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Exploiting Bluetooth for deploying indoor LBS over a localisation infrastructure independent architecture

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Abstract: This paper presents an evaluation of using the low cost Bluetooth wireless technology, as a localisation technique, fitted in a lightweight approach for providing web-based location aware content through Java enabled handheld devices. This approach separates the positioning system from the content access mechanisms, while being generic and independent to the selection of the localisation technique, i.e., GPS, Bluetooth, etc. A test case application for Bluetooth enabled smart phones demonstrates the capacity of the approach, when combined with Bluetooth localisation, to provide location based content retrieval to the widest possible array of end users, while using their personal mobile devices, without the need to acquire and manage specially built user terminals. Useful results are also extracted for Bluetooth's behaviour, while being used as a localisation technique, with regard to the provided accuracy, usual inquiry time, possible interference from other wireless technologies and imposed hardware requirements.

Keywords: location aware content retrieval; smart phone applications; indoor environments; Bluetooth; GPS; Ajax applications; location based services.

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1 Introduction

In the last decade, great evolution has been realised in the deployment of location based services (LBS). Many architectures for providing LBS have been proposed and several studies have been conducted regarding the use of the most suitable localisation technique for each category of application, taking in account their diverse set of requirements. However, most approaches are posing specific hardware or software requirements or they are considering a narrow scope of wireless technologies, rendering them beneficial for special categories of LBS applications. The use of expensive infrastructure, special tags, sensors and handheld devices increases the deployment cost. Furthermore, human interaction is required most of the times to support their operation.

Future approaches for LBS will target to provide localised services using capabilities that are common in the majority of the mobile devices. This direction is strongly supported by the enormous penetration of mobile phones with multiple wireless sensing technologies (such as Bluetooth, GPS, Infrared, Wi-Fi) and advanced video capabilities, PDAs and GPS navigators to the international market. These advancements in the handheld devices will allow end users to access innovative services through proper positioning and the establishment of wireless communication links.

Thus, a major challenge is the design of an LBS architecture that will provide interfaces to be used with different localisation technologies and be applicable to most LBS categories. The collected location information and the selected technique should be transparent to the end user and the feedback required should be kept to minimum.

Towards this direction we present a lightweight approach for providing location aware content retrieval, implemented on Java enabled handheld devices. The proposed approach is built as an open, standards-based, modular architecture, comprising a core of platform independent components and interfaces for supporting different types of services, through web technologies.

Although this approach supports multiple radio localisation technologies, as it separates the positioning system from the content access mechanisms, in this paper, we evaluate it with the widely accepted and low cost Bluetooth wireless technology, which proves to be a reliable solution for use as a localisation technique in indoor environments. The proposed architecture is implemented in a laboratory environment and experimental results, evaluating the behaviour of the Bluetooth approach on an e-guidance application scenario are presented.

The basic reason for selecting Bluetooth for our evaluation is that, since Bluetooth is becoming a standard feature in most handheld devices, it eliminates the need for the user to carry additional sensory devices, as needed by other location-sensing technologies. Bluetooth enabled handset sales worldwide are projected to grow at a compounded annual growth rate of approximately 7.68% over the years 2011 through 2015, as stated in a recent research report published by Global Industry Analysts, Inc. (Bluetooth SIG Industry Statistics, 2008) and Bluetooth low energy technology will be incorporated into hundreds of millions of mobile phones.

The paper is organised as follows, Section two presents the available localisation techniques, the parameters that are important while designing LBS and the already proposed architectures, Section three details how Bluetooth can be used for providing LBS under the proposed architecture, Section four describes the different components' characteristics and the experimental setup for our implementation while Section five presents the experimental results. Finally Section six concludes the paper with a discussion of current challenges and future work.

2 Related work

2.1 Background information – criteria and requirements for designing LBS

As described in Herden et al. (2003), in order to develop an efficient platform to provide LBS, the following requirements need to be fulfilled: terminal independence, simple user interface, minimal communication over mobile telephone networks, integration of mobile devices, simple integration of existing internet services, high availability of the services even at high loads, scalability, openness and low cost. Furthermore, in Ciavarella and Paterno (2003), the design criteria when developing location-aware indoor mobile applications are analysed in detail. The most important of them are the following: easiness of navigation through web browsers, navigation feedback and minimal graphical interaction, orientation support in the surrounding environment and minimum redundancy in input commands. Another requirement in cases where multiple localisation technologies need to be supported (e.g., when switching from indoors to outdoors) is the separation of the positioning system from the content access mechanism.

2.2 Short comparison of indoor position tracking technologies

Position tracking technologies aim at measuring the movement of the mobile terminal. These technologies provide great accuracy, but are limited in terms of geographic coverage. To explicitly localise the users in indoor applications, three recent technologies are mainly exploited: WLAN, Bluetooth and Infrared. In Yanying et al. (2009), advantages and disadvantages of each of them are highlighted. Hereafter, we provide an overview of the most popular position tracking technologies.

WLAN technology allows devices to immediately connect to a LAN. As stated in Ciavarella and Paterno (2003), to designate the position of a user in a building, WLAN is not so simple a solution, because the system has to apply triangulation methods to the data coming from at least three access points in the user's proximity. One limitation of such systems is the fact that WLAN tags are relatively bulky and power hungry, rendering them absolutely inappropriate for devices that are resource-limited.

Bluetooth technology is an ad hoc technology that requires no fixed infrastructure and is simple to install and configure. A fundamental strength of Bluetooth is the ability to simultaneously handle both data and voice transmissions with low power and cost. The Bluetooth Core Specification version 2.0 introduces Enhanced Data Rate (EDR) that achieves data rates of 3 Mbps, while the current implementation, Bluetooth version 2.1, reduces the power consumption when devices are in the sniff low-power mode, a characteristic very useful in LBS applications.

Infrared (IrDA) protocol of communication supports high data rates and requires line-of-sight contact. The IrDA systems perform positioning estimations in a very accurate way and their emitters are small, light-weight and easy to be carried by a person (Yanying et al., 2009). But, IrDA suffers from some critical drawbacks. It rebounds over the surfaces, it requires the sender and the receiver to be aligned and the system hardware requirements are very expensive.

Apart from the above three widely accepted technologies for position tracking, another two, the Global System for Mobile communications (GSM) and the Global Positioning System (GPS) have also been inspected. However, as stated in Ranchordas and Lenanghan (2003), cellular positioning technologies are an opportunistic option – something like an alternative for tracking using the existent infrastructure – and they are not in any case the original purpose of cellular networks and consequently, they are less accurate. On the other hand, GPS and recently Assisted GPS (AGPS) are used from the majority of LBS systems for outdoor tracking. The position calculated by a GPS receiver requires the current time, the position of the satellite and the measured delay of the received signal. The position accuracy is primarily dependent on the satellite position and the signal delay.

Additionally, and although popular for several applications, the option of RFID tags was not discussed as an implementation choice, as experience from relative projects has shown several disadvantages (Floerkemeier and Lampe, 2004), focusing, especially, on the restriction to short-range communication. Finally, we must also mention the ZigBee technology, which is targeting the control applications industry – where low data rates are required – and low power, low cost and ease of use are mandatory prerequisites (remote controls, home automation, etc.).

2.3 Existing systems and approaches for providing LBS

In this subsection we refer to the most important existing approaches for providing LBS in different environments. It is important to refer that, in terms of positioning, roughly half of the LBS systems rely on GPS while a large group of them use infrared beacons. Furthermore, almost half of the systems include some means of interaction with the user in order to determine his position. An analytical survey and a classification of the existing LBS systems based on the main medium used to sense location is provided in Yanying et al. (2009).

While outdoor localisation is almost exclusively performed using GPS, indoor location systems have successfully employed a variety of technologies. The Active Badge (Hopper et al., 1993) system uses infrared emitters and detectors to achieve 5–10 m accuracy, while Cricket (Priyantha et al., 2000) uses ultrasonic ranging to estimate location with a few centimetres accuracy. Furthermore, research projects as RADAR (Bahl and Padmanabhan, 2000) use fingerprinting from four 802.11 access points in order to achieve localisation of laptops with an accuracy of 3–4 m of their true location. PlaceLab (Schilit et al., 2003) has even more ambitious goals by seeking to create a comprehensive location database which uses fixed commodity Wi-Fi, GSM and Bluetooth devices as global beacons. Finally, in Otsason et al. (2005) a GSM indoor localisation system is presented that achieves a mean accuracy of 5 m in large multi-floor buildings.

These systems exhibit varying degrees of accuracy and system requirements while some of them offer solutions only for outdoor or indoor environments, e.g., when the GPS technology is exclusively used. However, a common characteristic of the aforementioned systems is that they are tightly coupled with the localisation technique, user device, and/or content access mechanisms and technologies. These restrictions significantly scale down the potentiality of widely deploying LBS for both providers and end users. Furthermore, possible advantages of low-cost Bluetooth localisation infrastructure for providing indoor LBS have not been widely illustrated and exploited.

In Zafeiropoulos et al. (2007), we describe thoroughly the lightweight architectural approach, mentioned in Section 1, for providing location aware content retrieval to Java enabled mobile terminals. The distinguishing characteristic of this approach is that it is modular in all its interfaces and to a great extent independent from the localisation technique and the mobile device used.

3 An approach for providing LBS using Bluetooth technology

In this section, the proposed approach for providing web-based location aware content retrieval is presented. As already mentioned, it requires only Java enabled devices, while it can incorporate an arbitrary number of localisation technologies, thus achieving considerable flexibility. However, in this study we focus on the use of Bluetooth for providing localisation information. The overall approach is based on open standards and open source components. For the rest of the paper, wherever the term ‘point of interest’ is mentioned, we refer to each point that triggers a content request to the mobile device.

The proposed architecture incorporates characteristics that render it suitable for a wide variety of location-based applications, where a user is moving towards and outwards specific points of interest which are steadily placed in specific spots within an area and specific information should be provided to the user according to the closest point of interest he/she is located at. In the following subsections, the overall advantages as well as configuration issues of using the Bluetooth localisation technology in the generic architecture are presented.

3.1 Using Bluetooth for providing LBS – characteristics and justification

Bluetooth wireless technology is a short-range communications technology intending to replace the cables connecting portable and/or fixed devices while maintaining high levels of security. The operating range depends on the device class (three classes available with range from 0.5 m to 100 m). Bluetooth technology operates in the unlicensed industrial, scientific and medical (ISM) band at 2.4 to 2.485 GHz. A Bluetooth piconet can have seven active slaves and up to 200 inactive devices in parked mode (Patil et al., 2006). For location sensing applications, just to discover another Bluetooth device is adequate, thus a Bluetooth sensor would be able to detect up to 200 Bluetooth devices. Location accuracy depends on the sensing range of the device, which also depends on the Bluetooth device class.

The Bluetooth Baseband Specification defines the Bluetooth point-to-point connection establishment as a three-step procedure. Firstly, neighbourhood information is collected through the inquiry procedure. Secondly, a paging procedure may be subsequently used to establish connections between neighbouring devices, while in the final phase piconet properties are negotiated upon (Zaruba and Gupta, 2004). According to Zhang and Riley (2006), 20 seconds is sufficient time for device discovery of up to seven devices. When the device discovery period is reduced to ten seconds, the average devices that are being discovered are reduced to 4–5. Furthermore, Peterson et al. (2006) state that 99% of scanning devices are detected when inquiry time is reduced to 5.12 seconds using Bluetooth v1.1, while this time can be reduced to 3.84 seconds for the standard discovery process and 1.28 seconds for the interlaced discovery process using Bluetooth v1.2.

An issue frequently mentioned when using Bluetooth piconets is its potential interference in Wi-Fi networks. Bluetooth technology's adaptive frequency hopping (AFH) capability is designed to reduce interference between wireless technologies sharing the 2.4 GHz spectrum. The Bluetooth signal hops among 79 frequencies at 1 MHz intervals, something that gives a high degree of interference immunity. From the experiments described in Patil et al. (2006), it can be implied that with proper placement of both the Bluetooth tags and the Wi-Fi access points, we can minimise the interference in the installation place, something that we have applied in the demonstration application and the relevant experiments.

Taking the above characteristics into consideration, we can conclude that Bluetooth has the accuracy and range characteristics that match the requirements for supporting a variety of applications, while interference among Bluetooth and Wi-Fi can be controlled. It presents an appropriate location sensing inquiry time and in combination with the ubiquity of the Bluetooth enabled devices and the extremely low cost of Bluetooth receivers and transceivers, consist a strong candidate location-sensing technology, especially when considered in a lightweight framework that can exploit complementary technologies. In the following section, we will discuss about the theoretical background of our work by clearly presenting the mathematical definitions and relationships among the power at the receiver and the transmitter, as well as the transmitting range.

3.2 Theoretical background

The distance estimation algorithm is based on Friis equation (Castano et al., 2004) for free space environments. Thereby distance estimation is calculated according to a known reference power and the actual measured power. In equation (1), $P_r(d)$ and $P_r(d_0)$ are the power levels of the receiver at distance d and a reference one, for a known distance d_0:

$$P_r(d) = P_r(d_0)(\frac{d_0}{d})^2 \tag{1}$$

The received power level is converted to a distance estimate by using a radio wave propagation model. A simple log distance model (Niculescu and Nath, 2001), shown in equation (2), is chosen.

$$P_r = P_t + G_t + G_r + 20\log(\lambda) - 20\log(4\pi) - 10n\log(d) - X_a \tag{2}$$

In equation (2), $P_r(dBm)$ and $P_t(dBm)$ are the power levels of the receiver and the transmitter, and $G_r(dBi)$ and $G_t(dBi)$ are the antenna gains of the receiver and the transmitter respectively (Kotanen et al., 2003). Wavelength is $\lambda(m)$ and the distance between the transmitter and the receiver is $d(m)$. The exponential term n denotes the influence of walls and other physical obstacles. An error term is also included in the equation, since X_α is a normal random variable. The exponent n is equal to 2.0 in a free space environment (Kóng, 2000), but it may vary when it should be estimated for indoor environments.

In equation (3), d is the estimated distance where the variable X represents the possible error that is imposed from the selection of the term n and is estimated around 4 *dB*. Distance estimate d was compared to the true distance and the absolute error was calculated.

$$d = 10^{\frac{\Pr(d_0)dBm - \Pr(d)dBm - X}{10*n}} \tag{3}$$

Assuming that we have a receiver with a power sensitivity threshold around –45 dBm, in Section 5 we present the maximum theoretically estimated range distances compared with the measured ones. We have supposed that $n = 2.3$, as stated in Kotanen et al. (2003) for indoor environments.

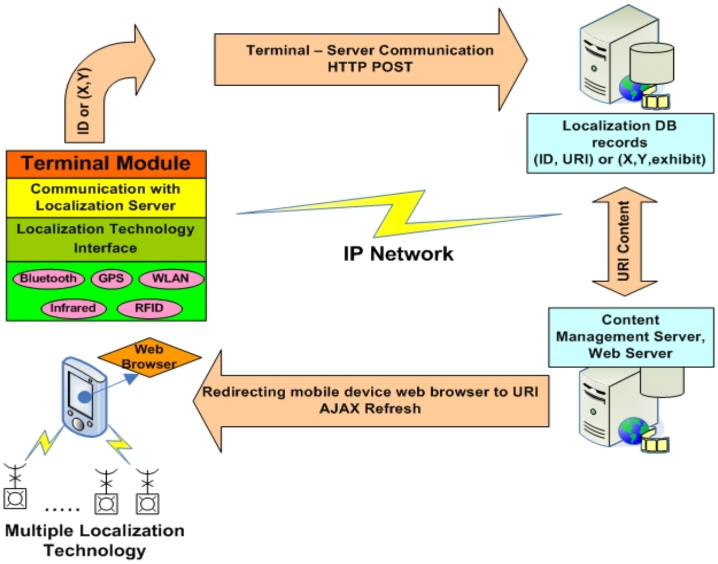
3.3 Fitting Bluetooth localisation in a lightweight system architecture

Although a Bluetooth based architecture can provide localisation services for environments where a Bluetooth infrastructure has been deployed, in order to provide a generic solution, we are presenting a generic architecture capable of exploiting complementary technologies, such as GPS, whenever they are available. The transparency to the localisation technology used is achieved by separating the positioning system from the content access mechanisms, as well as the selection of the specific localisation radio mechanism, according to the implementation site.

The different components of the proposed approach are the end-user terminals, the backend platform components and the communication infrastructure, as it is shown on 0. The main characteristics of these components are the following:

- The *localisation techniques* that can be integrated to the user device or provided as a separate hardware module, e.g., Bluetooth, Infrared, GPS.
- The *communication network* infrastructure, which can be any IP enabled access network, e.g., a WLAN, GPRS, 3G network.
- The *terminal module*, that 'runs' on the mobile device. This is essentially a J2ME middlet application which implements the generic localisation approach abstracting the underlying localisation mechanism, enables location tracking by using the terminal localisation device interfaces, and communicates with the server-side component, which translates physical location to content URIs. It also provides the user with the appropriate graphical user interfaces deployed on his device.
- The *localisation server* for binding location information given by the user terminal with a specific point of interest. The association can be performed independently of the localisation mechanism selected, as the content is completely orthogonal to the localisation mechanism and can be renewed easily. This kind of association is URI-based, because each point of interest corresponds to a specific content URI in the server.
- The *CMS* that provides automatically the content, related to each point of interest, through the IP access network.
- The *redirection mechanism*, which is based on Ajax technologies. As far as the terminal-side is concerned, it has to support JavaScript. Otherwise, the redirection is implemented through periodic HTTP refreshes on the server-side.

Figure 1 Core elements of the architecture (see online version for colours)



The main distinguishing feature of the proposed approach, in comparison with the implementations reported in previous sections, is that the various system components are designed and implemented in a modular manner in order to select the most appropriate in each specific installation. This modularity regards:

- The separation of the positioning system from the content access mechanisms.
- The selection of the localisation radio mechanism, accordingly with the implementation site.
- The selection of the terminal mobile device. The only requirement for the mobile device is to be Java enabled, something very common in the majority of the new generation mobile phones, PDAs etc.
- Independence from the underlying hardware infrastructure. The entire system is based on web technologies, which can be deployed easily in any server.
- Independence from the content being available to the end-user. All the content is available through the content management server and can be renewed dynamically without any change or intervention to the system.

In comparison with the criteria and the requirements that are presented in Section 2.1, we can state that the proposed approach fulfils almost all of them. It allows the exploitation of full benefits of location-aware services to user devices that are Java and Bluetooth enabled features that are very common in the majority of the new generation mobile phones, PDAs etc. The content can be viewed using any version of a mobile web browser that supports JavaScript. Furthermore, contrary to other LBS frameworks, the entire process is transparent, simple and friendly to the user since no input is requested. The user only receives the appropriate content on the mobile device according to his position within the area of coverage. The architecture is designed so that the entire amount of data is transferred through the local communication infrastructure.

4 The demonstration application and experiments setup

In the following subsections, an implementation of the generic architecture introduced in Section 3.3 and a specific demonstration application scenario are described in detail.

4.1 Implementation details

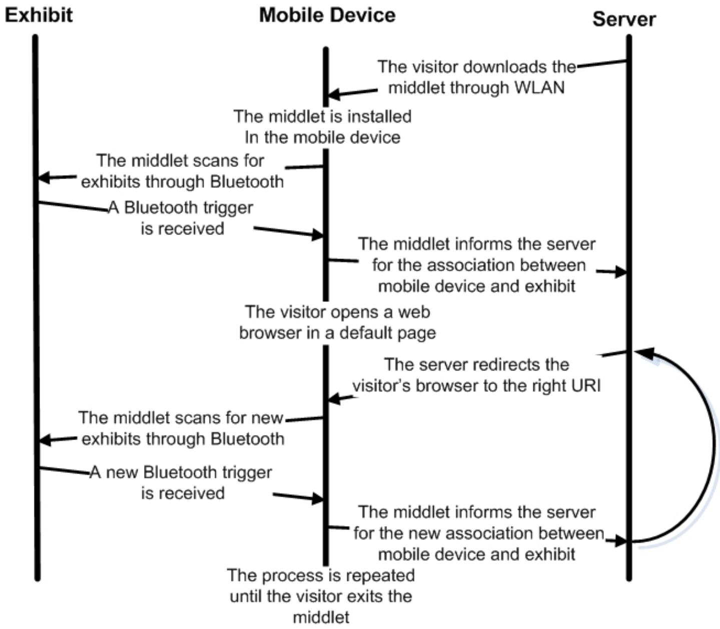
As described earlier, in order to search and select the desired point of interest in an e-guidance scenario, we have developed a Java middlet. A periodical search for points-of-interest that exist within the scope of the terminal is performed by the middlet and the nearest point-of-interest is selected within the guidance environment.

The database of the proposed application is installed on the server. This database hosts all the required information about the points of interest, the devices that run the application and information regarding the association between them. Additionally, various actors for different users in the database scheme have been defined.

As far as the application logic is concerned, the employed middlet receives input from all the terminal devices, updates the database with the new user and localisation information, queries the database for the content of the new point of interest, and it posts back proper URIs with the new point of interest information.

After the initial installation of the middlet on the end-users' terminals, their browsers point to the web pages incorporating the nearest corresponding point of interest. Ajax technology is used in order for the terminals to remain active, waiting for the application to update the database with the next point of interest.

Figure 2 Operation scenario steps



4.2 Operation scenario

The simple steps that the user has to follow in order to access the application, as well as the subsequent interaction scenario among the system modules are explicitly stated in operational order (see 0):

1. The user downloads the middlet through the IP network using a web interface and installs it on a specific mobile device.
2. The mobile device scans repeatedly, in a defined time space, for points of interest through the appropriate localisation technique.
3. Every time the middlet recognises a new point of interest, it communicates with the server and informs it about the new data. The communication is done via HTTP POST messages.
4. The server stores information about the nearest point of interest where each user is located at every moment and consequently sends to the terminal device all the related content.

5 The user opens a web browser to his terminal device in a predefined default page and through the redirection mechanism, he is being redirected to the page with the content of the selected point of interest.

6 Each time a new localisation trigger is received, the user is redirected automatically to the content of the new point of interest.

Special attention has to be given on the proper placement of the points of interest. In case of redundant points that need to be identified within a limited space, only one localisation interface is installed. In this occasion, the corresponding web page is displayed on the user terminal display with multiple thumbnail images for the points of interest, to allow the user to select the desired web page.

In the next section, the experimental platform is described and specific choices are made for the points of interest and their communication range with the users' devices.

4.3 Experiment's platform configuration and deployment

Several experiments were carried out in our laboratory (7.5 m × 6.2 m room) in order to study the behaviour of the Bluetooth enabled devices. We examined the way the signal strength variation affected the tracking performance and measured major characteristics of our implementation. It is important to mention that at the moment the present paper was written, available Bluetooth devices in the market, had not made signal strength information dispensable, since it is an optional characteristic, according to the Bluetooth specification. Thus, we focused our experiments on the evaluation of the behaviour of these devices while used for e-guidance purposes. Once the middlet detected the signal of a Bluetooth tag, the corresponding position of this tag was reported as the nearest tag to the current position of the mobile user.

In our laboratory environment, Bluetooth localisation technique was selected for the positioning and 802.11 g WLAN technology for the IP network communication. The employed devices were, an IEEE 802.11 g wireless LAN access point and one to five Bluetooth tags installed in specific points inside the laboratory area. As far as Bluetooth tags are concerned, we used Bluelon Bodytags BT-002. These tags embed the Bluetooth standard v1.2 – which achieves up to 3 Mbps – for software and hardware specifications, are equipped with lithium ion batteries and have a class 2 radio with a range of up to 50 m, which can be adjusted. For the portable client, we utilised a standard Nokia N95 smart phone with Symbian OS, and Wi-Fi and Bluetooth capabilities.

In our test cases, we placed the Bluetooth tags at different places inside the corresponding area. All the tags were installed approximately 1 m from the ground and at least 50 cm away from any other electronic device. The experiments were divided into four sets: the first one represents the transmission behaviour of one Bluetooth tag while changing the transmitted power, the second summarises the results extracted from different positioning schemes while using two, three, four and five Bluetooth tags and changing the transmitted power, the third estimates the time needed for the redirection of the mobile device browser to a new URI when a new Bluetooth tag is reported, and finally the last one collected experimental results with regards to the necessary Bluetooth inquiry time.

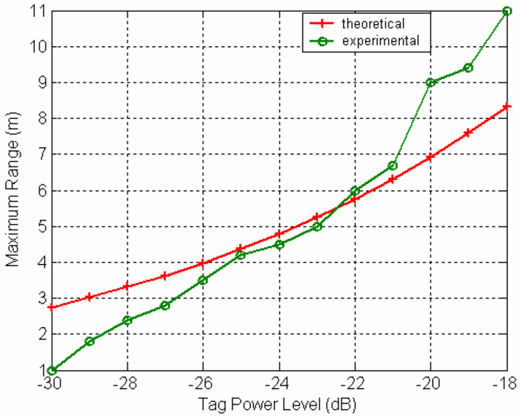
5 Experiments results

The following subsections provide a detailed description of the performance evaluation results for each of the experimental sets. The rationale for the employed devices and the required power and distance modulation are presented, in order to cover the entire test area and thus, render the application reliable in every case.

5.1 Correlation between power level and maximum transmitting distance

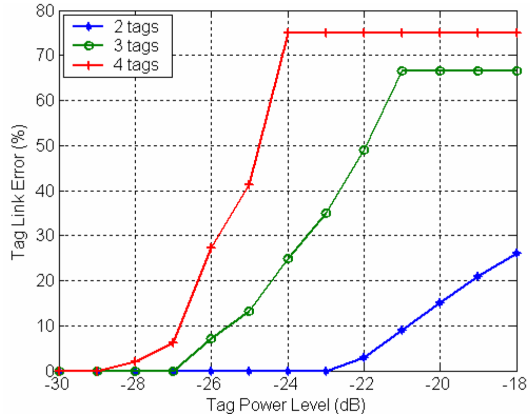
In this experiment we placed a Bluetooth tag in a specific position and we measured the maximum distances where the signal of the tag was received (the MAC address of the tag was recognised by the middlet), while changing the transmitting power level of the tag from –30 dB to –18 dB with a 1 dB step. In 0, the above measurements are presented compared with the theoretically expected, as mentioned earlier. The experimental measurements are close enough to the theoretical ones, especially for the power levels from –28 dB to –21 dB. The differences are due to the variation in the accurate sensitivity level of the smart phone used, to the appropriate selection of the parameters X and n – which are stated in equation (3) – and to the measurement error. This variation in the power level makes our tags capable to cover a distance from 1 m to 11 m.

Figure 3 Maximum covered distance for various power levels (see online version for colours)



In Figure 4, the tag link error is presented when placing two, three and four tags in different positions – as shown in 0, 0 and 0 in Subsection 5.2 – and measuring if the recognised tag is the nearest one or not. These measurements have been conducted only in the interference regions. We can see that based on the number of the tags we can adjust the power level in such an order that the probability of an erroneous decision would be very small. More specifically, the error for the survey area is kept small as long as the power is below –25 dB in every case. Thus, the minimum power level should be chosen according to distance criteria (see Figure 3) in order to minimise the interference error. In case where two tags are present, the link error is below 30% even for the highest possible transmission power. In the other two cases, the wider potential interference area increases the error as it is shown in Figure 4.

Figure 4 Link error for various power levels (see online version for colours)



5.2 *Site survey in laboratory environment with two, three, four and five Bluetooth tags*

In this section, we present the results that were extracted, with regards to the behaviour of Bluetooth for providing LBS in indoor environments. We have tested our approach under different scenarios. We have placed tags in different positions inside our laboratory and recorded the results of the experiments while changing the transmitted power of the tags. In the following figures some typical scenarios are shown. In each figure we have numbered tags, numbered points inside each region and numbered the time which is shown beside the person that was testing the application. Each numbered point means that in this point, our application recognised as nearest the tag with the same number. Accordingly, the numbered time means that running the application in a real time scenario, the user was redirected to the URI of the Bluetooth tag with the same number at this moment. We should mention here that the mobile user is moving with an approximate speed of 0.33 m/sec.

In the following scenario, we installed two Bluetooth tags with the same transmitting power in a distance about 9.4 m one from each other. While changing the transmitting power from –30 dB to –24 dB we had no interference regions, at –23 dB the interference region was very small and in a big distance from the two tags and at –22 dB the interference region was as shown in 0.

In this case, there are two large regions where only the nearest tag is recognised and the user is redirected to the URI of the right tag. Inside the interference region, if the mobile user is closer to one tag this is possibly recognised as the nearest one, but this is not always the case. While moving to the centre of the interference region, there is a probability of 50% for each tag to be chosen as the nearest one. From the results of the real time application we can see that, until the middle of the walking distance (in the middle of the interference region), the mobile user is viewing the URI’s content of the first tag (with number 1 in the Figures), then he is redirected to the URI of the second tag while moving from the interference region to the second’s tag region and redirected again to the URI of the first tag when passing from the second’s tag region to the first’s tag region accordingly.

Figure 5 Results during a walking in the two tags' case (see online version for colours)

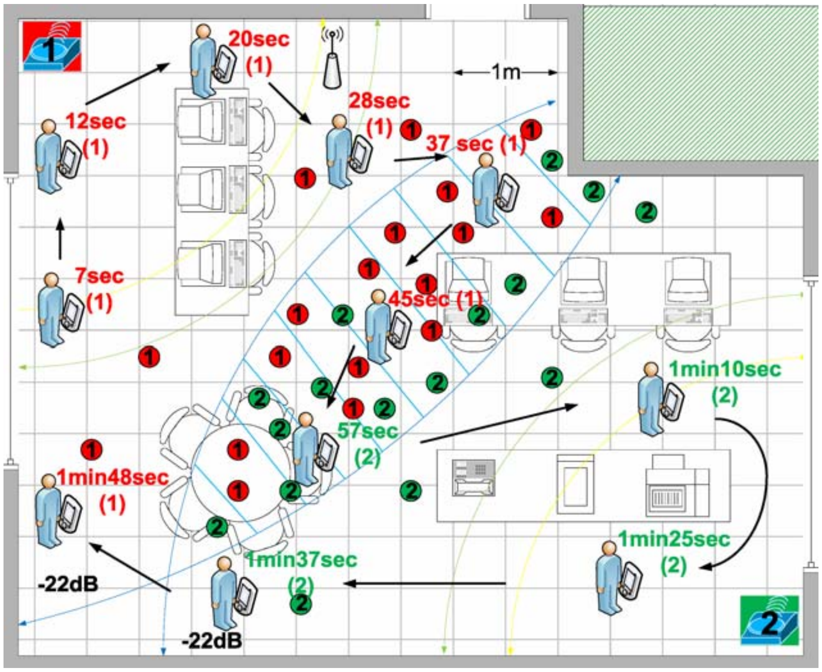
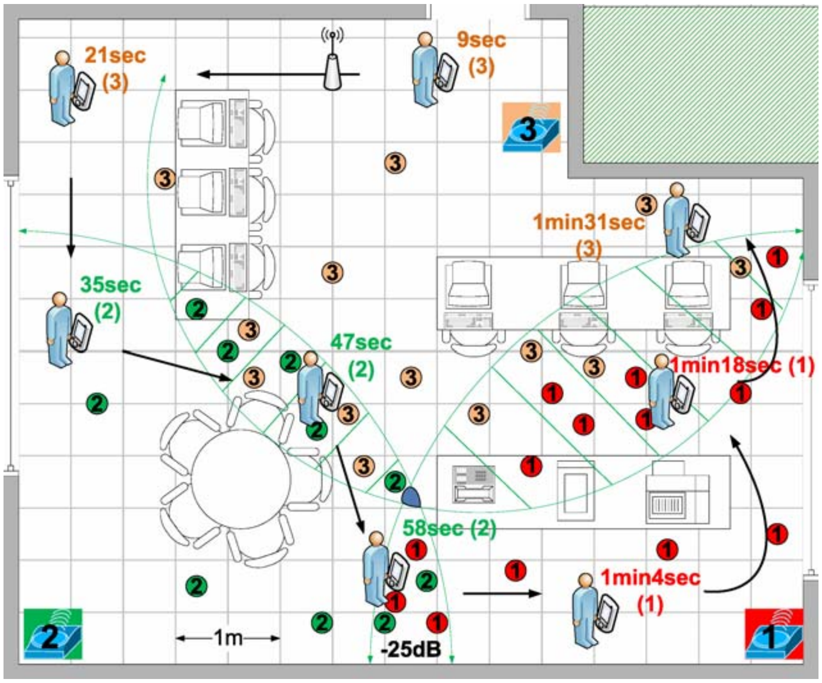


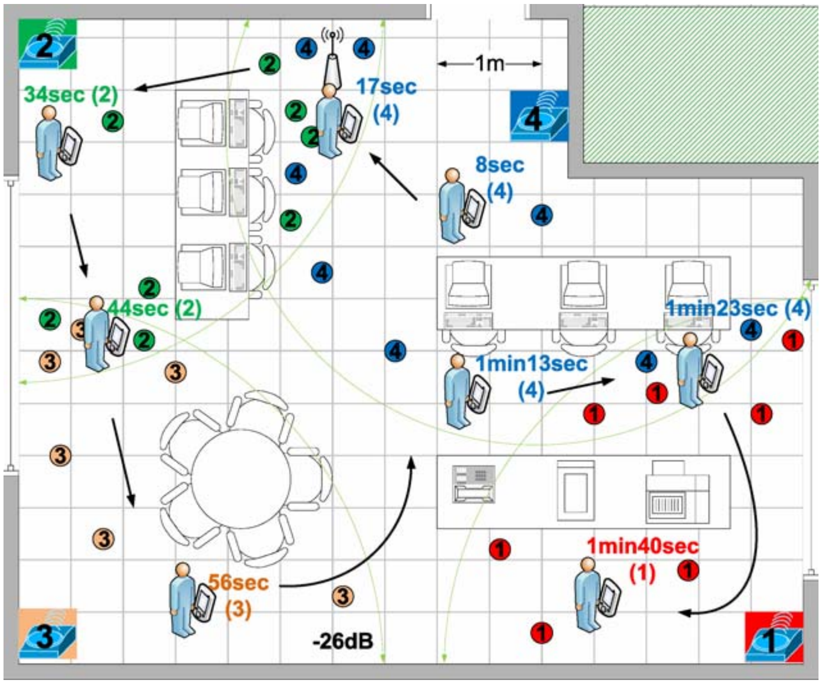
Figure 6 Results during a walking in the three tags' case (see online version for colours)



In the subsequent scenario, we installed three Bluetooth tags with the same transmitting power in distances from 5.8 m to 7.5 m. While changing the transmitting power from –30 dB to –27 dB we had no interference regions, at –26 dB the interference region was very small and between the first and the third tag and at –25 dB the interference region was as shown in 0.

Similar results are also extracted in the case shown in 0, where we installed four Bluetooth tags in distances from 5.8 m to 9.4 m and changed the transmitting power from –30 dB to –26 dB (in Figure 7 the transmitted power is –26 dB). If we wish to cover the entire room, we can simply change the transmitted power of the third tag from –26 dB to –25 dB.

Figure 7 Results during a walking in the four tags' case (see online version for colours)



Finally, in the case shown in 0, a central tag is configured to operate at a higher power level than the other four, which are installed in the corners of the room. In this occasion the region is divided into several smaller regions that can be uniquely identified. If the application recognises one of the corner tags, or two tags (one corner tag and the central tag), then we can conclude that the user is closer to the specific corner tag. This approach is also implemented as an alternate selection in the middlet in case of such a topology. In the next figure, the power level of the corner tags is –28 dB and the power level of the central tag is –27 dB.

Figure 8 Results during a walking in the four tags' with one central case (see online version for colours)

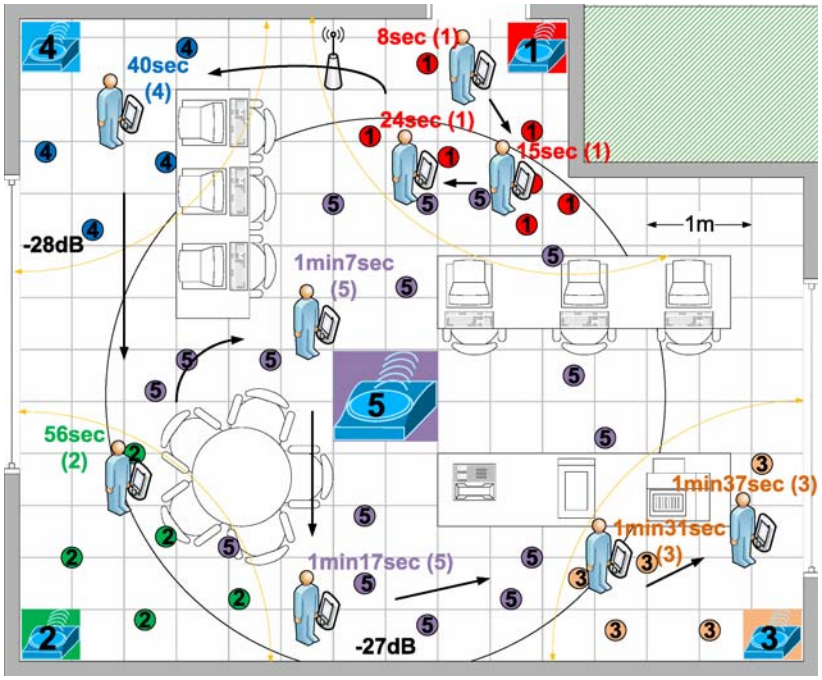
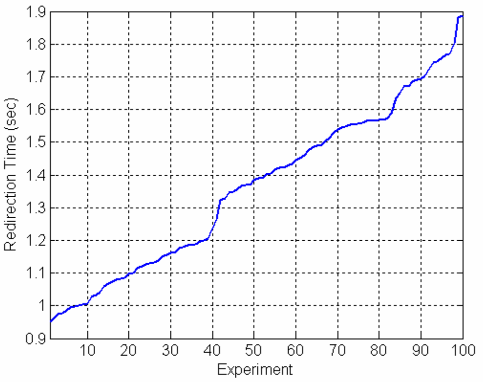


Figure 9 The redirection time (see online version for colours)



5.3 *Measurement of the redirection time*

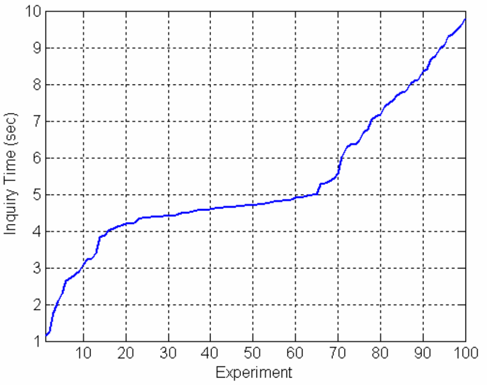
In this subsection, we present the results extracted from measuring the required redirection time of the mobile device's browser. With the term redirection time, we refer to the time between the instance when a different tag is recognised from the middlet and the instance when the browser is redirected to the URI associated with this different tag.

For the sake of convenience we performed 100 experiments in order to extract the redirection time required and sorted the results, which are summarised in 0, where we can conclude that the redirection time varies from 0.6 sec to 1.9 sec, values that are very small and do not create problems to the functionality of the application. It is important to mention that most values are constrained in the area from 1.4 to 1.6 seconds and follow a random pattern.

5.4 Measurement of the inquiry time

In this section, we present the measurements conducted regarding the time required for the middlet to scan for Bluetooth devices and successfully recognise the first one. For this purpose 100 experiments were performed, covering the cases where one, two and three Bluetooth tags were present and active. We noticed that when we were close to a Bluetooth tag then the inquiry time was very small (two seconds maximum). In cases where we were in coverage of two and/or three tags, the inquiry time was increasing and fluctuated from 5 sec to 9.8 sec. Finally in cases of coverage of one and/or two tags, the inquiry time was lower and varied from 2 sec to 6 sec, with a median close to 4.5 secs as depicted by the almost stationary part of the plotted line covering the experiments from number 10 to almost 70. This variation for the inquiry time, which is shown in 0, is satisfactory enough for most applications intending to provide LBS.

Figure 10 The inquiry time (see online version for colours)



6 Conclusions and future work

Based on the prerequisite that it is desired to allow an LBS application to dynamically select the employed localisation technique, the appropriate software and hardware infrastructure for the backend platform, as well as the terminal mobile device, we have argued that a comprehensive solution should address the challenges of modularity and openness. We therefore proposed an approach for providing location based content retrieval that attempts to address these issues, while we described an architectural framework for enabling such a system.

The application of the framework has been evaluated in a prototype system with the use of Bluetooth as the localisation technique, highlighting some of the issues involved in providing LBS. From the experiments conducted we can conclude that Bluetooth can be used for this purpose, especially for e-guidance and tracking applications. By selecting the appropriate power levels for the Bluetooth tags, in accordance with the distance we wish to cover, the proposed approach behaves very well. Furthermore, the measured inquiry and redirection times are small and do not impose substantial restrictions to the application.

Future work will include the support of user-transparent handover process aiming at the selection of the most suitable localisation technique in heterogeneous environments. Experimental work is currently underway towards evaluating and comparing the behaviour of the different localisation techniques in several environments. A study is also going to be conducted regarding the accuracy of measurements while using triangulation methods combined with localisation techniques such as WLAN or Bluetooth with received signal strength indication (RSSI) measurement capabilities. Finally, we are going to use Bluetooth for the communication network, in addition to positioning purposes, and evaluate its behaviour and functionality.

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