Near Field Sensing in Wireless LANs

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Abstract — **Miscellaneous WLAN-based localization methods focus on preferably precise location estimation and tracking. However, the infrastructure of a WLAN system can also be utilized for relative spatial assessment within discrete zones, not using a reference coordinate system. This paper proposes a WLAN-based localization prototype that is capable of unambiguously distinguishing detached interaction zones, allowing applications to imitate near field communication (NFC). Operation is accomplished by customary mobile devices not equipped with NFC technology but a WLAN interface. A prototypical payment scenario at cash-desks in a store proves the concept, where customers are required to securely show their electronic store card, i.e., bring their mobile device into a near, non-interfering zone to their cashier. The paper provides measured figures revealing clearly distinguishable interaction zones in WLAN environments.**

Keywords – Near Field Sensing; Interaction Zones; Wireless LAN.

I. INTRODUCTION

Near Field Communication (NFC) has evolved as the preferred technology for applying contactless interaction services at near distances. It is therefore considered an indispensable paradigm in mobile computing environments [1]. Several commercial fields of application profitably make use of NFC, e.g., access control systems, payment systems, or time measurement systems (e.g., using RFID chips attached to the shoes of runners at marathon events). However, employing NFC implicates disadvantages in terms of non-restrictive mobile interaction: people are either required to carry a smart card for each individual application or a commercially hardly available NFC-equipped mobile phone, which accordingly diminishes broader utilization.

The alternative for near range communication, also based on radio frequency signals, is Bluetooth [2]. Although, the penetration of Bluetooth is already widespread and has found its way into a majority of state-of-the-art mobile phones, it has hardly won recognition concerning public mobile applications, primarily due to security and privacy concerns of its users. Likewise, Bluetooth offers a low bandwidth for service applications and restricts the number of clients to be served by specification.

In order to overcome these impairments regarding low penetration and security issues, we propose a complementary option for contactless interaction at near distances based on Wireless LAN [3]. This technology is widely spread and considered as mature and trustworthy. Latest investigations on WLAN localization [4] have revealed the ability of the Wi-Fi medium to unambiguously recognize the presence of mobile devices at very near distances. Moreover, WLAN offers a broad service bandwidth and comprises elaborate security concepts. Hence, it is an eligible and powerful alternative to NFC in terms of contactless interaction at spatial proximity [5] [6].

The paper is structured as follows: Section 2 deals with selected points of state-of-the-art methods and technology. Section 3 gives an insight into the proposed WLAN architecture for discrete zones separation. Section 4 illustrates the applicability of the architecture in the frame of a use-case scenario. Section 5 provides figures and measured results and finally, section 6 concludes the paper and prospects future work.

II. RELATED WORK

Near field sensing is a popular method for determining the proximity of a mobile user to the known location of one or several sensors and has been widely studied on the basis of various radio technologies. Hightower and Borriello’s survey on location sensing [7] revealed three distinct approaches for inferring the proximity of an object or a person to a sensor resulting from *“a physical phenomenon with limited range”* that is either physical contact, the contact of an ID tag (e.g., credit card, RFID tag, etc.) with a sensor device whose location is known, or the being in range of one or more access points in a wireless cellular network. Alternatively interpreted regarding the underlying distance, a separation of the user’s vicinity to a known location into three distinct zones of proximity can be concluded, i.e., a direct zone, a near zone, and distant zone. In this work we emphasize a different classification using a near zone and several graded distant zones for interaction (cf. Section 5). Indulska and Sutton refine the term proximity sensor in [8], which according to them describes a sensor that locates an entity or device as being within a region. In order to accurately estimate a mobile user’s position however a setup of a number of overlapping proximity sensors is needed. Given a region with sufficiently overlapping sensor ranges, the location can then be triangulated. At its core, the approach accentuated in this work

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can be seen as a variant of a proximity sensor system. A main claim however is to reliably distinguish a greater amount of interaction zones. To this end, the proposed system utilizes peer-to-peer communication to cooperatively narrow down the radio proximity ranges and consequently conclude on more discrete zones.

The term proximity sensing itself has become popular in the course of Bluetooth technology research. As in this work, most contributions in the Bluetooth context concentrate on signal strength measurements utilizing stationary beacons [9] or PCs as sensor stations [10]. In either way, location estimation is achieved by detecting the close proximity of a mobile device to a beacon or a sensor station making use of the limited radio communication range of the Bluetooth technology. Another important aspect that we are also emphasizing in this paper has been demonstrated in [11]. Hay and Harle use a localization approach that realizes the tracking of mobile phones without installing additional software. The acceptability of our presented system strongly depends on such usability considerations in a real-life setup. Consequently, our system avoids any form of user-side software modification by solely depending on a web browser for service consumption.

In the context of localization accuracy, ultrasound technology is considered the most precise sensor technology for determining the location of an emitter, allowing accuracy results of 10 centimeters and below [12]. In [13], the Active Bat system has been presented as one of the first systems to utilize ultrasound sensor infrastructure for indoor localization using a time difference of arrival (TDOA) algorithm to track a user carrying an emitter tag. To refine the potential whereabouts of its clients, the back-end system constructs a bounding region for each Bat emitter in relation to the radio zone covered by the nearest sensors. Similar to the WPE approach this system combines sensor readings to a fingerprint for each zone to classify the covered environment into separable regions. Another usage of spatial regions was demonstrated by the Relate system [14]. Mobile peers equipped with an ultrasound sensor were used to study the incorporation of proximity aspects into the user interface and present a toolkit API for mobile applications.

In the last decade of research, the most prominent basis platform for near field sensing and interaction was RFID. The LANDMARC system [15] proposes stationary deployed RFID readers as sensors to determine the position of active tags within range. For positioning refinement, the received signal strength is compared to the measurements of reference tags deployed at known positions. A use case for RFID localization related to the application presented in this paper was discussed in [16]. In their work, sequentially deployed RFID readers provide queue length estimation that senses the proximity of tags passing by. In this paper we suggest to apply 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.

Localization in the context of WLAN technology does typically no longer involve near field sensing, especially because the accuracy achieved by other approaches for location estimation allows a much finer location resolution (e.g., using particle filters [17]). WLAN provides a higher range of signal dispersion as the Bluetooth technology for instance, meaning that the communication range between two stations comes up to 100 meters in indoor environments. Applying a straightforward Cell-of-Origin (COO) algorithm does not narrow down the client's location notably. The NearMe Wireless Proximity Server [6] addresses this issue on a proximity sensing basis by applying a peer-to-peer technique. Instead of computing absolute location information of mobile clients, the 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). The similarities in the signatures help estimating the distance. Similar to the system presented in this paper, NearMe does not rely on a training phase since it uses relative location instead of absolute location (e.g., WGS-84 coordinates). A similar neighborhood reasoning localization approach has been described in [18]. They improve WLAN-based position estimation with ZigBee sensor readings that compensate dynamically appearing signal interferences (as provoked by passers-by). Though such interferences do not affect close proximity detection achieved by the WPEs, we use a comparable technique to improve distant zones separation.

III. WLAN-BASED NEAR-FIELD SENSOR NETWORK

The main design objective for near-field sensing in Wireless LANs was to implement a system operating without any client pre-requisites but a WLAN interface and a mobile internet browser for service access. Commercial availability of WLAN in public places and its integration into modern mobile phones suggest these goals. In addition, sophisticated encryption already realized on common WLAN infrastructure, security measures and the bandwidth of the 802.11 standard allow for elaborate applications (e.g., multimedia web applications) as opposed to NFC or Bluetooth.

In our approach, all the processing components are settled in the WLAN infrastructure, aiming at reliably separating spatial zones of interaction. Customized networked WLAN sensors (i.e., off-the-shelf access points running a modified software kernel) utilize proximity recognition by evaluating signal peaks of connected devices. The client is not requested to emit special tracking signals – the system uses the client's communication traffic originated from (web-)service consumption for proximity detection purposes. In contrast to absolute location estimation the system does not need a preceding training phase.

Figure 1 illustrates the system architecture of the near-field sensor network. The nucleus of our system is contained within conventional access points, further referred to as "sniffers". They are executing an altered Linux operating system and customized proximity detection software. In our setup we use Linksys WRT610N access points with a 533MHz system processor and two separate WLAN interfaces covering the 2.4GHz and the 5GHz frequency band). The 2.4GHz band (802.11bgn) is used for proximity detection and service provisioning. The 5GHz band (802.11an) acts as backbone network for the sniffers.

The hardware platform is capable of concurrently running the proximity detection algorithms, a web server and a database in the background, incorporating service provider functionality in the sniffers. Optionally, our setup supports interfacing with a back-end server to ease the integration into existing service infrastructure at potential deployment sites.

As shown in Fig. 1 a sniffer consists of 4 components:

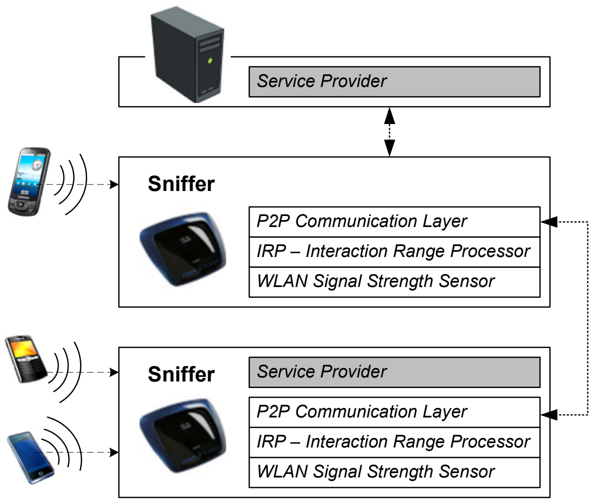

Figure 1. System Architecture

1. A *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 purpose is to supply the second component layered above with measurement data in real time.
2. The *interaction range processor* (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.
3. In order to allow sniffer cooperation the system entails a *peer-to-peer communication layer*. During an initial discovery phase each sniffer executes a simplified voting algorithm using broadcasts on the backbone network. The first appearing sniffer is assumed the master peer, which waits for other sniffers to appear on the network until the configuration application is triggered. The master peer acts as central instance hosting the configuration for defining the sensor network topology and additional parameters that represent the setup environment. After configuration, each cooperating sniffer continuously reports live proximity measurements to the master peer, which acts as front-end and determines the relative location of inquiring clients on the basis of the sensor input delivered by the sniffer network.
4. Finally, the front-end application offered by the *service provider* differentiates the clients' locations into interaction zones by applying a set of topology depending separation patterns. 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 sniffers 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.

Signal strength fluctuation provoked by people in the line of sight between sensor and the inquiring client is compensated by using a stationary control signal emitter placed behind the region of interest [19] (see Fig. 2). The control signal is steadily broadcasted by a WLAN-enabled device (e.g., an ordinary access point or a mobile phone) and measured at each sniffer. The initial signal strength value of the control signal is stored as a reference at each sniffer, enabling adjustments for client signal measurements during live operation.

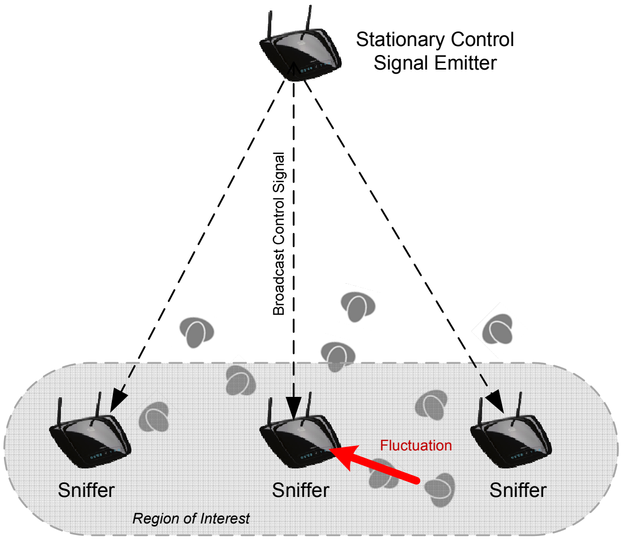

Figure 2. Stationary Control Signal Emitter

IV. USE CASES

Our system has prototypically been implemented for 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 sniffer at every cash desk mounted at spatial proximity to the cashier. The clients are requested to hold their mobile phones close to the appropriate sniffer 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.

Figure 3. Proximity interaction

Figure 3 shows snapshots of the prototypical arrangement: a Linksys access point is used as the sniffer and detects physical closeness of an off-the-shelf mobile phone (here: Motorola Defy operating on Android 2.2). The browser component of the phone enables the user to consume the provided service of the sniffer recognizable by an authorization screen for “showing” the user’s store card, which only then offers an enabled button when the phone is close enough to the sniffer (a detailed discussion on results is given in section 5). For confirming the button click near the access point every cash desk is equipped with a screen showing the customers’ identification data through the sniffer 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. Figure 4 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 close enough 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).

Figure 4. Parallel interaction at cash desk scenario

Beyond operations at very close distances (i.e., in the near interaction zone), the sniffer 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 sniffers. 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 (cf Figure 5).

In general, the sniffer 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. [20]). 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 sniffer 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.

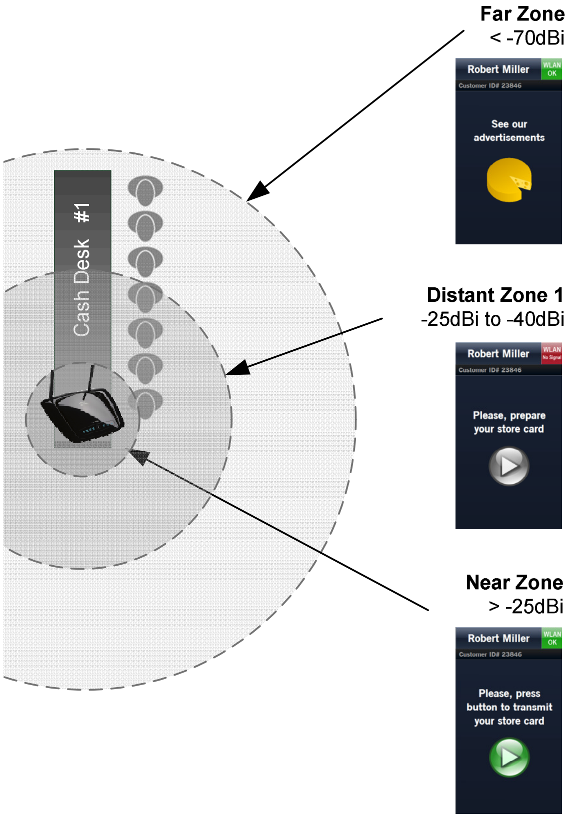

Figure 5. Interaction zones

V. RESULTS

The majority of WLAN localization systems deal with 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).

Laboratory-based experiments revealed 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 sniffer 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 lists the measured signal strengths obtained by the sniffer sensor arrangement in the setup described in Section 4 (four cash desk lines) using a HTC Desire smart phone. The quadruples in the table columns refer to the measurements taken by the four sniffers [sniffer$_0$, sniffer$_1$, sniffer$_2$, sniffer$_3$]. The highlighted entries mark the respective sniffer assigned to the cash desk line. The bold-faced values in the near zone column illustrate distinct measurement peaks allowing a unique classification.

TABLE I. MEASUREMENT RESULTS

	0m (*near zone*)	3m (*dist. zone 1*)	9m (*dist. 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**]

Even though the measurements related to distant zone 1 and 2 seem decisive regarding their associated sniffer, the signal strength values within this range tend to fluctuate in the order of ±10dBi mainly due to multipath 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.

Concerning response times the system is dependent on a recurring signal emission (e.g., small UDP packets) of the mobile device. In our setup we have chosen an average transmission interval of 1.5 seconds, which is slow enough not to overload the wireless network backbone and fast enough to apply for the use-case. Generally, the transmission interval (and therefore the response time) is selectively adaptable to specific use-cases.

In this context, scalability of the system is coherent to the physical limits of WLAN. Adding one access point likely increases accuracy regarding the distant and the far zones. Besides, the setup of the cash-desk scenario restrains the users in sequential lines and therefore provides constructional boundaries for the number of clients to be served by one sniffer.

VI. CONCLUSION AND FUTURE WORK

WLAN-based localization mainly focuses on accuracy aspects concerning absolute positioning as an indoor alternative to GPS. In this work we present a WLAN setup that can be used as an alternative to Near Field Communication utilizing a proximity-based mechanism to determine relative spatial associations of mobile users. To this end, we have developed a network of wireless proximity sensors, 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.

Funded results presented in [19] confirm that 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, but has not been verified, yet. In this context, further investigation has to be conducted on filter patterns for separating the zones combined with the arrangement of the sniffer sensors (e.g., parallel, circle, square, radial, etc.) and also on analytical error estimation and on power consumption issues compared to Bluetooth or NFC in order to prove the sufficiency of our proposed model.

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