User-profiled Platform with Advanced Navigation Support

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***Abstract*—The increasing spreading of top-medium range mobile phones offering advanced capabilities and the broader use of short-range wireless technologies embedded in them are laying the foundations for the development of new added-value services. In this paper we present an architectural solution for delivering location-based services over heterogeneous mobile phones tailored to the preferences of individual users. We then discuss the performance of a solution for proximity marketing derived from the platform, in terms of localization accuracy and client-application usability.**

***Keywords*-smartphones; indoor positioning system; user's profiling;**

I. Introduction

In this paper we present the PROMO system, which is a project originally aimed at the implementation of an on-demand proximity marketing service that has been evolving in a novel platform for the provisioning of new added-value services on mobile phones in an indoor environment [1], [2], and discuss its technological solutions to the several challenges in this area.
PROMO is based on a client-server architecture. The client runs on a mobile phone, while the server runs on a host. They exchange data over Wi-Fi. PROMO's key feature is that it performs a continuous tracking of the user's device.
As detailed in the next sections, PROMO determines the position of a device using a pattern matching technique and assuming that each location possesses a unique RF signature (fingerprint). Such signatures are based on Wi-Fi received signal strength (RSS). To reduce the system's set-up costs, including software installation, server-side service configuration and server-side components distribution, a domain-specific development technique has been utilized.
The PROMO system has been already successfully demonstrated in some of its components [2], and we present here the trials performed on a deployment in a real mall (section V) and the future work (section VI).

II. System Design

The architecture of the PROMO platform is designed to implement all business logic features on the server side, leaving on the client side (smartphone) GUI.

The client of the PROMO system runs on a mobile device (smartphone, tab, etc). The communication with the server is implemented over the Wi-Fi connection available in the area where PROMO is present. Clients communicate with the server using HTTPS protocol. The communication is based on the exchange of JSON (JavaScript Object Notation) objects.
The client has an internal object database to store information generated by the server: JSON calls are made only when necessary to limit network overhead, *i.e.* when the user changes his preferences or after a threshold T is elapsed. A *sessionID* is associated to a user at each login. The sessionID is valid for a time H, which can be configured at server side. The user usually logins only for the first time and its login information is saved in a local keychain. If the session expires, the keychain mechanism transparently requests a new sessionID.

PROMO provides mechanisms for delivering contents (*e.g.*, advertising) based on user profile and position. The system is able to localize the user, select and deliver a set of information interesting for her/him based on her/his position and guide the user to a point of interest (*e.g.*, a shop where a product is available). PROMO can also provide a navigation assistant for helping people move inside buildings. All these features are provided by the PROMO Administration Server (Figure 1) or PAS, which contains modules for accessing the user profile (User Profiling Access), assisting localization and navigation (Localization and Navigation Assistant), selecting and delivering contents (Content Selection and Delivering), managing contents (Content Management and E-Marketing), managing customers and profiles (Customer and Profile Management), managing maps and navigation (Map and Navigation Management). The server performs content selection based on user and content profiling, and delivers contents to the client application.

III. Indoor Localization

PROMO indoor localization uses a technique based on empirical measurement of signal strength [3] that works in two stages: *off-line training* and *on-line location determination*. During the off-line phase, each Wi-Fi access point

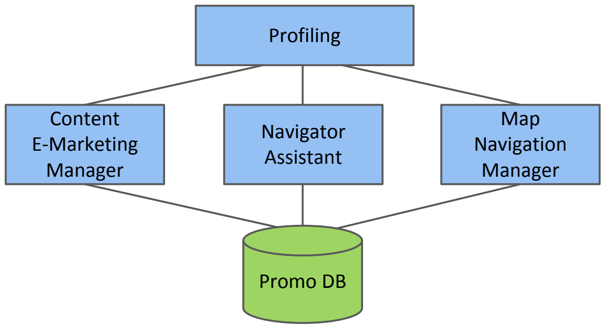

Figure 1. PAS architecture

(AP) gathers RSS level using a mobile device over a predefined area. The list of RSS collected from each AP, at the same timestamp and while the device is standing in the same location, represents a fingerprint. Fingerprints are stored in the PROMO database along with the information of the associated location and form the radio map. Location data includes the coordinates (latitude, longitude) on a map and a description (a name, a room number, etc.). The RSS levels are used as features to determine the location. In the on-line phase, the real-time fingerprint received from APs is compared with the fingerprints stored in the radio map, and a suitable match location is returned as the estimated location. Matching is done using the K nearest neighbourhood method, where k=1. The metric used is the Euclidean distance in the power space (in mW).

Let $A = \{a_1, a_2, ..., a_p\}$ be the set of APs in the surveyed area, $S_i = \{rss_{a_1}, rss_{a_2}, ..., rss_{a_m}\}$ the set of RSS data (fingerprint) collected at some known location l_i. We compute the sample mean of the collected RSS at point l_i over $k = 9$ samples and then store the mean RSS tuple $\overline{S}_i = \{\overline{rss}_{a_1}, \overline{rss}_{a_2}, ..., \overline{rss}_{a_m}\}$ in our database. Our training data source is the list of tuples: $\{\overline{S}_i, l_i\}$ $i = 1...n$, where n is the number of sample points. Now, suppose $s'_k = \{rss'_{a_1}, rss'a_2, ..., rss'a_n\}$ is the observed RSS data at the unknown location l_k.

Let s and $\overline{s}$ represent the set of APs employed to populate, respectively, RSS vectors S_i and $\overline{S}_i$. We compute the Euclidean distance between the observed data and the training data as:

$$d_i = \sqrt{\sum_{n \in s \cap \overline{s}} \left(S_n - \overline{S}_n\right)^2}, |n| \geq 2 \quad (1)$$

where RSS is expressed in mW. Let j be the number of $d_i > 0$, $i = 1..n$. We then order d_i in descending order and select the training location with the smallest Euclidean distance. To avoid unrealistic locations, during the off-line training phase we build, if possible, the *neighbour graph*, which is a list of tuples (l_i, l_j), i = 1...n, where l_i represents a training location, l_j a neighbour location. If the time elapsed from the last location estimation is less than a fixed threshold T (3 seconds), then we check whether the candidate location is a neighbour of the previous location and validate it.

IV. Configuration and Adaptation

The PROMO system provides a tool with specific functionalities for customizing the server-side infrastructure of the PROMO solution. This tool, which is based on the Eclipse development platform, allows configuring and adapting the required software parts to produce specific instances of the installed infrastructure. An approach based on domain-specific development techniques has been utilized: the tool is based on an abstract model and on source code generators. The model is used for specifying the abstract information concerning configurations and adaptations of the infrastructure. Information, such as IP addresses for the servers, usernames, passwords, installation directories, customization attributes of JPS pages, and configuration properties of databases and application servers, can be provided. In addition, the tool allows automatically retrieving, from a versioning system, the source code parts, which need to be adapted and integrated with the generated code. Then, from the information provided at model level, the generators automatically produce and customize the required source files, and the compiled executables are finally distributed to the target environments.

V. Comprehensive System Evaluation

To test and validate the PROMO platform, we implemented a proximity marketing service tailored to the needs of individual users and deployed it in a real mall. This solution is offered inside a specific building and essentially consists in sending information about special offers to the phones of end users based on their interests and their location.

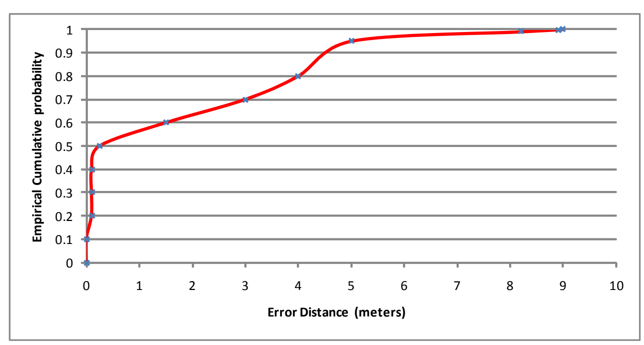

Figure 2. CDF of the Error Distance

1) Accuracy of Localization: Figure 2 shows the cumulative distribution function (CDF) of the error distance. As it can be seen, the error distance of the estimated position is less than 4 meters 80% of the times.

Table I summarizes the performance of our system in two situations: when the level of human activity was insignificant

Activity level	Average (m)	Std. Dev. (m)	Max (m)	90% Percentile
Minor	1.45	1.78	8.95	3.98
Major	1.50	1.81	8.98	4

Table I
ERROR DISTANCE SUMMARY

and when was significant. The average error distance of the system when there was minor human activity is 1.45m, while the standard deviation is 1.78m. The 90% percentile of the error distance is about 4m and the maximum error distance is about 9m. These results meet the granularity of the positioning information of a typical location based services that can be implemented over the PROMO platform (*e.g.*, in our test proximity marketing solution, a user receives advertisements related to "nearby" shops). Performance slightly degrades when there is fading induced by major human activity [4], which is a primary cause of RSS instability.

The results reflect the features of our localization algorithm. Since we choose the measurement point that has the smaller Euclidean distance from the observed RSS list and we consider the neighbour graph, the estimated position is mainly the nearest measurement point or its neighbours. Indeed, the accuracy depends on the distance between adjacent measurement points. Our measurements points are at an average distance of 4m and that explains why the 90% percentile of the error distance is about 4m.

Also, if possible, the localization algorithm chooses a candidate location that neighbours a previously estimated location: for this reason, the maximum error distance is the distance between two adjacent measurement points (*i.e.*, about 9m). Finally, the use of the neighbour graph prevents fluctuations among distant points caused by the presence of people and limits oscillations of the estimated position between adjacent points.

2) System Usability: To evaluate our prototype for proximity marketing in terms of usability and ease of use, we asked some participants to complete a questionnaire (Table II and III), in which their opinions over a range of statements were recorded on a 5-point scale, where 5 corresponded to the most positive response, and 1 to the most negative.

#	Question	Mean
1	Application's user interface easy to follow and clear	3.4
2	Menus and contents are comprehensible	4.4
3	It is easy to make mistakes while using the application	1

Table II
QUESTIONS USED TO EVALUATE THE PROXIMITY MARKETING APPLICATION

In general, the evaluation results were positive. Participants found the application's user interface easy to follow and clear. Negative comments were only made about the low resolution of the map interface for showing the position of the device. Furthermore, strongly positive results were obtained for the intuitiveness of menus and contents, and for the possibility of making mistakes while using the application. During the trials, no errors or application failures were detected. Lastly, the collected responses regarding the system's location sensing indicate that localization worked successfully.

Question	Yes	No
Were there errors or application failures?	0	100
Does the application show the correct location?	95	5

Table III
FEEDBACK ON LOCALIZATION ACCURACY

VI. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a platform for delivering information over smartphones based on user's location and user's profile. The solution is based on the client-server paradigm and on the data exchange over Wi-Fi APs deployed in an indoor environment. WiFi is also used for performing continuous tracking of the user's device. We have described our localization algorithm, the conceptual and software architecture of PROMO, along with a tool for streamlining the configuration and installation of added-value services based on the PROMO platform. Furthermore, we have evaluated the accuracy of our localization algorithm and tested the client-application user-friendliness of a proximity marketing solution based on PROMO that has been deployed in a real mall.

In the future, we would like to investigate solutions for detecting the position of the device when no-infrastructure is available and (possibly) improving localization accuracy. This will be done by combining our localization algorithm with local inertial measurements from smartphone sensors (accelerometer, gyroscope and magnetometer), and by integrating Near Field Communication (NFC) elements, such as location tags.

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