare environment. In: 2019](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref38)

[39] [Regulation (EU). 2016/679 of the European parliament and of the council of 27](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref39) [global IoT summit (GIoTS). IEEE; 2019. p. 1](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref38)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref39)[6](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref38).

[40] eXtensible Access Control Markup Language (XACML) Version 3.0 (2013). http: [april 2016 (general data protection regulation). Off J Eur Union 2016;L119:1](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref39)–[88](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref39).

\docs.oasis-open.org\xacml\3.0\xacml-3.0-core-spec-os-en.html.

[41] [Holcer S, Torres-Sospedra J, Gould M, Remolar I. Privacy in indoor positioning](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref41)  [systems: a systematic review. In: 2020 international conference on localization and](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref41)

[42] [Greaves B, Coetzee M, Leung WS. A comparison of indoor positioning systems for](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref42) [GNSS (ICL-GNSS); 2020. p. 1](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref41)[–](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref42)[6](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref41).

[access control using vir- tual perimeters. In: Fourth international congress on information and communication technology - ICICT 2019, London, UK, february 25-26, 2019, vol. 1; 2019. p. 293](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref42)–[302](http://refhub.elsevier.com/S2590-0056(20)30036-9/sref42).

13