Anyplace: A Crowdsourced Indoor Information Service

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***Abstract*—People do most of their activities, business, commerce, entertainment and socializing indoors. As all of these are increasingly aided by online services and indoor spaces are becoming bigger and more complex, there is a growing need for cost-effective indoor localization, mapping, navigation and information services. In this paper, we present a complete *Indoor Information Service*, coined *Anyplace*[1], which has an open, modular, extensible and scalable architecture, making it ideal for a wide range of applications. Our service features three highly desirable properties, namely *crowdsourcing*, *scalability* and *accuracy*. *Anyplace* implements a set of crowdsourcing-supportive mechanisms to handle the enormous amount of crowd-sensed data, filter incorrect user contributions and exploit Wi-Fi data from heterogeneous mobile devices. Moreover, it uses a big-data architecture for efficient storage and retrieval of localization and mapping data. Finally, our service relies on the abundance of sensory data on smartphones (e.g., Wi-Fi signal strength and inertial measurements) to deliver reliable indoor geolocation information that received several international awards.**

Keywords*—*crowdsourcing, indoor, search, navigation

I. Introduction

People spend 80-90% of their time in indoor environments[2], including shopping malls, libraries, airports, university campuses, schools, offices, factories or hospitals. Given that humans are nowadays equipped with mobile computing devices creates a growing need to enterprises, to seek for efficient and cost-effective technology to perform a variety of compelling applications in indoor spaces [2], e.g., workforce tracking, inventory management, supply chain management, security and safety regulations. Retailers are also interested in enhancing shopping experience, analyzing shopping behavior, and offering coupons or advertisements more effectively. Moreover, the entertainment industry envisions to design new games, which could exploit the actual environment of the players as the playground, and communication companies want to offer new services to their customers [2].

Today's technological market and gadget culture allow for the realization of such indoor services with the omni-presence of sensor-rich mobile devices and Wi-Fi *Access Points (APs)* in indoor environments. Mobile phones can measure the signal strength received from surrounding APs and receive information on their location based on geolocation databases, which maintain information about those APs (i.e., the signal intensity of these transmitters at known locations in space). Fine-grained indoor mapping with detailed *Points-Of-Interest (POI)* registration can be achieved through *crowdsourcing* [1], by mobile custodians, of both indoor models and signals. Navigation is then the main extension of all the above, completing what we would call *Indoor Information Services (IIS)*.

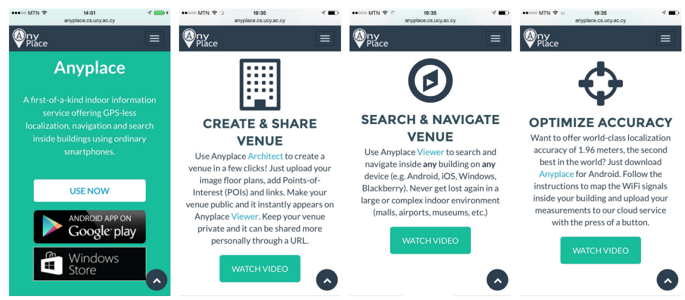

Fig. 1. **The *Anyplace* welcoming and descriptive screens of its features.**

Existing IIS services (e.g., *SkyhookWireless.com, Google.com, Navizon.com, Infsoft.com, Indoo.rs, IndoorAtlas.com, MazeMap.com*) can be categorized based on the localization technology, back-end architecture and participation they use, and on the accuracy and location privacy they achieve. The service can run either on the mobile phone itself (*terminal-based*) or on a remote server (*network-based*). The majority of the network-based systems do not provide location privacy to the users, as the localization process is performed on the server that provides location at a coarse granularity (i.e., km or hundreds of meters) up to a fine granularity (i.e., 1-2 meters) [5]. On the other hand, the terminal-based systems inherently guarantee location privacy as the localization is performed on the mobile device.

Another important distinction among IIS is whether the knowledge base is populated by the service provider alone or by the users in a participatory fashion (*crowdsourcing*). The commercial systems mostly follow the non-participatory path to populate their databases, which makes them more trustworthy on the data they provide, but forces them to limit their services to the building they were able to map using experts or agents. Systems mainly developed as research projects in academia, follow the participatory scheme, which allows for faster and cheaper database population and maintenance.

[1]Available at: http://anyplace.cs.ucy.ac.cy/
[2]US Environmental Protection Agency, http://epa.gov/iaq/

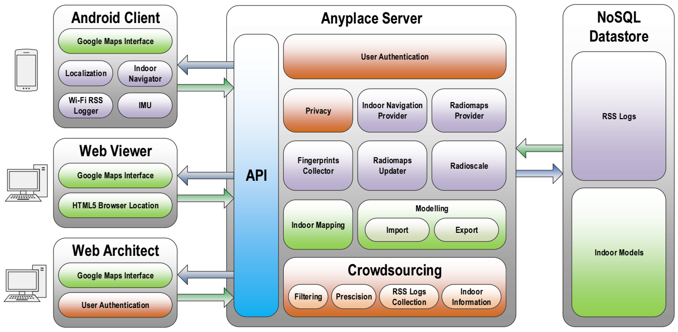

Fig. 2. **The *Anyplace* Indoor Information Service Architecture.**

In this article, we present a complete *Indoor Information Service*, coined *Anyplace* (an earlier version of our architecture appeared in [4]). Anyplace has an open, modular, scalable and extensible architecture that collects indoor information using crowdsourcing in a user-friendly manner. Anyplace combines the accuracy of a network-based service, and the availability and privacy of a terminal-based service.

The goal of Anyplace is to enable entities, such as individual users, companies, organizations, etc., to realize indoor information management systems, including POI search and navigation, on top of existing wireless networks. It allows for any user to map a building and add POIs, and keeps multiple versions according to the different input data received from different users. For instance, the same convention center would be used one way for one event and in a totally different way, e.g., different POIs for another event. Anyplace implements a set of Map-Reduce mechanisms to handle the enormous amount of crowdsourced sensory data, filter incorrect user contributions and exploit readings collected by heterogeneous mobile devices [3].

We follow a modular architecture that allows to plug-n-play additional modules, either for extending system capabilities by implementing new features (e.g., activity recognition, indoor/outdoor transition), 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 big-data management back-end service, with a Google Maps user interface, to ensure efficient and scalable storage and retrieval of localization and mapping data. It also supports offline analytic processing of sensor data using Map-Reduce.

II. Anyplace System Architecture

Our platform consists of five main components, including the *Server*, the *Architect*, the *Viewer*, a *NoSQL datastore*, and a client application running on Android smartphones acting as a *Logger* and a *Navigator* (a navigator is also available for Windows Phone). The Anyplace reference system and module architecture is illustrated in Fig. 2.

A. Anyplace Server and Datastore

The *Server* follows a big-data architecture and provides a Web 2.0 API using JSON objects for mapping, navigation and localization. It uses Couchbase as its back-end database for scalability and fast metadata retrieval.

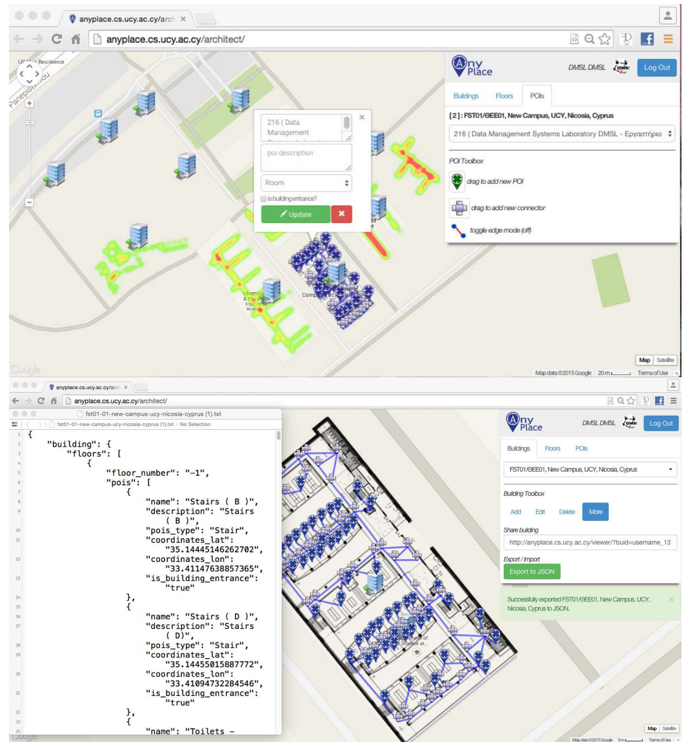

Fig. 3. **Anyplace Architect: (Top)** Managing a campus of buildings through the architect Web app (cross-platform HTML5 interface). The architect allows a user to add floormaps, POIs and connectors using drag-n-drop. It also allows to overview the collection of Wi-Fi Radiomaps and the management of crowdsourcing tasks. **(Bottom)** Export/Import of indoor semantics (in JSON) is expected to boost openness and data portability among different indoor management platforms, facilitate data entry and extensibility.

The *Server* delivers indoor navigation directions to the user upon request based on the Radiomaps stored. The Privacy module enables smartphone users to calculate their location on their own device by downloading minimal parts of the stored Radiomap, "hiding" among k random AP areas. It stores buildings, floorplan maps, and POIs information in JSON, which can be imported and exported. To keep the size of the Radiomap low, the Radio-scale module aggregates all the uploaded RSS values into a grid of predefined resolution.

In addition, the *Server* features several modules that perform crowdsourcing functionality. Importantly, the differential RSS module outputs RSS differences, instead of absolute RSS values, for fusing the data contributed from devices of various vendors into a single generic Radiomap. In addition, the outlier filtering module checks the validity of the contributed RSS data by comparing the MAC addresses of the APs at the presumed user location to the relevant data in the Radiomap[3].

B. Anyplace Architect

The *Architect* Web application offers a feature-rich, user-friendly and account-based interface for managing indoor models in Anyplace (currently a user logs in with any Google account). Particularly, after logging in a user can 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

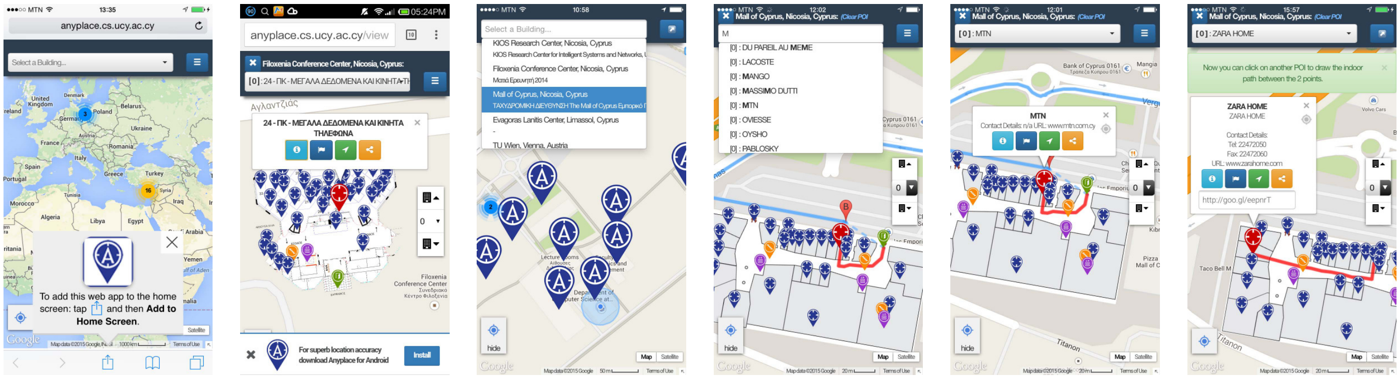

Fig. 4. **Anyplace Viewer: (i-ii)** Opening Viewer on iOS (i) and Android (ii) presents a clustered-view of Anyplace buildings but also allows users to install the given web app on any smartphone home screen (iOS, Android, Windows, etc.); For Android there is an additional Navigator & Logger App available through the Play Market; **(iii)** Location-based *Outdoor Search* for buildings publicly listed in Anyplace; **(iv)** *Indoor Search* of POIs and descriptions belonging to a building selected in a previous step; **(v)** *Oudoor-to-Indoor* navigation (outdoor navigation using the Google Maps API); and **(vi)** *Indoor-to-Indoor* navigation also showing "URL Sharing" and "Info" options.

shown in Fig. 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 in space with a mobile device and correcting the indoor models).

The architect also provides a range of other functionality, namely: (i) *invitation/revocation of crowdsourcer accounts* to collect Wi-Fi Radiomaps as well as the monitoring of the progress in terms Wi-Fi Radio heat-maps (see Fig. 3 top). An assigner can easily identify whether a given collection is satisfactory or not and thus define quantitative acceptance criteria for the output of crowdsourcers; (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 (e.g., an expo building has different but similar models for different events).

The Architect is a *Web App* (*HTML5, CSS3, JS*) that enables the quick visualization of buildings modeled in Anyplace. It's built with the *AngularJS* framework and it utilizes the *Google API* (*Maps, Directions, Heat-maps and URL shortener*) to present and process data on a map along with the *HTML5* Geolocation for localization. For the styling of the user interface, the open-source toolkits *Bootstrap* and *FontAwesome* were used along with the *jQuery UI* library that orchestrates user interface interactions and effects.

In the future we aim to: (i) *incorporate advanced graph automation tasks*, which will check the indoor model (e.g., graph connectivity, automatically connect overlapping stairs and elevators); (ii) *provide specific indoor libraries*, which will contain different POI types and images for stadiums, malls, campuses, hospitals, etc.; (iii) incorporate algorithms to handle click-streams of error reports and dispute resolution techniques (e.g., using majority voting algorithms); and (iv) *investigate the integration of IndoorGML*[3], which is expected to boost openness and data portability among different indoor management platforms but also facilitate easier data entry.

C. Anyplace Viewer

The *Viewer* is again a Web App that enables the quick visualization of buildings modeled in Anyplace. To appreciate the necessity of this design, assume that a mobile user is lost in some complex University campus. Fortunately, the person sees somewhere an advertisement of the Anyplace service. Upon visiting the website through his mobile internet plan, the user instantly obtains a searchable map of all buildings in the area, performs location-based range search and quickly gets to his target. The UX/UI of the Viewer has 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.

The Viewer is ideal for a first-time user that doesn't want to waste considerable time before launching the service through an app downloaded from some 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. A more involved user can download the Anyplace Navigator from the various markets and enjoy advanced functionality (e.g., superb accuracy, performance, caching and prefetching, privacy, etc.)

One final note is that the Viewer enables a user to share short URLs of POIs using email, the web, social media, etc. A user receiving such a URL can instantly project navigation instructions to the target POI. This functionality has already been extensively incorporated in various websites in the form of a *Viewer Widget* (i.e., the viewer is installed and executed within any external website using iframes). The *Viewer* has been implemented on a common codebase with the *Architect*.

D. Anyplace Navigator & Logger

The combined *Navigator* and *Logger* is a designated tool for Android users, which can benefit from Wi-Fi fingerprinting [4], [5] available under this platform. The *Navigator* allows

[3]IndoorGML, http://indoorgml.net/

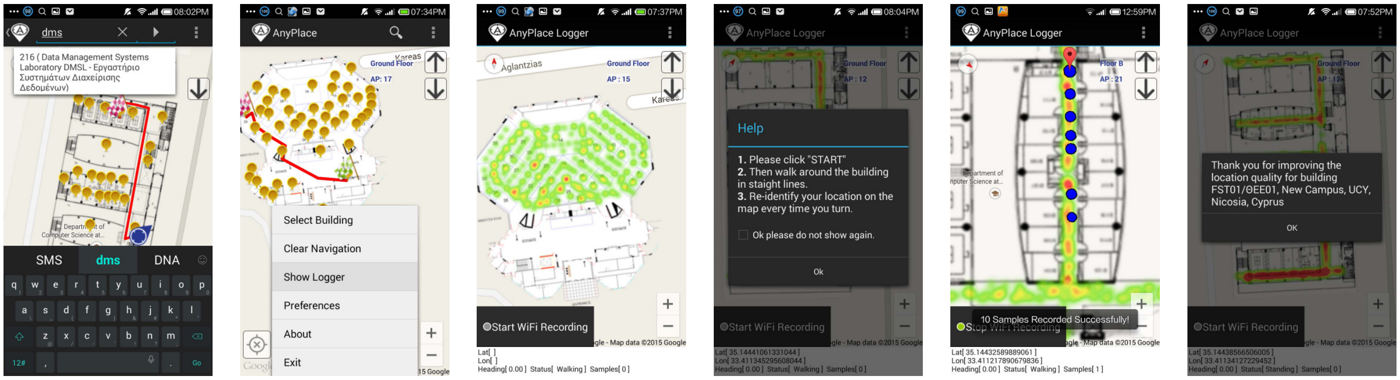

Fig. 5. **Anyplace Navigator and Logger:** **(i)** *Search and Navigate:* A user executing *Navigator* searches for POIs and receives navigation instructions using accurate local IMU and Wi-Fi algorithms; **(ii)** *Open Logger:* While browsing another distant building, the user opens the *Logger*; **(iii)** *Heat-map:* The user now knows where to initiate the collection of Wi-Fi fingerprints given that certain areas are not covered (i.e., here the logging will fail as the user is not inside the given building); **(iv)** *Guide:* The user returns to the building he is currently at and receives instruction on how to improve the Radiomap of the venue; **(v)** *Collect:* The user walks in straight lines and locally collects the data; and **(vi)** *Upload:* The user uploads the Wi-Fi signals to the Anyplace cloud service.

users to see their current location on top of the floorplan map and navigate between POIs inside the building, similarly to the *Viewer*. The main difference, is that the Navigator now offers superb accuracy of 1.96 meters, which received the second award by Microsoft Research at IEEE IPSN'14 [5]. The *Logger* application enables users to record RSS readings from nearby Wi-Fi APs and upload them to our *Server* through a Web 2.0 API (in JSON).

A user installing Anyplace from the Google Play market can use the *Navigator* in any building listed on Anyplace (public or private). The same applies to the *Logger*, with the difference that Wi-Fi logging can only be enabled if a user is actually inside a given building (similarly to waze.com). This allows the Anyplace service to minimize the reception of wrong signals from crowdsourcers, which will only be able to contribute data if they are physically inside a building.

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. 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 (Fig. 5). 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 *Logger* on the other hand is used by volunteers for contributing RSS data and for crowdsourcing the Radiomap. Crowdsourcers can select the desired building and floor, modify the walking sensitivity as well as 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 the Anyplace cloud service.

III. Demonstration Experience

Our system has low setup time because it will rely on the Wi-Fi infrastructure available at the conference venue. If necessary, our team can quickly deploy additional smartphone APs to provide adequate Wi-Fi coverage. Thus, only the floorplan digital map of the demo site is required.

We will demonstrate the real-time localization capabilities of *Anyplace* by allowing attendees to carry an Android smartphone running the *Navigator* software and viewing their travelled path, while walking around the demo area. At the same time the participants will be able to appreciate the potential of indoor location-oriented services by carrying out POI search and navigation.

They will also have the opportunity to interact with the *Architect* website in order to add and annotate indoor spaces in a straightforward way or simply explore other annotated buildings that are publicly available through the *Viewer* mode.

Acknowledgments

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