Enhancing Mobile Interaction Using WLAN Proximity

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Abstract. Over the last decade a manifold of WLAN-based localization methods have evolved, whereupon most approaches focus on accurate location estimation and tracking using absolute coordinates. In this paper we propose a system prototype utilizing WLAN infrastructure for relative spatial determinations using discrete, unambiguously distinguishable zones. The prototype allows imitating near field communication (NFC) and beyond using conventional mobile devices not equipped with NFC hardware but a WLAN interface. We prove the functional correctness of our system in the course of a payment scenario at cash-desks, where customers are required to "show" their electronic store card at spatial proximity to their cashier without interferences from neighbors.

Keywords: Proximity Interaction, WLAN Proximity Engine, Sensor Network.

1 Introduction

Contact-free computer interaction at spatial proximity is considered an indispensable paradigm in mobile computing environments [1]. Typical setups comprise access control systems, sports applications (e.g., time measurement in mass sports events) or payment systems. The preferred technology for those setups is commonly based on radio frequency signals, embedded into NFC or Bluetooth standards [2]. However, employing NFC or Bluetooth bears certain disadvantages with respect to non-restrictive mobile interaction. In terms of NFC usage people are required to carry a separate tag (smart card) for each distinct application or a (non-commercial) NFC-enabled mobile phone, which consequently reduces its public applicability. The Bluetooth standard on the other hand is broadly integrated into commercially available mobile phones. Nevertheless, it has barely found its way into public mobile applications primarily due to security and privacy concerns of its users. Moreover, the bandwidth for service applications is low and the number of clients to be served is limited.

In this work, we propose an approach for contact-free computer interaction at spatial proximity (within a certain interaction range) [3] based on WLAN, which is widely spread, commercially available and considered as a mature, trustworthy technology. Based on recent research on WLAN localization [4] we have identified the potential of the Wi-Fi medium as an alternative to NFC. It offers a broader service bandwidth, elaborated security mechanisms and has reached a high degree of penetration in public environments. Hence, more sophisticated service applications can be built upon WLAN technology in the context of contact-free proximity interaction [5] [6].

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2 Related Work

The technique of proximity sensing for determining the position of a mobile user relative to the sensor's position has been widely studied with respect to various radio technologies. In [7], Hightower and Borriello presented a survey on location sensing describing three different approaches for inferring the proximity of an object or a person to a sensor by *"using a physical phenomenon with limited range"*. According to them such phenomenon can either be physical contact, the contact of an ID tag (e.g., credit card, RFID tag, etc.) with a reader device whose location is known, or the being in range of one or more access points in a wireless cellular network. Seen from another perspective, they distinguished between three zones of proximity (direct, near, and distant contact). The system proposed in this paper emphasizes a different classification using a near zone and several graded distant zones for interaction (cf. Section 5). In [8], the term proximity sensor is refined describing a sensor that locates an entity or device as being within a region. To determine the exact position however a setup of several proximity sensors with overlapping ranges applying triangulation algorithms is needed. The WLAN Proximity Engines (WPE) accentuated in this work can basically be interpreted as proximity sensors. In order to reliably distinguish a greater amount of interaction zones our system allows for a cooperative peer-to-peer communication among the WPEs (cf. Section 3).

In terms of the underlying sensor technology, RFID has been a prominent basis for proximity-based localization and interaction in the last decade of research. The LANDMARC system [9] uses stationary RFID readers as sensors to localize active RFID tags that appear within range. The localization process then refines the position of the tag by comparing the received signal strength to the measurements of reference tags deployed at known positions. In [10], a RFID-based monitoring system for a queuing environment is proposed, comprising sequentially deployed RFID readers that provide queue length estimation by sensing the proximity of tags passing by. The setup suggested in this paper makes use of proximity information in a different way. Derived from the proximity to one or more stationary sensors we associate mobile users with certain interaction zones. These zones determine the user's interaction interface with the back-end server systems.

Ultrasound technology is considered the most precise sensor technology for determining the location of an emitter at the time of this writing, allowing accuracy results of 5 to 10 centimeters [11]. The Active Bat system [12] has been one of the first systems to utilize ultrasound sensor infrastructure for indoor localization. It employs a time difference of arrival (TDOA) algorithm to track a user carrying an emitter tag. In order to narrow down the potential location of a Bat emitter the system generates a bounding region for each Bat dependent on the radio zone covered by the nearest sensors. Similar to the WPE approach this system combines sensor readings to a fingerprint for each zone that separates the covered environment. In [13], the Relate system makes use of the spatial relations of mobile peers equipped with an ultrasound sensor. They study the incorporation of proximity aspects into the user interface and present a toolkit API for mobile applications.

In the context of Bluetooth proximity sensing most contributions concentrate on signal strength measurements using stationary beacons [14] or PCs as sensor stations [15]. In either way, the proximity of the mobile device to another station allows to infer on the location of the user profiting from the limited radio communication range of the Bluetooth technology. In [16], a localization approach is presented that allows the tracking of mobile phones without software modification. This important aspect has been one of our main objectives for building the WPEs because the acceptability of our system strongly depends on such usability considerations in a real-life setup.

In the field of WLAN-based localization proximity sensing has been relegated to a niche existence. This is mainly due to its radio propagation characteristics. In opposition to Bluetooth, WLAN provides a higher range of signal dispersion, i.e., two stations might communicate at a distance of up to 100 meters in indoor environments. Consequently, a simple Cell-of-Origin (COO) approach does not narrow down the client's location. The NearMe Wireless Proximity Server [6] addresses this issue by applying a more sophisticated approach. By skipping the intermediate step of computing absolute location information of mobile clients, the NearMe system determines the proximity of two mobile users by mutually exchanging lists of Wi-Fi signatures (i.e., lists of access points and clients signal strengths). Based on similarities in the signatures the distance can be estimated. Like the system presented in this paper, the NearMe system does not need to be calibrated beforehand since it uses relative location instead of absolute location (e.g., WGS-84 coordinates). In [17], a neighborhood detection algorithm based on ZigBee sensors supports wireless LAN-based localization to compensate signal interferences provoked by people and alike. Even though such interferences do not affect close proximity readings obtained by the WPEs, we apply a similar algorithm to improve the distinction of distant interaction zones.

3 A WLAN Sensor Network

The system presented in this work aims at reliably separating zones of mobile interaction on the basis of networked WLAN sensors that solely utilize proximity localization and consequently do not rely on a preceding training phase. In our prototype setup (cf. Section 4) we use these interaction zones to provide different views and functionality to mobile clients embedded in a web service. Our main design objective was to implement a system operating without any client pre-requisites but a WLAN communication interface and a mobile internet browser for service access. The resulting advantages of this approach are twofold. On the one hand, the usability of the system benefits from the commercial availability of WLAN in public places and its integration into modern mobile phones. Sophisticated encryption and security measures are already realized on common WLAN infrastructure. The deployment of our system is merely a matter of configuration. On the other hand, the bandwidth of the 802.11 standard allows for elaborate applications (e.g., multimedia web applications) as opposed to Bluetooth. As a further benefit the client's communication traffic originated from service consumption is reused for localization purposes and, consequently, acts as signal emitter process.

Figure 1 depicts the basic system architecture. The core of our system is built upon off-the-shelf access points (further referred to as WPE – WLAN Proximity Engine) altered with a Linux operating system and enhanced with customized software. As sketched in the figure, our prototype setup uses *Linksys WRT610N* access points that feature a 533 MHz processor and two separate WLAN interfaces covering the 2.4GHz and the 5GHz frequency band. In our setup the 2.4GHz band (802.11bgn) is used for proximity localization and service provisioning. The 5GHz band (802.11an) acts as backbone network for the WPEs. Due to its processing power the hardware platform is capable of concurrently running the proximity engine, a web server and a database in the background. Hence, service provider functionality is incorporated in the WPE device. Optionally, our setup supports interfacing with a back-end server to ease the integration into existing service infrastructure at potential deployment sites.

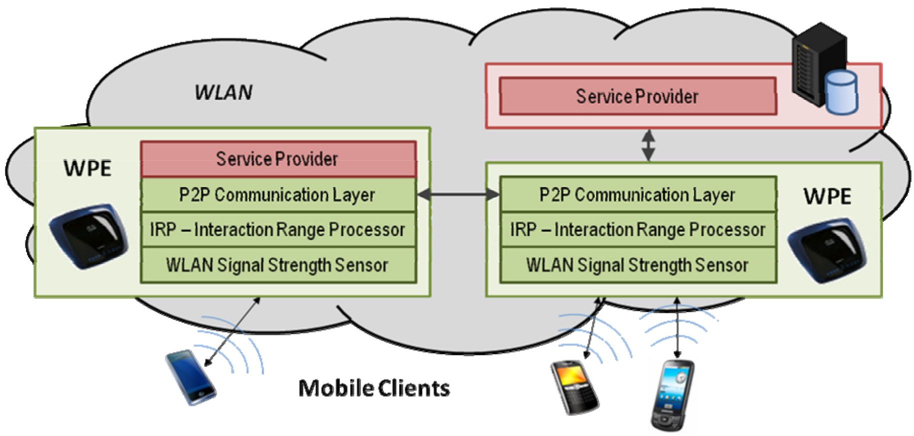

Fig. 1. System architecture

As sketched in Fig.1 the WPE software comprises four components: (*i*) a WLAN signal strength sensor, (*ii*) an interaction range processor (IRP), (*iii*) a peer-to-peer communication layer and (*iv*) a service provider. The WLAN signal strength sensor is realized as a low-level daemon process that queries the interface driver in raw packet monitoring mode for RSSI (Received Signal Strength Indicator) measurements of the mobile clients. Its sole purpose is to supply the IRP with measurement data in real time. The IRP uses these data to separate spatial regions into distinct interaction zones. As our proposed setup demands for reliable zone separation, the IRP uses unambiguous peak values to determine the respective interaction zone of a mobile client. The system distinguishes the near interaction zone (i.e., signal strength measurements of -25dBi and higher) and several distant interaction zones graded by signal strength thresholds. Depending on the amount of cooperating WPEs and the characteristics of the setup environment the granularity of distant zones can be refined. A more detailed discussion on refining these interaction zones is given in Section 5.

In order to allow WPE cooperation the system entails a communication layer that utilizes a peer-to-peer principle. During an initial discovery phase each WPE executes a simplified voting algorithm using broadcasts on the backbone network. The first appearing WPE is assumed the master peer, which waits for other WPEs to appear on the network until the configuration application is triggered. The master peer acts as central service provider hosting the configuration application that is responsible for defining the sensor network topology and additional parameters that represent the setup environment. After configuration, each cooperating WPE continuously reports live proximity measurements to the master WPE. The service provider instance at the master peer acts as front-end and determines the relative location of inquiring clients on the basis of the sensor input delivered by the WPE network. Finally, the front-end application differentiates the clients' locations into interaction zones by applying a set of topology depending separation patterns.

For compensating signal strength fluctuation provoked by people in the line of sight between sensor and the inquiring client, our system emphasizes the usage of a stationary control signal emitter placed behind the region of interest [18]. The control signal is steadily broadcasted by a WLAN capable device (e.g., a normal access point or a mobile phone) and measured at each WPE. As part of the configuration process the initial signal strength value of the control signal is stored as a reference at each WPE. During live operation the fluctuation in the control signal strength serves as adjustment factor for client signal measurements.

4 Use Cases

The applicability of our system is being demonstrated in the course of a supermarket cash desk scenario under laboratory conditions: four cash desks have been arranged in parallel with a distance of about 1.5m to each other. Our application prototype implements an electronic store card utilizable on the clients' mobile phones which can be "shown" to the cashier on a single button click and automatically associated to the correct cash desk and purchase. The challenge in this setup is to confidently detect the correct desk by WLAN depending on the client's proximity when the client presses the button on his mobile phone. Moreover, it must be assured that several clients in a queue at the same cash desk are handled correctly even when they simultaneously press their buttons. The setup provides for a WPE at every cash desk mounted at spatial proximity to the cashier. The clients are requested to hold their mobile phones close to the appropriate WPE and press a button in order to initiate network traffic which can be used to explicitly determine physical closeness. This further triggers an authentication process to ensure correct association of client and service.

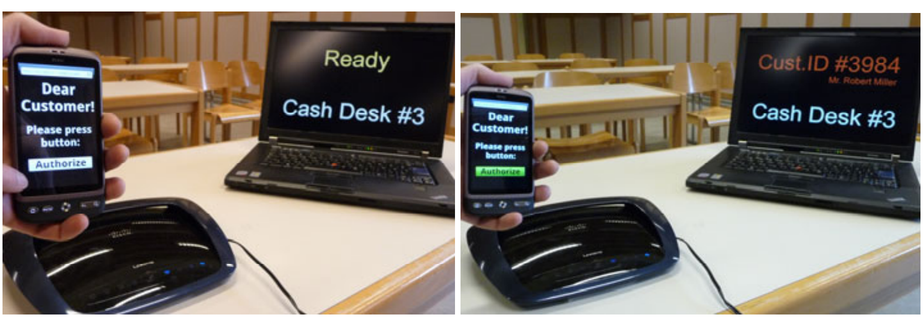

Fig. 2. Cash desk scenario (user interaction)

Fig. 2 shows a snapshot of the prototypical arrangement: a Linksys access point is used as the WPE and detects physical closeness of an off-the-shelf mobile phone (here: HTC Desire operating on Android 2.2). The browser component of the phone enables the user to consume the provided service of the WPE (recognizable by an authorization screen for “showing” the user’s store card). For confirming the button click near the access point every cash desk is equipped with a screen showing the customers’ identification data through the WPE service.

We have arranged this setup in four parallel lines in order to simulate a supermarket cash desk scenario with customers being simultaneously served at the four desks and interfering in the queues. Fig 3 exemplarily illustrates that two customers in different lines and at different proximity to the cash desk are handled correctly, i.e., they are only then identified when their mobile device is closer than 30cm to the access point when pressing the authentication button. This near zone is intended to manage security related interaction (e.g., exchanging customer identification data).

Fig. 3. Cash desk scenario (parallel interaction)

Beyond operations at very close distances (i.e., in the near interaction zone), the WPE sensor network is capable of distinguishing further discrete interaction zones (cf. Section 5) enhancing the variety of applications that can be set up upon, e.g., for non critical operations characterizing a semi-close area around the WPEs. At the far distance zone the system could advert to latest offerings and common vendor services.

In the vicinity of the checkout lines customers may be reminded of cross-checking their shopping list, by means of a web-service provided by the supermarket, which customers may fill out at home. Enqueued in a checkout line the customers' waiting time could be shortened e.g., by participating in a (yet anonymous) quality survey rewarded with credits. These credits can finally be encashed right away in the near interaction zone, where the customer is identified for the first time.

In general, the WPE approach contributes to an innovative interaction paradigm in mobile computing environments, where people are able to trigger electronically controlled actions just at spatial proximity without the needs of glimpsing at displays, typing, clicking or pressing buttons (cf. [19]). Usually, human attentiveness is required by conventional interaction metaphors via display and/or keystroke at the place of event in order to open a gate, buy a ticket, start or stop an engine, etc. However, attentiveness for pressing a button or glimpsing at a display may occasionally be unavailable when the involved person must not be distracted from performing a task (e.g. while driving in a car) or is handicapped through wearable limitations (e.g. gloves, protective clothing) or disability. As the WPE on the one hand is capable of discretely detecting physical proximity and on the other hand includes a customizable service provider component it is possible to automatically trigger those actions just at physical closeness of a person, i.e., dismissing displays and keypads in order to ease human computer interaction.

5 Results

In indoor localization research, most contributions concentrate on accurate location estimation and user tracking in indoor environments to supply location-based services with absolute coordinates of the users' current whereabouts. This work emphasizes the usage of discrete interaction zones for application scenarios that benefit from clearly separated zones that can be associated with different functionality (e.g., consumer interaction in the supermarket, public display interaction, access control systems or elderly care scenarios).

First experiments with the WPEs showed that signals emitted at distances < 30cm (LOS and NLOS) can reliably be differentiated from those sent out beyond. Weak signals transmitted at distances > 15m also show significant measurement characteristics. Consequently, one single WPE can robustly determine three zones: (*i*) the near zone identified by signal strength measurements greater than -25dBi, (*ii*) the far zone identified by signals less than -70dBi referring to distances of > 15m (indoors and NLOS), and (*iii*) the distant zone for measurements in between these two extremes.

Table 1. Measurement results of the WPE sensor network using a HTC Desire smart phone

	0m (*near zone*)	3m (*distant zone 1*)	9m (*distant zone 2*)
Line0:	[**-04**, -34, -39, -40]	[**-29**, -35, -37, -36]	[**-45**, -41, -41, -38]
Line1:	[-32, **-05**, -29, -32]	[-35, **-31**, -46, -35]	[-38, **-40**, -46, -40]
Line2:	[-36, -26, **-11**, -27]	[-39, -35, **-34**, -29]	[-46, -43, **-41**, -41]
Line3:	[-44, -36, -26, **-08**]	[-38, -36, -37, **-33**]	[-42, -47, -44, **-41**]

Table 1 lists the measured signal strengths obtained by WPE sensor arrangement in the setup described in Section 4 (four cash desk lines). The quadruples in the table columns refer to the measurements taken by the four WPEs [WPE_0, WPE_1, WPE_2, WPE_3]. The highlighted entries mark the respective WPE assigned to the cash desk line. The bold-faced values in the near zone column illustrate distinct measurement peaks allowing a unique classification. Even though the measurements related to distant zone 1 and 2 seem decisive regarding their associated WPE, the signal strength values within this range tend to fluctuate in the order of ±10dBi mainly due to multi-path propagation, attenuation provoked by people in the LOS and emitter characteristics of different WLAN chipsets. In order to robustly separate the two distant zones these fluctuations must be compensated. Hence, we use the collaboratively obtained average value of the measurements to mitigate signal variability. Since the strength of the WLAN signal decreases logarithmically, the system is able to reliably separate four interaction zones in the course of our sketched setup arrangement (cf. Fig. 4).

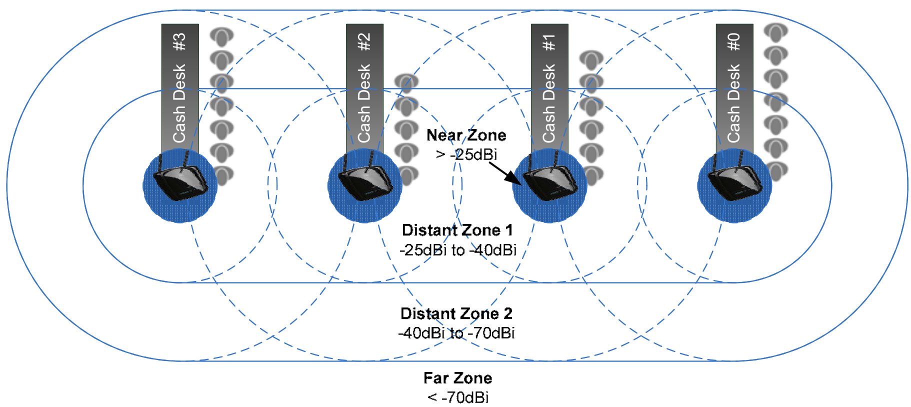

Fig. 4. Identified zones of interaction

6 Conclusion and Future Work

The idea of using WLAN-based localization has been a matter of research mainly investigating accuracy aspects concerning absolute positioning as an indoor alternative to GPS. In this work we envision a human computer interaction scenario utilizing a proximity-based mechanism to determine relative spatial associations of mobile users. To this end, we have developed a network of Wireless Proximity Engines, i.e., either detached or collectively applicable entities associating mobile devices with discrete interaction zones. In the course of a prototypical cash desk setup we have robustly distinguished four interaction zones providing specific customized services (e.g., store card authorization, advertisement delivery, electronic shopping list, etc.). Our system is instantly operable without any training effort and users can interact without any prerequisites on the client-side but a WLAN interface.

According to the results presented in related work [18], the accuracy of indoor localization benefits from spatial variability, i.e., the reflection, diffraction or absorption of the WLAN signal by stationary obstacles (such as furniture, walls, doors and alike) leading to unique characteristics of each potential location spot. Given such characteristics typically found in real-life environments the number of distinguishable interaction zones is likely to increase. In this context, further investigation has to be conducted on filter patterns for separating the zones combined with the arrangement of the WPE sensors (e.g., parallel, circle, square, radial, etc.).

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