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Parking Assistance System for Indoor Environment

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Abstract—In the last decade, indoor location based applications, such as touristic guide in museums or shopping guidance in supermarkets, have been developed rapidly requiring suitable and accurate indoor positioning. However, location sensing in indoor environments is a challenging task and an intensively researched topic. Fortunately, wireless technologies can help us derive location information. In this paper, we propose and introduce our positioning and navigation system for indoor parking garage environment, called iParking, which has been under development. The iParking system collects real-time parking lot occupancy data, and tracks and navigates vehicles entering the parking garage to a preselected, e.g., the closest to the favorite shop, free parking lot. The driver's smartphone is used as the navigation interface. The system is built on a background Wi-Fi infrastructure making the deployment and maintenance economical. Currently, we have been implementing a prototype of our iParking system in a parking garage of a shopping mall for demonstration purposes.

Keywords-iParking; Indoor positioning; Wi-Fi; Parking; Navigation; Android

I. INTRODUCTION

Outdoor navigation services are available for almost everybody today thanks to the Global Positioning System (GPS). Position sensing and navigation have potentials also in indoor scenarios, like tourist/shopping guidance or indoor parking. Using a smart indoor parking assistance system reduces the parking lot seeking time, reduces CO2 emission, lowers the degree of human involvement in traffic control and helps avoid driver frustration. However, estimating the location in indoor environments is a challenging issue and it has been in the focus of research for a while. Fortunately, wireless technologies with careful design can be applied for indoor position sensing and navigation services.

In this paper, extending our former work [1] we propose and introduce our iParking system which is an intelligent parking assistant for indoor environment. It is Wi-Fi (IEEE 802.11 standard family) based, because Wi-Fi is a prevalent technology for indoor positioning providing an acceptable compromise between cost and accuracy. As a prerequisite, our iParking system collects real-time occupancy data about the parking lots of the given parking garage. This is carried out via either ultrasonic sensors, which are usually deployed together with shaping the parking lots, or other dedicated sensors deployed posteriorly for this special purpose.

The vehicles entering the parking house are tracked continuously by the iParking system's Wi-Fi based background infrastructure. For position estimation we use signal fingerprint algorithms. In general, the use of one fingerprint database is enough, but in our system we combine several ones to increase the positioning accuracy. In this case, the algorithm can switch from one database to another and adapt to the actual conditions in the parking garage. For example, we maintain a different fingerprint database for pedestrians, who want find their cars parked in the garage, and in-vehicle users.

For navigation, we use the driver's smartphone as it would happen on a GPS based navigation device. The target, free parking lot is preselected at the entrance of the garage via a simple procedure using preferences, such as the closest disabled parking space, family parking lot, or the closest parking lot to the entrance of the favorite shop. The preferences can be set also in advance before one departs from home.

Currently, we have been implementing a prototype of our iParking system in a parking garage of a shopping centre for demonstration purposes. The garage has 3 levels. Our demo sector is located on level 1 covering approximately 2000 square meters, one fourth of this level. This area contains about 150 parking lots. The background Wi-Fi infrastructure, used for position sensing, consists of 10 APs (Access Point), 3 Ethernet switches and a Linux based central server. The client side of the developed navigation software runs on Android smartphones and tablets. It provides an intuitive graphical user interface with simple navigation functions.

We could achieve 5–7 meter positioning accuracy so far making the navigation part a challenge. At the moment, we have been working on improving this accuracy up to 2–3 meters which seems to be enough for smooth navigation. Using some heuristics, for instance, adaptation and multiple fingerprint databases showed an increase in positioning accuracy. Thus, we could increase the average accuracy to 1.7–4.5 meters in our test scenario. We have been investigating the possibilities of further improvements.

The rest of the paper is structured as follows. In Section II, we overview some related, indoor positioning systems shortly. Our iParking system is introduced and described in Section III, and we present its prototype implementation with a short preliminary evaluation in Section IV and Section V, respectively. Finally, we give a summary in Section VI.

II. Overview of Indoor Positioning Systems

Indoor positioning systems can be classified according to the used position estimation technique (eg., triangulation, scene analysis, proximity), the applied wireless technology (eg., Wi-Fi, Bluetooth, RFID, UWB), or the performance metrics (eg., accuracy, scalability, complexity, cost) [2]. Since our iParking system utilizes Wi-Fi signal fingerprint methods, we focus our overview on Wi-Fi and scene analysis based indoor positioning systems. In scene analysis algorithms, the fingerprints of a scene must be collected first (off-line phase) and the location of the mobile device is estimated in the second phase (online phase) by matching the measurements with the closest a priori location fingerprints. For finding the best match(es) several pattern recognition techniques exist, like probabilistic methods, K-nearest-neighbor (KNN), neural networks, support vector machine (SVM), etc. [3].

The first published in-building user location and tracking system was RADAR [4, 5]. The authors proposed an approach based on empirical measurements and signal propagation model to upload the fingerprint database with received signal strength (RSS) values. In order to find the best matching RSS value measured by the user, the KNN algorithm is applied.

Another system is COMPASS proposed in [6]. In COMPASS, the positioning algorithm uses a fingerprint-based technique in which the signal strength of a given mobile device is measured by different APs. Moreover, digital compasses are utilized for getting a relatively accurate position. Thus, the user’s orientation, considered also in the location estimation, can be measured by a digital compass which is integrated in most of today’s mobile devices.

The Horus system [7, 8], applies a joint clustering technique that uses RSS probability distributions to address the noisy wireless channel. Location clustering reduces the computational cost of searching the radio map and increases the accuracy of the location determination system without scalability problems in larger coverage areas.

Several systems were deployed using Bayesian model for topological localization [9, 10, 11]. In these probabilistic solutions, the host computes the likelihood of a number of different locations, based on the RSS values. The Ekahau system [12] is a commercial wireless location sensing system that combines Bayesian networks, stochastic complexity and online competitive learning.

However, none of these systems provides navigation services.

III. iParking System

Our iParking system combines two approaches to investigate different positioning solutions. In the first approach, the position of a mobile device can be determined at any point of the covered area. The other approach is based on positioning gates and valid locations are only pre-defined points of the field, thus the exact positions of the gates and their proximity. The former approach comes to the front when the task is, for instance, to find the parked vehicle in the garage and the driver should be navigated back to his/her car. The latter approach is reasonable when the vehicle is navigated in the garage because it can be located only on the garage roads (or in the road segments) and in the parking lots. Fortunately, both approaches can be supported by almost the same background Wi-Fi infrastructure.

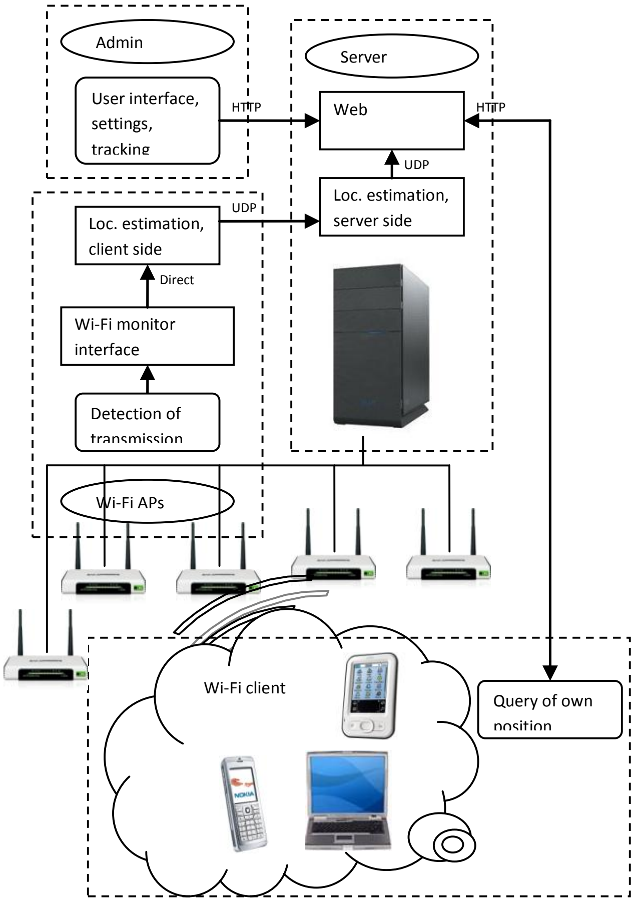

Figure 1. Major components of the iParking system and their connections

The major hardware/software components of our iParking system and their connections are depicted in Fig. 1.

The system basically consists of three components: i) the central server, which stores the fingerprint database(s) and runs the server side of position calculation if it is needed; ii) the communication infrastructure with Wi-Fi access points which serve as signal monitors and handle the connection of user devices; and iii) the Wi-Fi client devices via which the positioning and navigation service can be used. The figure shows also a dedicated user, the Admin, which can access to the server via a web interface, and can configure the access points, track the client devices and manage the iParking system. In the following, we discuss the functions of these major components in detail.

A. *Central Server*

The central server is a dedicated computer which basically stores the signal fingerprint database(s) and runs position calculations when the infrastructure is in charge of determining the location of the visiting mobile node. Actually, we store two different fingerprint databases on our central server. One is used for pedestrian users, who want to find their cars parked in the garage, while the other one is for in-vehicle customers. Of course, the number of specific fingerprint databases can be increased depending on other features, as well.

In the presented iParking system, we used a simple algorithm to decide which database should be applied. The users entering the garage at the car entrance will use the in-vehicle database (the fingerprints were recorded with a device located in a vehicle), while the users coming from inside the building will utilize the pedestrian fingerprint database (the fingerprints were recorded with a device carried by a pedestrian). We used centralized fingerprint management, however an alternative is if the mobile device determines its own position assuming that it has enough storage capacity, computation power and it possesses the fingerprint database. This alternative may have also benefits when device specific fingerprint databases are available.

The server can be installed with an appropriate distribution of any operating system (eg., Linux, Windows) which is optimized for the limited hardware. We are running an embedded Linux version on our central server tailored for the required tasks.

The main functions of the server are: stores the map and the fingerprint database(s) of the parking area; monitors the occupancy of the parking lots via ultrasonic sensors; continuously collects Wi-Fi signal strength information of the visiting mobile devices via access points; calculates the positions of the mobile nodes to be tracked; and sends back the calculated position information to the visiting device via the Wi-Fi infrastructure.

B. Communication Infrastructure with Wi-Fi Access Points

Since our iParking system is based on Wi-Fi technology, we use Wi-Fi access points at the perimeter of the background infrastructure. The main function of the communication infrastructure is to ensure the connection between the central server and these Wi-Fi APs, and to provide a wireless link for client devices to access the iParking system.

The communication infrastructure is responsible for forwarding the traffic between the APs and the central server, and it is used to configure the APs remotely. The direct wireless link between the APs and the client devices can be considered as also part of the communication infrastructure.

Additionally, the communication infrastructure may be used to handle other types of traffic, eg., it may support Internet access for end users. However, in our prototype system no other services are implemented.

The main functions of the Wi-Fi access points are: collect the necessary data (RSS information of each client device) for the position estimation algorithm; forward the collected data to the central server; connect the client devices to the background infrastructure; forward the computed position estimation back to the client devices.

C. Client Devices

The provided positioning and navigation services can be used via the users' mobile devices, thus they are the clients of our assisted parking system. Smartphones or tablets equipped with Wi-Fi interface are capable to monitor signal strength data; to receive position information; to display the garage map; and to run the navigation software. Moreover, the users' interactions are handled also via these devices.

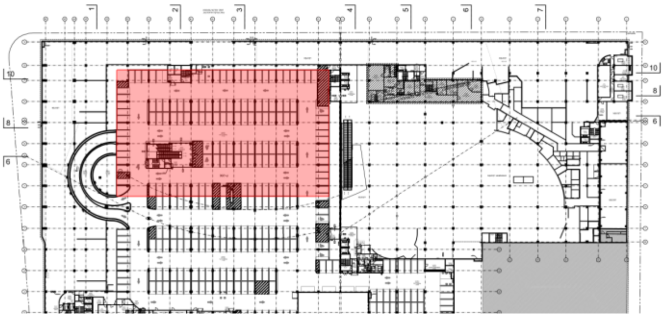

Figure 2. Level 1 of the parking garage and the demo sector

IV. PROTOTYPE IMPLEMENTATION

A. Demo Sector

As a proof of concept, we have been implementing a prototype of our iParking system. We have chosen the parking garage of a shopping center as the test location. The garage has three levels from which level 1 has been selected to host the demo sector. Fortunately, this level consists of two totally distinct parts. One of them is used by officers and the other one is used by normal visitors. The two parts are separated by an entrance gate. We set out only a section of level 1 from the public part for our experiments, roughly covering one fourth of the whole territory. Level 1 of the parking garage and the demo sector are shown in Fig. 2. The demo sector is highlighted with red color.

The selected demo sector is convenient to handle, because it has only one entrance and exit for vehicles, another one for pedestrians, and consists of three lanes (roads) with some junctions. The covered parking area is about 2000 square meters with around 150 parking lots.

B. Logical System Structure and Physical Setup

Our principle in designing the network was to place the Wi-Fi access points in the way that everywhere in the demo sector we can perceive the signal with strong enough strength of at least three APs (to be able to investigate also triangulation based positioning algorithms), but keep the number of deployed APs as low as possible.

It turned out that 10 APs are sufficient to satisfy this condition. Furthermore, we used three Ethernet switches to connect the APs to the central server. Fig. 3 shows the logical structure of our prototype system.

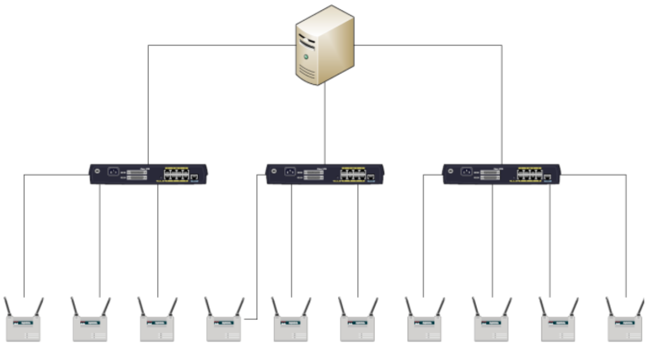

Figure 3. Logical system structure

To be able to test the two different positioning approaches (mentioned in Section III) simultaneously without the need of deploying two separate systems, we chose suitable network elements. The main difference between the two systems lies in the antenna type selection. To implement the first approach, we selected omni-directional antennae, while for the second approach we used directional antennae. Thus, we needed such wireless APs which can handle two antennae with different types without changing the physical setup. The selected devices of our prototype system are the following:

- TP-LINK TL-MR3420 300Mbps 3G WLAN router;
- TP-LINK TL-ANT2408C 2.4GHz 8dBi indoor desktop omni-directional antenna;
- TP-LINK TL-ANT2409A 2.4GHz 9dBi directional antenna;
- TP-LINK TL-SF1008P 8-port 10/100M desktop PoE switch (4-port PoE);
- TP-LINK TL-PoE10R 5V/12V PoE adapter;
- ASUS AT4NM10T-I server.

The physical setup in the demo sector is depicted in Fig. 4. The APs are deployed more or less uniformly covering the sector. They are cabled to the switches which are connected to the central server. These cables are also used to power the APs via PoE (Power over Ethernet) technology. Fig. 5 shows the signal coverage of the access points using omni-directional antennae (first approach) while Fig. 6 depicts the same in case of using directional antennae (2nd approach).

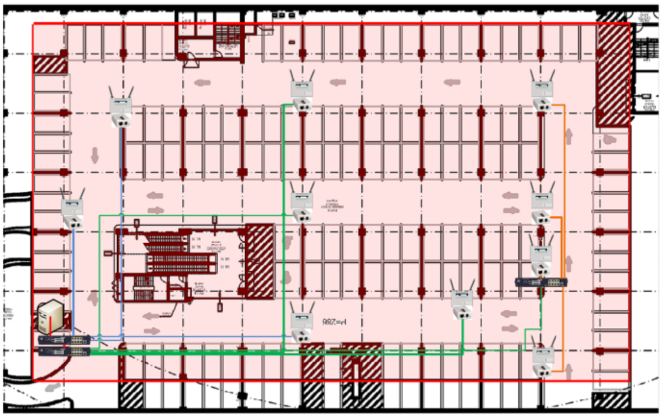

Figure 4. Physical setup of our prototype system

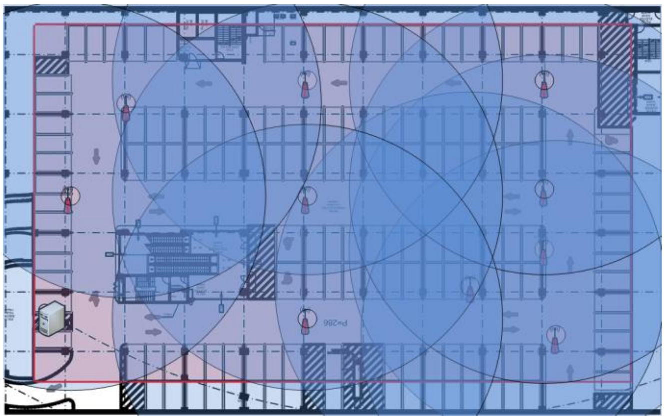

Figure 5. Signal coverage in case of using omni-directional antennae

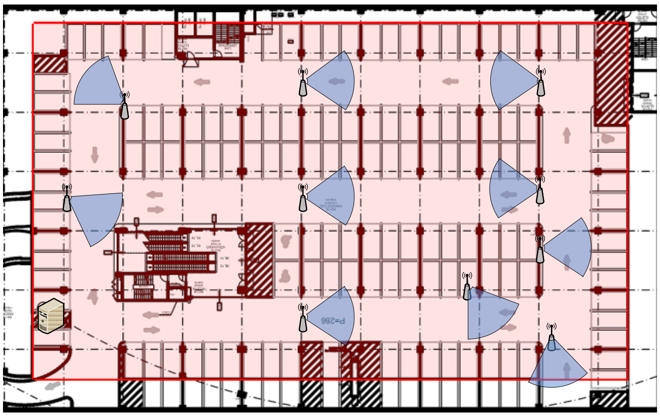

Figure 6. Signal coverage in case of using directional antennae

C. *Positioning Methods*

As we mentioned above, our iParking system is prepared to investigate different localization approaches. For estimating the exact position fingerprint based methods and triangulation techniques can be used. For a less precise positioning and assessing only in which road segment the vehicle is using sensor gates can be an alternative approach.

Figure 7. Screenshot of shopping mall selection

So far, we have implemented a fingerprint based method. In this case, first we build the fingerprint database[1] of the given area by measuring and collecting RSS data of all the APs in predefined points of the area. We set these points as the junctions of a grid with 4m grid distance. Then, the visiting device to be located continuously measures any perceived signal from the APs and sends these measurements to the server. The server calculates the position estimation based on the stored fingerprint information running a positioning algorithm, which is the KNN algorithm in our case, and sends back the result to the visiting device.

We modified the original KNN algorithm and extended it with weighted average calculation, memory and road fitting methods. The position is calculated as the weighted average of the two nearest RSS neighbor coordinates and the previous returned position, shown in the following equation:

$$(x_t, y_t)' = w_1\cdot(x_{KNN1}, y_{KNN1}) + w_2\cdot(x_{t-1}, y_{t-1}) + w_3\cdot(x_{KNN2}, y_{KNN2}),$$

where w_n is the applied weight ($w_1 > w_2 > w_3$). The calculated $(x_t, y_t)'$ is used to find the closest reference point in the fingerprint database if road fitting is switched on. The proposed position calculation method smooths out the effect of sudden RSS variations due to false measurements and keeps the estimated vehicle position on the route.

D. Navigation

The navigation software is running on the driver's Android based mobile device. After selecting the shopping mall (see Fig. 7) it presents the map of its parking garage (see Fig. 8).

Entering the garage the driver on a touch screen expresses his/her preferences to find an appropriate free parking lot. Based on that the iParking system selects a lot and sends its coordinates to the driver's mobile device. The navigation software computes a shortest path to the selected lot, and based on the continuously received position estimation updates navigates the driver. Fig. 8 shows a screenshot of the navigation interface.

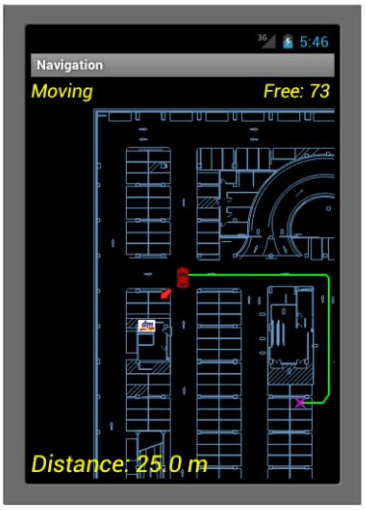

Figure 8. Screenshot of the navigation interface

V. PRELIMINARY EVALUATION

The minimum required accuracy of a parking assistance system depends on the dimensions and the floor plan of the parking garage, the allowed driving speed, and some other factors. In the iParking demonstration sector, the parallel routes are 10 meters far from one another, the floor plan is fairly simplistic, and the allowed driving speed is 30km/h resulting in 2–3 meters required accuracy for smooth navigation according to our experiments. We could achieve 5–7 meters average accuracy[2] with the implemented fingerprint based positioning method so far, which makes the navigation challenging.

The accuracy can be improved if adequate fingerprint database is selected as the reference. We have analyzed a simple fingerprint algorithm that selects the reference database according to the entrance point of the user. In case of users coming from inside the shopping mall and looking for their car, a pedestrian database is selected for the KNN algorithm, while users entering from outside the building through the garage entrance will require the usage of the in-vehicle database. We have analyzed the performance of the adaptive fingerprint database selection and compared the positioning accuracy using the different databases in the different scenarios. The measurements were performed on an assigned 200m long track in the parking garage. From entering the garage until reaching the end of the track, about 30–40 position estimations were logged on the central server. The average of the estimated position accuracy is presented in Table I.

TABLE I. AVERAGE POSITIONING ACCURACY FOR DIFFERENT TYPE OF USERS AND FINGERPRINT DATABASES

	Pedestrian DB		**In-vehicle DB**	
	Simple	***Road fit***	***Simple***	***Road fit***

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[1] Our fingerprint database is a collection of measured Received Signal Strength (RSS) values between the measuring device and all the APs

[2] Accuracy was measured by comparing the real and computed positions of the user device

Pedestrian	2.61m	1.76m	8.29m	8.02m
Vehicle	11.31m	11.22m	4.50m	4.21m

According to the obtained results, significant improvement can be achieved if the reference database is selected based on the user features. Moreover, switching on the road fitting function in the positioning application the average error distance can be decreased further.

We investigated also the effect of the parking lot occupation level on the positioning accuracy. We experienced 4–6 meters as the mean error when the parking garage was almost empty. On the other hand, the mean error increased up to 8–10 meters when the occupation level of the parking lots was above 75%. The reference fingerprint database was recorded in the empty garage. These results point out that the parking vehicles influence substantially the signal propagation properties, as we expected. Thus, using several fingerprint databases and select the appropriate one based on the actual situation can help here, too.

Other systems can offer higher average positioning accuracy in basic scenarios. For example, the RADAR system's accuracy is around 2–3m [4, 5]. The Horus system's accuracy is within 2.1m with 90% probability [7, 8]. For smooth navigation our iParking system's accuracy should be also increased into the range of 2–3 meters.

At the moment, we are working on improving the performance of the positioning part by extending the basic algorithm with memory, route fitting techniques and other heuristics, and by implementing and investigating other localization approaches, such as sensor gates.

VI. SUMMARY

In this paper, we introduced and described our intelligent indoor parking assistance system called iParking. Our system, using a Wi-Fi based background infrastructure, tracks the position of the vehicle entering the parking garage and navigates the driver via his/her smartphone to an appropriate free parking lot. Currently, we have been implementing a prototype of our iParking system in a parking garage of a shopping centre and working on improving the positioning accuracy.

As future work, we plan to investigate further the effect of using several specific fingerprint databases combined with advanced database selection algorithms. Moreover, we plan to introduce other location based services on top of the basic positioning and navigation system, such as personal navigation, shop advertisements, virtual tours, etc.

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