FMS: Managing Crowdsourced Indoor Signals with the Fingerprint Management Studio

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***Abstract*—In this demonstration paper, we present an integrated indoor signal management studio, coined *Fingerprint Management Studio (FMS)*, which provides a spatio-temporal platform to: (i) manage the collection of location-dependent sensor readings (i.e., *fingerprints*) in indoor environments; (ii) estimate the localization accuracy based on the collected fingerprints; and (iii) assess Wi-Fi coverage and data rates. The demonstration will present the components comprising FMS, namely *CSM (Crowd Signal Map)*, *ACCES (Accuracy Estimation)* and *WS (Wi-Fi Surveying)*, through a compelling map-based visual analytic interface implemented on top of our open-source indoor navigation service, coined Anyplace. We will present FMS in two modes: (i) Online Mode, where attendees will be able to collect and analyze real fingerprints at the conference venue; and (ii) Offline Mode, where attendees will be able to interact with measurements of University campus in Cyprus, a Hotel in the US and an Expo in S. Korea.**

***Index Terms*—Crowdsourcing, Management, Fingerprints**

I. Introduction

The pervasiveness of smartphones along with the fact that people spend 80-90% of their time in indoor environments is leading to the uptake of a new class of *Internet-based Indoor Navigation (IIN)* services [3], which might soon diminish the need of Satellite-based localization technologies in urban environments. IIN services rely on geo-location databases that store spatial models, such as floor-maps and *Points-of-Interest (POIs)*, along with wireless, light and magnetic signals used to localize users and provide better power efficiency and wider coverage than predominant approaches. In our previous work [3]–[5], we developed a modular, scalable and efficient IIN architecture, coined Anyplace[1]. Our service has to this date obtained more than 145,000 real user interactions, with many more users using its standalone installations on the Web, making it gradually a leading open-source IIN architecture.

A determining characteristic of *Anyplace*, compared to prior academic and industrial systems (e.g., Microsoft Radar [2], Ekahau.com, Mazemap.com, Google Indoor), is that it takes a rigorous approach on collecting indoor signals using *Crowdsourcing* [1]: volunteers engage in participatory sensing campaigns to collect location-dependent sensor signal samples using a *Logger*. Crowdsourcing 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 [3]. 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). At the same time, however, it raises new challenges, such as, managing collected signals and inferring value out of it.

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

In this demonstration paper, we present an integrated indoor signal management studio, coined *Fingerprint Management Studio (FMS)*, which provides a spatio-temporal platform to: (i) manage the collection of location-dependent sensor readings (i.e., *fingerprints*) in indoor environments; (ii) estimate the localization accuracy based on the collected fingerprints; and (iii) assess Wi-Fi coverage and data rates. FMS comprises of the following components: (i) *CSM (Crowd Signal Map)*, which is a map-based visual management environment to orchestrate the crowdsourcing effort of indoor signals for ethical benefit; (ii) *ACCES (Accuracy Estimation)*, which enables the qualitative assessment of localization accuracy before deploying the localization service (i.e., in the laboratory as opposed to the field) using Gaussian Processes Regression and the *Cramer-Rao Lower Bound* (CRLB); and (iii) *WS (Wi-Fi Surveying)*, which enables the qualitative assessment of Wi-Fi coverage using the signals collected by crowdsourcers.

Currently, there is no other academic or industrial system that brings the location and Wi-Fi components of FMS under the roof of an open-source stack, which will be invaluable to researchers and practitioners at the conference and beyond.

II. Overview of FMS

In this section we outline the technical details of the components comprising the Fingerprint Management Studio.

CSM (Crowd Signal Map): is a map-based visual management environment to orchestrate the crowdsourcing effort of indoor signals. It particularly allows the crowdsourcing coordinators to have a clear understanding of where additional effort is necessary or to delete erroneous entries. We provide multi-granular visual analytic structures (heatmap and coverage maps) that enable the management of data in space and time exposing both performance and high resolution. Figure 1 shows one such example where the stencil bar on the left provides quick access to all functionality of FMS. Particularly, the user observes through the heatmap where fingerprints have been sampled (red shows high density). It also shows with purple squares where the Wi-Fi signal strength is between -90dBm and -100dBm (i.e., intermittent connectivity). A histogram time selector enables the user to focus on different time ranges.

ACCES (Accuracy Estimation) [6]: is our novel framework for offline positioning accuracy assessment at arbitrary locations for which fingerprints have been collected. Our approach is constructed in three steps: First, we apply a black-box technique for fingerprints interpolation based on a widely used statistical instrument called *Gaussian Processes*. This tool allows to: (i) predict sensor readings at chosen locations given the initial input data (*FM*); and (ii) estimate the uncertainty of such predictions in the form of the variance of a Gaussian distribution. Then, given such predictive distribution, we derive a theoretically solid lower bound for the uncertainty in the location estimation, i.e., the localization error, in the form of a *Cramer-Rao Lower Bound* (CRLB). The CRLB construct is used in estimation theory to derive lower bounds on the variance of an estimator of deterministic parameters. We utilize the derived CRLB as the *ACCES navigability score* and show its results in the form of a blue heatmap.

WS (Wi-Fi Surveying): surveying formally refers to the process of planning and designing a wireless network so that *Access Points (APs)* are positioned optimally, with respect to wireless coverage, data rates, network capacity, roaming capability and Quality of Service (QoS). Given that an AP network is already in place when an IIN architecture is deployed, the aim of FMS is to provide retrospective visual analytics to network architects for subsequent decision support, e.g., where to install new APs and stronger antennas or where to change the SSID broadcast channels to avoid collisions at the MAC layer. The WS component shows the reception quality of Wi-Fi in five classes, based on the RSS indicator of the MAC addresses. It also records in a database the prefixes (3-Byte to 5-Byte) of the 6-Byte MAC addresses for various manufacturers (we use Wireshark.org OUI database). AP inference is carried out with a weighted threshold algorithm: if all signals for an AP MAC address are weaker than a given threshold (e.g., -60dBm), we derive the AP location using the centroid of the AP signal strengths. Otherwise, the AP location is derived based on the strongest signal.

III. Demonstration Scenario

During the demonstration, the attendees will be able to appreciate the functionality, the visualization abstraction and the performance of FMS in a real setting.

Demo Artifact: FMS has been integrated to our award-winning Anyplace Architect and is available to the open public as of release v3.3. Our system has a low setup time because it relies on the Wi-Fi infrastructure available at the conference venue. If necessary, our team can quickly deploy additional

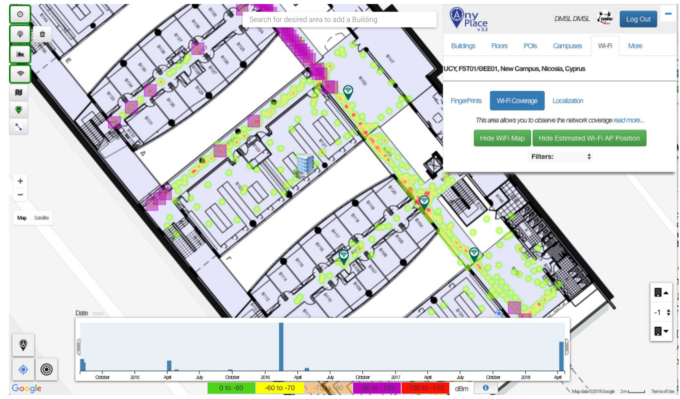

Fig. 1. The Fingerprint Management Studio (FMS) provides a spatio-temporal platform to: (i) manage the collection of location-dependent *fingerprints* in indoor environments; (ii) estimate the localization accuracy based on the collected fingerprints; and (iii) assess Wi-Fi coverage and data rates.

smartphone APs to provide adequate Wi-Fi coverage. Thus, only the floorplan digital map of the demo site is required.

Demo Plan: We will carry our demonstration out in 2 modes: (i) Online Mode, where we will ask conference attendees to collect Wi-Fi fingerprint data using the Logger and upload them to the Anyplace IIN. We will provide respective Android devices to the attendees. Conference building floor plans will be prepared and uploaded to the Anyplace IIN in advance. After uploading the fingerprints, attendees will be asked to observe and interact with the collected data in order to improve decision making (e.g., where to collect more fingerprints for better localization accuracy and/or where to setup an IoT device for best network connectivity). Finally, the audience will be asked to use the Anyplace Navigator to take advantage of the updated indoor models; and (ii) Offline Mode, where we will ask conference attendees to interact with some per-constructed indoor models. Particularly, we will ask the audience to compare the Wi-Fi connectivity, localization accuracy and crowd signal maps of a number of models, e.g., University campus comprising of 58 buildings in Cyprus; a hotel in the USA and a multi-floor expo center in S. Korea.

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