Indoor Positioning using Wi-Fi – How Well Is the Problem Understood?

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***Abstract*—The past decade has witnessed substantial research on methods for indoor Wi-Fi positioning. While much effort has gone into achieving high positioning accuracy and easing fingerprint collection, it is our contention that the general problem is not sufficiently well understood, thus preventing deployments and their usage by applications to become more widespread. Based on our own and published experiences on indoor Wi-Fi positioning deployments, we hypothesize the following: Current indoor Wi-Fi positioning systems and their utilization in applications are hampered by the lack of understanding of the requirements present in the real-world deployments. In this paper, we report findings from qualitatively studying organisational requirements for indoor Wi-Fi positioning. The studied cases and deployments cover both company and public-sector settings and the deployment and evaluation of several types of indoor Wi-Fi positioning systems over durations of up to several years. The findings suggest among others a need for supporting all case-specific user groups, providing software platform independence, low maintenance, allowing positioning of all user devices, regardless of platform and form factor. Furthermore, the findings also vary significantly across organisations, for instance in terms of need for coverage, which motivates the design of orthogonal solutions.**

I. Introduction

Motivated by the challenge of indoor positioning, a substantial amount of research has focused on methods for indoor Wi-Fi positioning. For instance, a search for Wi-Fi and positioning on Google scholar [1] returns over ten thousand papers. Already in 2007 a survey covered over fifty papers presenting different methods for Wi-Fi positioning [2]. Since then research on the topic has increased its output and is by now accompanied by articles that study the links between Wi-Fi positioning and other positioning technologies.

Research articles on WiFi indoor positioning are foremost method oriented, e.g, most of them propose a new technique to address one general goal, e.g., positioning accuracy as evaluated on collected datasets. General arguments are given to promote addressing the specific topic of the presented contribution. However, these claims are often not backed up with statements grounded in insights from positioning system stakeholders (e.g., future owners or users) or real-world use experiences with deployed systems. Therefore, it is largely unknown whether or not research is addressing the most pressing issues, e.g., it is unclear whether further accuracy gains are more pressing than, e.g., the improvement of methods that allow for positioning of devices of a broader variety of operating systems and form factors. Therefore, an understanding of the organisational requirements for indoor Wi-Fi positioning as deployed in real-world use, e.g., at companies or public-sector institutions such as hospitals, is needed to justify both further research on known issues as well as on yet mostly unaddressed issues. To the best of our knowledge, so far no studies have been published which focus on reporting the organisational requirements for indoor Wi-Fi positioning.

Research on Wi-Fi positioning has inspired commercial businesses to provide—on common smartphones and within urban areas—positioning systems that, e.g., allow to pinpoint the building you are in or enable a points-of-interest application to show you that there is two kilometres to the nearest shopping mall. For such positioning systems earlier studies claim accuracy levels of 30-70 meters—depending on calibration level and algorithm used [3]. Furthermore, quite a number of papers discuss applications of urban positioning, e.g., location-based games, life logs from place visits or location-based reminders [4]. At the indoor-level the research has also inspired businesses to provide site-specific indoor Wi-Fi positioning systems to individual organisations targeting an accuracy below 3 meters [5], [6]; however, such technology is not massively deployed yet. Recently, new players are entering the scene providing site-independent indoor Wi-Fi positioning for public spaces together with indoor maps, e.g., Google Maps 6.0 [7] targeting an accuracy of 5-10 meters [8]. However, given the lack of knowledge of organisational requirements it is hard to judge the application potential for these systems.

Given the substantial amount of research into methods for indoor Wi-Fi positioning in the last decade one would expect that there by now would exist a multitude of papers reporting on the deployment experience of indoor location-based applications which utilize indoor Wi-Fi positioning. Therefore it is a paradox that when the authors surveyed the literature only seven articles on the topic could be identified.

In the light of the published as well as of our own experiences on indoor Wi-Fi positioning deployments, we hypothesize the following: Current indoor Wi-Fi positioning systems and their utilization in applications are hampered by the lack of understanding of the organisational requirements present in the real-world deployments. This paper thus addresses the lack of knowledge of organisational requirements for indoor Wi-Fi positioning. Our case studies and deployments cover both company and public-sector settings and the deployment and evaluation of several types of indoor Wi-Fi positioning systems deployed for several years. The paper's contributions are as follows: We present findings of important requirements in different organisations based on case studies of deployed indoor Wi-Fi positioning systems both in company and public-sector settings. The findings suggest among others a need for supporting all user groups, providing software platform independence, low maintenance, and enabling of positioning for user devices regardless of form factor. Additionally, there is a need to establish application requirements for not only accuracy but also latency. Furthermore, the findings also vary significantly across organisations, for instance in terms of need for coverage, thereby motivating the design of orthogonal solutions.

II. Recap of indoor Wi-Fi-Positioning

For use in the reminder of the paper we will establish some terminology for Wi-Fi positioning systems building on the yet most extensive attempt to structure this field [2]. Indoor Wi-Fi positioning has been studied for more than a decade and research has proposed a variety of methods and algorithms building on the notion of location fingerprinting [9]. At the core of any location fingerprinting system is a *radio map* which is a model of network characteristics in a deployment area. A *positioning method* uses this radio map to compute a likely position given an observation of the current network characteristics. Additionally, positioning methods might fuse Wi-Fi derived positions with other sensor observations [10]. Wi-Fi positioning systems are classified according to the division of role as *device-based* if both taking measurements and positioning are performed by the device to be positioned, *device-assisted* if measurements are taken by the device and positioning is performed remotely, and *network-based* if the network carries out both the measuring and the positioning remotely.

Radio maps can be constructed by methods which can be classified as either empirical or model-based. *Empirical methods* use collected fingerprints to construct radio maps. *Model-based methods* use instead a model parameterised for the covered area to construct radio maps [9]. Furthermore, given recent trends we will in this paper subdivide the empirical methods into administrative, participatory and opportunistic fingerprinting. *Administrative fingerprinting* is carried out by the administrator of the system or by an expert hired on the behalf of the administrator [9]. *Participatory fingerprinting* refers to users of the positioning system collecting fingerprints when and where they want to [11]. *Opportunistic fingerprinting* refers to collection of fingerprints during normal system use without any user intervention and explicit ground truth provision, e.g., with the assistance of inertial sensors [12] or using unsupervised techniques to recover the mapping to the physical space [13] .

III. Organisational Requirements

In this section we address the knowledge gap regarding organisational requirements for indoor Wi-Fi positioning. Here, organisation denotes an organized entity involving several people with a particular purpose, such as a business or a public-sector institution or department. To gather knowledge about the organisational requirements, we chose the analysis of case studies as our guiding research method. This enabled us to study different cases of organisations and distill from the collected information the case-specific requirements and analyse how these differ among organisations.

The cases we consider have been chosen in order to cover the following two dimensions. Firstly, the type of organisation, e.g., public institution versus private company. Secondly, the size of the organisation in terms of number of potential users and total coverage area of buildings. We selected cases among organisations which we knew to either already have experiences with positioning or have an interest in trying out positioning. Consequently, we chose to study cases at a Small Private Company (SPC), a Medium-sized University Department (MUD), a Large Shopping Mall (LSM) and a Large Public Hospital (LPH). In the following, we will use the above abbreviations to denote either the respective deployment scenario or the respective stakeholder parties. Table I lists the studied organisations together with the number of potential system users, the size of the total coverage area and the type of the Wi-Fi positioning that was deployed. Within the organisations we contacted persons with an interest in or with experiences of using indoor Wi-Fi positioning. The contacted persons varied in their knowledge specifically about positioning and also in their level of technical knowledge in general.

Our procedure for gathering information for the case studies is primarily based on semi-structured interviews with stakeholders about their organisations' requirements for indoor Wi-Fi positioning. Additionally, for two of the organisations we deployed a positioning system at their site: for SPC, since the organisation did not have prior experience with positioning, and for LPH to to enable them to experiment with a different type of indoor Wi-Fi positioning. For the two latter cases we also did follow-up interviews after the deployments.

To guide the case study we have reviewed existing literature. However, we found no research studying in depth the organisational requirements for Wi-Fi positioning. Instead, as stated in the introduction, research in the field is motivated by and focuses on general goals regarding the improvement of accuracy or the reduction of deployment cost, and, accordingly, general arguments for these goals are given to promote the specific topic of the presented contribution to the field. In regards to organisational requirements, though, literature has so far focused foremost on capturing the technical differences among positioning systems by defining evaluation criteria capturing different technical aspects of these systems, e.g., resolution, accuracy, coverage, infrastructure requirements among others. Furthermore, the claims regarding the system's performances are often purely technical, but not backed up with statements grounded in insights from users and stakeholders. So far only two aspects of WiFi positioning deployments have been linked with and discussed in regards to the organisational requirements: Firstly privacy, e.g., in an academic setting [14] and secondly—and only in form of general comments—on social barriers for fingerprint collection [11] .

In the following we present the findings from the four case studies, structured according to nine requirement types we identified as important. These findings are summarized also in Table II which reveals that the identified requirements differ among organisations, suggesting that there may not be a ”one size fits all” indoor positioning system.

User Groups (O1) Several organisations, most clearly MUD and LPH, stated that they had several user groups, that were candidates for using a positioning system. These were for LPH: clinical staff, service staff, patients and guests; and for MUD: academic staff, technical staff, administrative

TABLE I. DETAILS FOR CASE ORGANISATIONS

	Description	Potential Users	Total Coverage	Wi-Fi Positioning Deployment	Interviewed
SPC	Small private company	70	A three story building	Empirical participatory fingerprinting	Two software engineers
MUD	Medium-sized university department	140 + students	Five buildings with three to five stories each	Model-based and empirical administrative fingerprinting	Network Administrator
LSM	Large shopping mall	100 + customers	Large building complex with 85 shops	Empirical administrative fingerprinting	Site Manager
LPH	Large public hospital	5000 + patients and visitors	Large building complex with 6000 individual rooms	Empirical administrative and participatory fingerprinting	Two Network Administrators

TABLE II. SUMMARY OF FINDINGS FOR ORGANISATIONAL REQUIREMENTS

	O1	O2	O3	O4	O5	O6	O7	O8	O9
SPC	Single	Incremental	Few	+	External	+/-	+	-	+
MUD	Multiple	Complete	Several	+	External	+/-	+	-	+/-
LSM	Single	Complete	Few	+	External	+/-	+	-	+/-
LPH	Multiple	Complete	Many	+	Local	+	+	+/-	+

staff, students and guests. From the studies we noticed that these groups differ in all of: i) how they utilize the space, ii) their mobility patterns, and iii) for how long they are within the premises of the organization. For instance within LPH, the staff comes and leaves at regular (work-shift) times, and depending on their function they are either largely stationary at one department, or move around the whole hospital. In contrast, guests who visit a hospitalized patient often go directly to a specific department—occasionally with a detour to some of the common facilities. Patients on the other hand either stay mainly in an department if they are hospitalized, and otherwise walk from an entrance to the department where they receive the ambulant treatment and exit the building afterwards. The two organisations LSM and SPC had foremost a single specific group in mind to provide positioning to: for LSM customers, and for SPC staff.

Coverage (O2) The organisations differ in how they view the requirements for coverage. When introduced to Wi-Fi positioning, SPC was favoring the concept of slowly growing the coverage to incrementally include places according to how much these were frequented, as this would easen the initial deployment. After trying this approach, they provided positive statements regarding growing the coverage. However, they also did not have a lot of experience with potential applications, which potentially could make them reconsider these statements. MUD, LSM and LPH stated that they would like complete coverage for their premises, so that the provided applications would work without outages and "dark spots" within the targeted areas and for the intended user groups and for tracked assets.

Form Factors (O3) Most of the organisations stated that they would like the positioning to work for several form factors of devices. SPC and LSM was focused on the positioning of smart phones, MUD on smart phones and tags and LPH considered all of laptops, smartphones, tablets, Wi-Fi-enabled badges, watches; where smartphones would be foremost used for people tracking, and tags asset tracking. Furthermore, given the rapid evolution of different form factors, a wish was stated to be able to adopt new device types and form factors as these enter the market.

Software Platform (O4) Some of the organisations pointed to that positioning should work regardless of the operating system of the devices to be supported. In particular, LPH stated they would like their applications to work regardless of the users' device operating systems. When visiting the organisations we also noticed how the organisations used and supported laptops, phones and tablets with different operating systems. LSM would like that all visitors would have access to position-based services wihtin the premises. Such platform-independent positioning is not trivial and may induce restrictions in other regards: For instance, in the SPC and LPH deployments potential system users were limited by the fact that the tested device prototype was implemented on the Android platform as device-side positioning is not possible to implement on current iOS devices due to the restrictions of the currently available APIs.

Infrastructure (O5) For LPH it was paramount that the positioning system came with a high level of reliability and availability—as soon as their work processes integrated positioning systems. To achieve this, they viewed it as a crucial measure that the positioning service was hosted within their own infrastructure. SPC and LSM instead did not have such concerns and were willing to accept a cloud-hosted service—such as the remotely hosted system that was eventually provided to them in the deployment.

Data Privacy (O6) For LPH it was important to protect location traces whenever these originate from a device carried by a identifiable person; the reason being, that they considered such traces as personal and privacy-sensitive data since, e.g. in the case of patients, medical conditions and their severity may be deduced from their in-hospital position traces. LSM, on the other hand, did not view privacy as an organisational issue, because the positioning was used by their customers without LSM having knowledge of the resulting position data.

Maintenance (O7) All organisations required explicitly that their positioning solution should have only a low degree of maintenance. LPH had already tried an empirical administrative fingerprinting-based solution and gave up on fingerprinting their premises exhaustively, once they had concluded that this task would take more than three months for a single person. Furthermore, because they invested in the positioning system as an add-on when replacing their wireless infrastructure, no major resources were assigned to running or configuring this add-on. A second maintenance issue that LPH encountered was, that there was no updating procedure in place to inform the installed system that an access point had been replaced, e.g., in place of a access point with a different identifier but of similar type and location—suggesting that old fingerprints could be reused. After the deployment, LPH saw some potential in empirical participatory fingerprinting as a low cost solution to improve accuracy in specific areas of the hospital. This fingerprinting approach was attractive also to SPC. Initially, they were concerned if such a solution was really cheaper, given that highly paid staff may end up spending work time on this task. However, after deployment SPC even suggested that the system should propose new places to users, where they should go to take a fingerprint. A problem encountered with this system was that people often selected the wrong floor, since the floors' layouts were very similar. The issue was partly solved by increasing users' awareness of what floor they selected when fingerprinting via presenting to them a different coloring of each floor. MUD had ran a model-based fingerprinting solution for three years with extremely low maintenance. E.g., when all access points were replaced after two years with newer models, only the mac addresses, residing in a single file, had to be reconfigured to get the system up and running again. They also tested a empirical administrative system in some parts of their buildings to improve accuracy but had given up fingerprinting it after all access points had been replaced. LSM did a partnership with an external party so maintenance was limited to providing information about their Wi-Fi infrastructure.

Fingerprinting Limitations due to Social Barriers (O8) When confronted with the social barriers that might affect the decisions, whether an administrator or expert could or should collect fingerprints , SPC did not view this as a major problem. They compared it to the duties of cleaning personnel or of a person watering the flowers—which also require access to and temporary presence in most of the premises. However, for participatory fingerprinting there may be restrictions: E.g., given the case that the system suggests that a participating user should fingerprint his boss's office, him entering that office unnoticed may not be considered as an acceptable action within the organisation. MUD had allowed earlier for such collection and therefore also did not view this as a major problem. LPH and LSM did not utter issues with the topic either. However, in a hospital setting there are a number of locations which are difficult to get access to, e.g., doctors' offices, resting rooms, and operation rooms, as these are either seldom unoccupied or considered private areas.

Accuracy and Latency (O9) When the stakeholders were asked upfront, LPH and SPC generally wished for room-level accuracy with high confidence and low latency. Wi-Fi positioning systems generally struggle to provide room-level accuracy (assuming rooms < 20 square meters) with high confidence (at least if not assisted by other sensor modalities or employing massive deployments of short range Wi-Fi access points). Therefore, the technology may not be able to fulfill the above wishes fully. LPH linked these wishes to a number of clinical applications—but also recognized that for other applications more relaxed requirements were sufficient, e.g., sub-department level for providing an overview of assets. LSM stated that for way-finding via in-app indoor maps they had gotten positive reactions from customers—despite the current positioning accuracy was coarser than room-level. MUD stated that for asset tracking they had gotten positive reactions when providing an (empirically determined) 6 meter median accuracy. In general, the organisations' stakeholders were unsure about the link between positive application experiences and specific requirements for accuracy and latency.

IV. Conclusions

In this paper we have hypothesized about the reasons for that after more than ten years of research on indoor Wi-Fi positioning, it has not yet achieved a widespread breakthrough in terms of real world deployments. We argue that this is due to a overly narrow research focus on algorithmic optimization of positioning accuracy in insufficiently realistic settings—at the expense of a broader understanding of the organisational side of indoor Wi-Fi positioning. The findings suggest among others a need to consider how to support all user groups, provide software platform independence, low maintenance, allowing positioning of all user devices, regardless of platform and form factor. We hope that the research community will address such challenges in future work.

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