The Anatomy of the Anyplace Indoor Navigation Service

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Abstract

The pervasiveness of smartphones is leading to the uptake of a new class of Internet-based Indoor Navigation (IIN) services, which might soon diminish the need of Satellite-based localization technologies in urban environments. These services rely on geo-location databases that store spatial models along with wireless, light and magnetic signals used to localize users and provide better power efficiency and wider coverage than predominant approaches. In this article we overview Anyplace, an open, modular, extensible and scalable navigation architecture that exploits crowdsourced Wi-Fi data to develop a novel navigation service that won several international research awards for its utility and accuracy (i.e., less than 2 meters). Our MIT-licenced open-source software stack has to this date been used by thaousands of researchers and practitioners around the globe, with the public Anyplace service reaching over 100,000 real user interactions.

1 Introduction

The omni-present availability of sensor-rich smartphones along with the fact that people spend 80-90% of their time in indoor environments has recently boosted an interest around indoor location-based services, such as, in-building guidance and navigation, inventory management, marketing and elderly support through Ambient and Assisted Living [3, 2]. The key enablers for the uptake of such indoor applications are nowadays, what we call the *Internet-based Indoor Navigation (IIN)* [13] services. These comprise of indoor models, such as floor-maps and *Points-of-Interest (POIs)*, along with wireless, light and magnetic signals used to localize users. As shown in [13], there is a rich spectrum of different types of services, but none of them provides infrastructure-free localization combined with rich modeling, crowdsourcing and privacy elements under the same hood. More importantly, none of them is freely available as an open source project limiting in this way the wide adoption of important scientific findings but also limiting transparency of happens behind the service.

In this overview paper we summarize the current developments around Anyplace[1], our open, modular, scalable and extensible architecture that collects indoor information using crowdsourcing. We follow a multi-tier architecture that allows to plug-n-play additional modules, either for extending system capabilities by implementing new features, or for enhancing user-experience by improving existing functionalities (e.g., map-matching and sophisticated data fusion to increase localization accuracy). Regarding scalability, Anyplace operates on top of a NoSQL data management back-end service, a JSON Application Protocol Interface (API), mobile clients for Web, Android and Windows Phone and a seamless integration with the Google Maps API for outdoor navigation and search, tiles and sattelite view. Anyplace has become an open-source project and is openly distributed

[1] Anyplace. `https://anyplace.cs.ucy.ac.cy/`

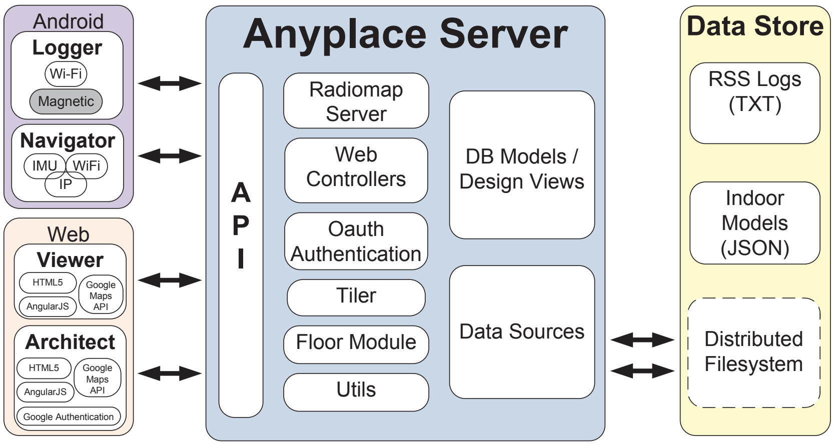

Figure 1: **The *Anyplace* Internet-based Indoor Information (IIN) Service Architecture.**

on Github using an MIT licence[2]. The public Anyplace service has to this date been obtained more than 100,000 real user interactions, with many more users using its standalone installations on the Web.

2 Overview of Anyplace

The Anyplace software stack consists of five main modules, including the *Server*, the *Data Store*, the *Architect*, the *Viewer* and two client applications running on Android smartphones, namely the *Logger* and the *Navigator*. A native Navigator is also available for Windows Phone. The Anyplace system architecture is shown in Figure 1.

The Anyplace *Server* contains the complete backend application logic of the service, including the modeling, crowdsourcing and API functionality. It is implemented in the Play Framework 2.2.x., which provides a lightweight, stateless and web-friendly architecture to build web applications. The *Server* delivers indoor navigation directions and information search and exploration queries through the JSON API. In addition, the *Server* features several modules that facilitate the crowdsourcing functionality, tiling of images uploaded, authentication of users and the interface to the design views of the data store. The Anyplace *Data Store* stores the indoor models and the collected Wi-Fi and other signals on storage.

The Anyplace *Architect* is a *Web App* (*HTML5, CSS3, JS*) that enables users to design and upload building structures to Anyplace. The Anyplace *Viewer* is a respective Web App that allows search and navigation off-the-shelf, without installation or logistical challenges. Both the *Architect* and the *Viewer* are built with the *AngularJS* framework and utilize the *Google API* (*Maps, Directions, Heatmaps and URL shortener*) to present and process data on a map along with the *HTML5* Geolocation for localization. The Viewer/Architect codebase can be encapsulated directly into native mobile apps using the Ionic Framework, which we have already tested with satisfactory results in another open-source project we developed, named Rayzit [1].

The combined Anyplace *Navigator* and *Logger* is a native Android application, which can benefit from Wi-Fi fingerprinting [13, 9] available under this platform. The *Navigator* allows users to see their current location on top of the floorplan map and navigate between POIs inside the building, similarly to the *Viewer* (iOS, Android, Windows). The main difference is that the Navigator offers superb accuracy, as it uses Wi-Fi Radiomap localization and the on-board smartphone sensors (i.e., accelerometer, gyroscope and digital compass), which are seamlessly integrated in our tracking module to smooth the Wi-Fi locations and enhance the navigation experience. The *Logger* application enables users to record Wi-Fi readings from nearby Wi-Fi access points

[2] Anyplace Github. `https://github.com/dmsl/anyplace`

and upload them to our *Server* through a Web 2.0 API (in JSON). It is used by volunteers for contributing Wi-Fi data and for crowdsourcing the Radiomaps of buildings. In order to facilitate the collection of quality Radiomaps, we present a heat-map of previously collected fingerprints in the building. Components for massive processing of Wi-Fi signals in Apache Hadoop (e.g., filter incorrect contributions and exploit readings collected by heterogeneous devices), have been developed but not integrated in the latest open release yet.

3 Localization in Anyplace

The localization literature is very broad and diverse as it exploits several technologies. GPS is obviously ubiquitously available but has an expensive energy tag and is also negatively affected from the environment (e.g., cloudy days, forests, downtown areas). Besides GPS, the localization community proposed numerous proprietary solutions including: *Infrared, Bluetooth, visual or acoustic analysis, RFID, Inertial Measurement Units, Ultra-Wide-Band, Sensor Networks, Wireless LANs, etc.*; including their combinations into hybrid systems [2].

Anyplace uses Wi-Fi Radiomap-based indoor localization, which stores radio signals from Wi-Fi APs in a database at a high density. The localization subsystem of Anyplace utilizes the following routine: in an offline phase, a logging application records the so called *Wi-Fi fingerprints*, which comprise of *Received Signal Strength (RSS)* indicators of Wi-Fi Access Points (APs) at certain locations (x,y) pin-pointed on a building floor map (e.g., every few meters). Subsequently, in a second offline phase, the Wi-Fi fingerprints are joint into a NxM matrix, coined the *Wi-Fi RadioMap*, where N is the number of unique (x,y) fingerprints and M the total number of APs. Finally, a user can compare its currently observed RSS fingerprint against the RadioMap in order to find the best match, using known algorithms such as KNN or WKNN [8]. A similar methodology can be applied to other types of signals, for instance, we are experimenting with magnetic fingerprints [10]. Both are considered infrastructure-free approaches, as Wi-Fi APs are ubiquitously available in urban and indoor spaces [9].

3.1 Crowdsourcing the Radiomap: The Anyplace Logger

Crowdsourcing has recently emerged as a promising solution for collecting the high volume of location-tagged data, e.g., the WiFi RSS radiomap of a multi-storey building, which are required to support indoor localization systems. In this context, volunteers engage in participatory sensing campaigns to collect location-dependent RSS samples. This is an attractive approach, because it splits the cumbersome and time consuming data collection task among the crowd. For example, it required 15 collectors for 2 weeks to collect point-by-point 200,000 Wi-Fi signal strength readings at 10,000 unique locations to cover the 450,000 m^2 COEX underground shopping mall area in S. Korea [13]. Another benefit from crowdsourcing is also the cost factor (e.g., the measurement survey upon the *Ekahau* system installation can cost 10,000 USD for a large office building with no maintenance included [7]). At the same time, however, it raises new challenges such as filtering incorrect contributions (trustworthiness), managing the radiomap size and fusing data from heterogeneous mobile devices [6].

The Anyplace *Logger*[3] is an Android application that allows volunteers to freely obtain RSS data and contribute it to Anyplace for improvement of the location quality. Crowdsourcers can select the desired building and floor, as well as modify the number of samples to be recorded and other settings, through the preferences screen. Subsequently, the users indicate their current location by clicking on the map and then click the on-screen buttons to initiate and end the logging process. In order to facilitate the collection of quality Radiomaps, we present a heat-map of previously collected fingerprints in the building. A crowdsourcer seeing this heat-map can easily identify areas where additional samples have to be collected. If a crowdsourcer is outside a given building no Wi-Fi signals can be collected. Upon finishing the collection of data, a user can upload this data to our or his cloud service through a Web 2.0 API (in JSON). The post-processed measurements are then available to other users that aim to localize accurately in the same building. At the University of Cyprus, 27 students crowdsourced

[3] Anyplace Logger. Video: `https://youtu.be/8EvioLZ6hvg`

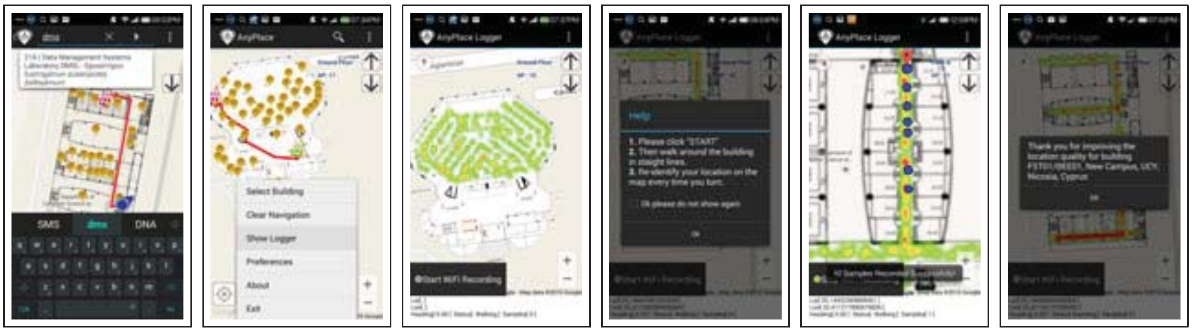

Figure 2: **Anyplace Logger and Navigator.** This is a native Android application that enables fine-grain indoor localization (up to 1.96m accuracy [9]) through the use of RSS fingerprints contributed by the crowd.

12 buildings (36,000 m^2) in a few hours while the rest of the 52 buildings were mapped by a single student. Similar efforts have already been observed on Anyplace for other campuses around the world.

3.2 Fine-grain Localization and Navigation: The Anyplace Navigator

The Anyplace *Navigator*[4] allows users to see their current location on top of the floorplan map and navigate between POIs inside the building with high accuracy. Particularly, the Navigator localization subsystem achieved an accuracy of 1.96 meters at the Microsoft Indoor Localization Competition at ACM/IEEE IPSN'14 [9] and was awarded the second position in its (infrastructure-free) category and third position overall. A user installing Anyplace from the Google Play market can use the *Navigator* in any public building listed on Anyplace. There is also a notion of private buildings whose access is limited to users having the unique URL. When the *Navigator* is launched, the building map and the associated POIs are automatically loaded by using the rough user location provided by the Google Geolocation API (see Figure 2). Then, the application downloads the RSS Radiomap of the relevant floor (subsequently the complete building) and displays the user location on top of the map. Moreover, users may search for POIs and get navigation directions from their current location. The *Navigator* also uses the onboard smartphone sensors (i.e., accelerometer, gyroscope and digital compass), which are seamlessly integrated in our tracking module to smooth the Wi-Fi locations and enhance the navigation experience.

3.3 Location Privacy

Location privacy refers to the the ability of an individual to move in public space with the reasonable expectation that their location will not be systematically and secretly recorded for later use [11]. The Anyplace was designed up-front with the aim to offer absolute location privacy. As such, localization structures (e.g., Radiomaps, POIs, connectors) are downloaded to the hand-held of a mobile user (u) from the Anyplace service (s) through the secure Anyplace API. All localization requests are then carried out in local mode on u, as opposed to s, which could fundamentally be compromised (e.g., by hackers or operators that install Anyplace on their servers). One downside of this approach, was that the localization structures would many times be outdated (i.e., these would not capture the latest crowdsourced data). As such, we got interested in investigating alternative hybrid localization strategies that would on the one hand exploit the utility of Anyplace, but on the other hand also offer controllable location privacy to the user. In [4] we devise the Temporal Vector Map (TVM) algorithm, where a user u camouflages its location from s, by requesting a subset of k entries from s, where k is a user-defined constant. Access the localization structures efficiently, is another complementary problem that we model and address using the Preloc framework [5].

[4] Anyplace Navigator. Video: `https://youtu.be/MO-473oWSfE`

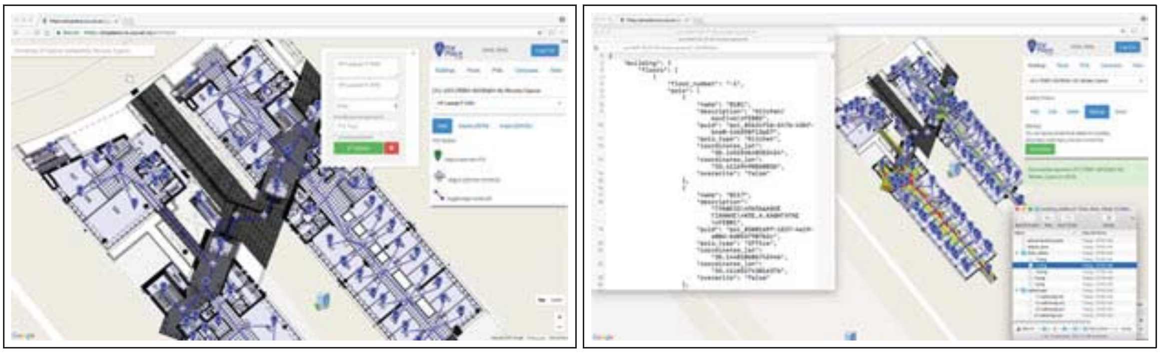

Figure 3: **Anyplace Architect. (Left)** Managing a campus of buildings through the architect Web app (cross-platform HTML5 interface). The architect allows a user to add floor-maps, POIs and connectors using drag-n-drop both interactively and in batch form. **(Right)** Import/export functionality in Anyplace simplifies data entry and promotes openness and data portability among different indoor management platforms.

4 Modeling in Anyplace

Unlike outdoor environments, indoor spaces are characterized by complex topologies and are composed of entities that are unique to indoor settings, such as multiple floors, rooms and hallways connected by doors, walls, stairs, escalators, and elevators [3]. To make things worse, doors may be one-directional (e.g., in security control in airports), while temporal variations may occur (e.g., a room may be temporarily inaccessible due to its opening hours). In this section we explain how buildings are managed in Anyplace and also summarize the predominant directions in this domain.

4.1 Managing Buildings and Campuses: The Anyplace Architect

The Anyplace *Architect*[5] is a web application that offers a feature-rich, user-friendly and account-based interface for managing indoor models in Anyplace. Particularly, it can be used to log-in with a Google account and place the blueprint of a building on top of Google Maps with multi-floor support. Using the floor editor, the user can upload, scale and rotate the desired blueprints to fit them properly, as shown in Figure 3. The user can later add, annotate and geo-tag POIs inside the building and connect them to indicate feasible paths for enabling the delivery of navigation directions. This interaction is carried out with drag-n-drop functionality that is cross-browser compatible and even operational on tablets and smartphones used in field deployments (e.g., while moving around with a tablet and correcting the indoor model).

The Architect also provides a range of other functionality, namely: i) *monitoring crowdsourcing progress* to collect Wi-Fi Radiomaps using color heat-maps (see Figure 3, right). An assigner can easily identify whether a given collection is satisfactory or not and thus define quantitative acceptance criteria for the output of crowd-sourcers; ii) *making a building public or private*, which automatically shares a building on the Anyplace *Viewer* interface (given that there are no collisions). Alternatively, a building can remain private and be shared among users through a URL (e.g., a person mapping a building for a specific event publicizes a private building to its audience by email or social media); and iii) *export and import of indoor models and Radiomaps*, which allows somebody to backup/restore a building, expedite user input of POIs, but also create a new model for a different purpose (i.e., template-based generation of a new building id for a new purpose).

[5]Anyplace Architect. Video: `https://youtu.be/dIVxcQ_5Wbg`

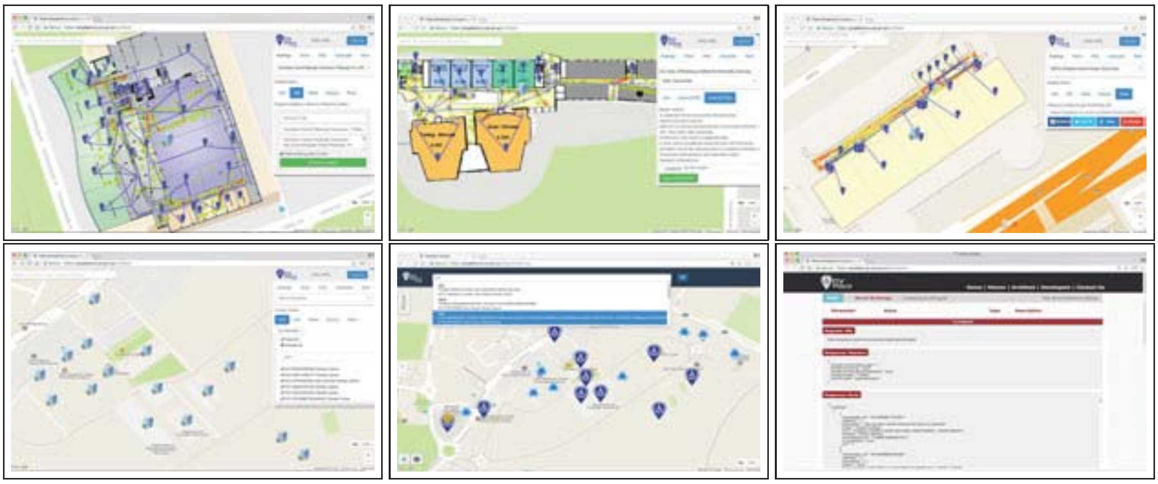

Figure 4: **Anyplace Information Layers. (Top)** Three buildings mapped on Anyplace (left-to-right): Hotel mapped in Pittsburgh, USA; Building at the University of Würzburg, Germany and a Convention Center, South Korea. Heatmaps facilitate architects to monitor the progress of the Radiomap collection. **(Bottom)** Campus layer allows information search and exploration across several buildings (left-to-right): Subset of the 52 buildings mapped at the University of Cyprus, the campus search engine that became available after the mapping, and the JSON Web 2.0 API that streamlines all data accesses from mobile apps and the web.

4.2 Modeling Directions

The technology road-map is towards indoor GIS integration where `indoorgml.net`, `geojson.org` or any other standard that may appear in the future and become fully inter-operable. Having the right modeling primitives will give rise to a variety of data management and query processing challenges in the future. Another direction is towards automated indoor model checkers (e.g., graph connectivity, automatically connect overlapping stairs and elevators) as these will make the mapping of an indoor space more straightforward. There already competing industrial systems, like `mazemap.com` and `micello.com`, which work directly with Autodesk's Industry Foundation Classes (IFC) data model that is used for the description of building and construction data. One final direction is the provisioning of libraries for managing specific types of objects in indoor spaces (e.g., office equipment, industrial appliances) but also libraries for representing indoor spaces more richly either using 3D models (e.g., `indoor.io`) or augmented reality.

5 Indoor Information Search in Anyplace

Indoor information search and exploration is among the most important aspects that complements indoor navigation. This happens as users will typically start their navigation out by first issuing a spatio-textual search that will return some Points-of-Interest (POIs) upon which navigation instructions to a particular target can be obtained. In this section, we describe how indoor information is modeled in Anyplace and how this helps in bringing forward a seamless navigation experience through the Anyplace Viewer.

5.1 Information Layers

In Anyplace, indoor data is organized in three logical layers (see Figure 4): i) Floor Layer; ii) Building Layer and iii) the Campus Layer. A floor layer comprises of a floor-map (i.e., JPG image), a set of POIs with anno-

Figure 5: **Anyplace Viewer.** This is a cross-platform web application optimized for mobiles, which supports indoor search, exploration and navigation over buildings mapped on Anyplace. It complements the native Anyplace apps with an alternative to open Anyplace URLs without the installation of a dedicated mobile app.

tations (e.g., door, entrance, office), edges connecting the POIs and sensor readings (i.e., Radiomaps). A floor is anchored in the WGS84 coordinate system, which is compatible with all tile layer providers such as Google Maps and Openstreetmaps. A building represents several floors logically linked together by POI edges (i.e., by connecting stairs or elevators of two floors). Every building has to feature at least one "building door" to which outdoor navigation instructions will be linked (this provides outdoor-to-indoor linkage). A building in Anyplace is identified globally uniquely through a *Building ID (BUID)*. Several BUIDs can be logically organized together through the Campus Layer to generate a globally unique *Campus ID (CUID)*. Both the BUIDs and the CUIDs can be obtained through the user interface and shared with a URL[6] through popular social media, email, SMS, embedded in websites as an HTML iframe or as a field in the respective API calls.

In the current release, we use the Google maps API for provisioning of the underlying map tiles but this doesn't restrict the utility of Anyplace to the particular provider (i.e., it could be Openstreetmaps, Bing Maps or any other service). The objective of linking to an outdoor web mapping service was to obtain search and navigation instructions for the outdoor world, while Anyplace then only focuses on navigation and information search in the indoor spaces it represents (e.g., Figure 2 and Figure 5). Google Maps also provides us with sattelite, birds-eye, street-map views and in certain occasions even floor maps and floor selectors (from Google Indoor), which can nicely complement the Anyplace experience. Google Indoor has a similar scope to Anyplace Architect, but it does so in a very centralized manner that eventually will only lead to a single mapping of some public building. On the other hand, Anyplace Architect allows anybody to add any type of building in as many representations as necessary. For example, one might create a general-purpose indoor navigation model of a hospital that is inherited and refined by some other user into a model for inventory management in that building or a new model that arranges a set of additional POIs on a map for a specific event. The import and export functionality of Anyplace provides a true opportunity for achieving these scenarios.

5.2 Viewing Indoor Mappings: The Anyplace Viewer

The Anyplace *Viewer*[7] is again a Web App that enables the quick visualization of buildings modeled in Anyplace. It is ideal for a first-time user that doesn't want to invest considerable time before launching the service through an app downloaded from a popular mobile market. The viewer enables off-the-shelf usage without installation or logistical challenges, which is many times an overhead when users aim to get to their destination quickly, as it only requires a web browser. A more involved user can download the Anyplace Navigator from the various markets and enjoy advanced functionality (e.g., superb accuracy, caching, etc.) The UX/UI of the Viewer has

[6]UCY Campus on Anyplace. `https://anyplace.cs.ucy.ac.cy/viewer/?cuid=ucy`
[7]Anyplace Viewer. Video: `https://youtu.be/uMFnxXnm1yc`

been implemented with a mobile user on-the-go in mind (i.e., thumb-based user interface, large buttons, less clutter) and is extremely straightforward to use.

Acknowledgments

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