Location Awareness in Community Wireless LANs[¥]

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Abstract: *The growing availability of wireless LAN technologies together with the pervasive use of mobile and embedded computing devices gives strong raise for internet services adapted to context, particularly the location of their use. In multi-user cooperation environments for closed area communities like learning and teaching teams in wireless university campus networks, location awareness is of substantial importance.*

The provision of location based services based on IEEE 802.11 WLAN technology is limited with respect to the automated provision of geographical position information of mobile devices or "users" respectively. For the seamless delivery of location based internet services in campus area wireless networks we propose to enhance IEEE 802.11 WLAN positioning capabilities by the integration of RFID technologies. We have developed a multi-user team awareness framework, CampusSpace, that on-the-fly and transparently collects and interprets position information of mobiles from the signal to noise ratio of IEEE 802.11 radios, and cartographically mapped RFID tags respectively. Up-to-the-moment position information is made available for a multitude of services on a centralized wireless campus location server in a generic representation within the RDF (Resource Description Framework).

Keywords: *Context Based Computing, Location Awareness, IEEE 802.11b, RFID, RDF.*

1. Introduction

The coordinated interaction of mobile users in shared virtual environments is one of the fastest growing industrial fields of application of the Internet, particularly its most popular service, the WWW. It is becoming an indispensable vehicle for the interconnection of humans in the interactive execution of their cooperative work agenda. The growing demand for almost unrestricted user mobility, however, is exposing new challenges to the design and delivery of Internet services to mobile devices.

To support mobile users interacting "on the move" and across geographical boundaries while sustaining their cooperation context (like teaching and learning in a university campus like setting) is the motivation for a software framework for cooperation environments proliferating context awareness.

In previous work [FeJo 99] we have developed a software architecture and distributed cooperative work environment, TeamSpace [Fers 01], allowing to configure and operate virtual spaces based on the metaphor of "shared network places" in a wired networking infrastructure. TeamSpace's implementation and operation is exclusively based on standard Internet technologies (http, Java, VRML), integrates synchronous and asynchronous means of multi-user cooperation, and systematically provides support for workspace awareness.

The traditional concept of workspace awareness as the "... up-to-the-moment understanding of another person's interaction with a shared workspace" [GuGr 99] involves knowledge on who is working in the workspace, what users are doing or going to do, how and when they are executing their work, and what their motivation is for doing it (why). In this paper, and as an extension of TeamSpace towards a community workspace (CampusSpace) operating in a wireless networking infrastructure of the University campus, we are particularly concerned with the issues of *where* individuals are working, *where* they are using or going to use services, and *where* mobile devices are located, colocated or roaming [FKV 00]. While TeamSpace uses dynamic user behavior data as collected by monitoring events from I/O devices (keyboard, mouse,

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touchscreen) to implement workspace awareness, we have extended the collection and exploitation of awareness information from the users physical activities in the campus workspace, like movement within and among offices or lecture halls, walking among buildings on campus, etc. Using a combination of IEEE 802.11 WLAN and RFID tagging technologies for enhanced position tracking of mobile devices thus allows for a seamless integration of user activities aside the interaction with desktop computing facilities into a shared virtual workspace opening a whole new dimension of awareness abilities.

CampusSpace aims at the provision of multi-user cooperation applications at a greater level of context awareness [RCDD 98], where the context of an application is understood as "*any information that can be used to characterize the situation of an entity*", an entity being "*a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.*" [Dey 01]. A key architecture design principle for CampusSpace was to decouple mechanism for collecting or sensing context information and its interpretation, from the provision and exploitation of this information to build and run context-aware applications [DA 00]. To support building context-aware CampusSpace applications, software developers should not be concerned with how, when and where context information is sensed. Sensing context, therefore, must happen in an application independent way, and context representation must be generic for all possible applications.

A very important dimension of context in CampusSpace applications is *location*, i.e. i) the **geographical position** of mobile objects like devices, equipment or persons within the campus area, and ii) the **spatial proximity** of objects to each other. In the Sentient Computing project [Hart 99], the approach to enable *location based services* is to collect and supply geographical position information of mobile objects by tracking devices (bats) that communicate with base stations based on ultrasound. A similar approach is followed in HP's Cooltown project [Kind 00], although employing different technology. So called "beacons" wirelessly emit URL's into physical spaces, thus allowing mobile devices who receive those URL signals to identify their geographical position. Web content requested by those mobile devices is dynamically adapted with respect to their position, thus allowing for location aware Web access. While both projects only consider (and gather) the geographical position of devices, CampusSpaces is conceived to sense both geographical position and spatial proximity, and to seamlessly integrate both sources of context data into a generic context representation. Context data related to i) is gathered via the signal strength perceived for mobile devices by IEEE 802.11b access points, while context data related to spatial proximity is collected by mobile devices via RFID sensing of a tagged physical space. Context data coming from these two sensors is interpreted, i.e. high-level information about a users location is abstracted from raw location coordinates, and aggregated into a single, generic location representation.

This paper is organized as follows. In Section 2 we introduce the concept of gathering, interpreting and aggregating context information from different sensors. Section 3 is dedicated to the service platform we have developed to host up-to the-moment context information in an application independent format, i.e. an RDF schema. Section 4 envisions a use-case scenario how Campus-Space is exploited by students and faculty in a wireless campus setting. Conclusions are drawn in Section 5.

2. Sensing Context

2.1. Gathering the Geographical Position

As a first source of context information with respect to the location of objects CampusSpace exploits the signal strength of roaming client devices registered at WLAN access points (APs). The University of Linz campus is equipped with Cisco 340 series APs, which are the base stations of an IEEE 802.11b WLAN network operating in the 2.4-GHz (ISM, Industrial, Scientific and Medical) frequency band. The 802.11b IEEE standard permits data rates of up to 11Mbits per second which is comparable to wired Ethernet date rates. Enabling one AP to serve more than one mobile device, the 2.4 GHz frequency band is devided into 12 partially overlapping channels operated in the DSSS (Direct Sequence Spread Spectrum) mode. One consequence of DSSS is that within one BSS (Basic Service Set), like e.g. a seminar room, no more than three access points can simultaneously be involved in communication without forcing packet collisions at the physical layer. Another important drawback is that the multiple access mechanisms implemented at the MAC layer (like DFWMAC with CSMA/CA, i.e. Carrier Sense Multiple Access with Collision Avoidance) impose an increasing number of communication capacity losses due to frequent inter-frame spacing delays, MAC competition delays and packet collisions at the MAC layer as the number of mobile stations (MSs) increases. In practice a maximum number of 15

MSs appears to guarantee a service quality of about 2 Mbit/sec Figure 1 shows a model of the first floor of the software department building hosting 3 APs, and their respective overlapping spheres of reachability for MSs. At any time of operation of a MS roaming in the department building, the MAC address of this MS is registered at one of the APs, thus providing position information at the precision of at least half the diameter of an AP influence sphere. For a moving MS a “handover” mechanism is induced by a MS recognizing a reduced signal strength to the registrar AP (*active scanning*). Based on the signal strengths collected from other APs within the proximity of the MS, it sends an *association request* (AR) to the one with the best signal quality. The new AP responds with an association response and registers the MAC address of the MS as received with the AR frame. At the same time, the *distribution system* (DS), and by that the old AP, are notified that the MS is now associated with the new AP. Since APs have a fixed installation in department buildings, the mapping of a MSs current position to the floor plan of a building can be determined by a simple table lookup. Roaming of MSs can be tracked over time and update the respective user’s geographical position.

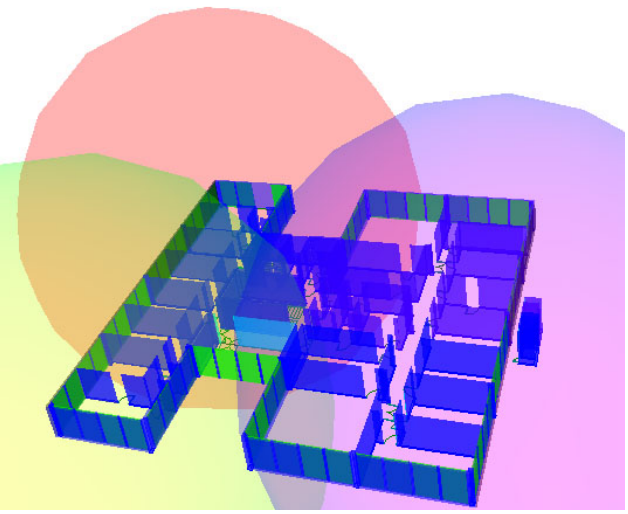

Figure 1: Reachability of APs

Association

An access point is able to provide the information which wireless devices are actual associated to it. With this information it is possible to map the wireless devices to a specific area at the wireless campus. Figure 2 shows the association table of a Cisco 340 access point with two iPAQs connected to it. For many applications this area information is not precise enough.

Association Table

Device	Name	GO IP Addr./Name	MAC Addr.	State
AP4800-E	AP340-4915b3	140.78.95.199	0040964915b3	
Generic 802.11	*00022d0742d9*	Unassigned	00022d0742d9	Assoc
Generic 802.11	*140.78.95.103*	140.78.95.103	00022d0742bc	Assoc
Generic 802.11	*140.78.95.221*	140.78.95.221	00022d0742c4	Assoc

Figure 2: Access Point Association Table

Signal Strength and Signal Quality

In addition the access points offer information about the transmission signal strength and quality. The *signal strength* (SS) is provided as dBm and the *signal to noise ratio* (SNR) is provided as dB. A signal strength of *s* Watts is equivalent to $10*log_{10}(s/0.001)$ dBm. A signal strength of *s* Watts and a noise rate of *n* Watts results in $10*log_{10}(s/n)$ dB. The signal strength calculated in dBm is also called *gain or loss of system power*. So if an access point provides the loss of transmission power while communicating with a mobile WLAN device, we can better specify the location of this mobile device. Different research projects have shown that the signal strength is a better indicator than the signal to noise ratio [BaPa 00]. The main problem of calculating the position information with signal strength information is that objects like concrete walls, metal objects, persons and even door frames affect the calculation. The calculation of signal energy lost in traversing a path in free space only with no other obstructions would be:

$$dB = \quad (92.4 + 20 * \log_{10}(\text{distance in kilometers}) + 20 * \log_{10}(\text{frequency in GHz}))$$

CampusSpace uses the association information for specifing the area in which an MS resides and the signal strength information to approximate a rough sphere within which the device is located.

2.2. Gathering Spatial Proximity

To sense spatial proximity of devices within in the campus area CampusSpace makes use of the RFID technology. An RFID (radio frequency identification) system is based on radio or electromagnetic propogation, i.e. the ability to allow energy to penetrate certain physical objects and read a tag that is not visible thereby to identify those objects remotely, either in the form of an identity code, or more simply that a tagged object is present (Electronic Article Surveillance). An RFID system thus consists of a tag or transponder, and a reader device. The transponder as a passive component responds by replying to an interrogation request received from an interrogator, i.e. the reader as an active component, either by returning some data from the transponder such as an identity code or the value of a measurement, or returning the original properties of the signal received from the interrogator with virtually zero time delay. Different frequencies of the radio system of the reader result in different reading ranges (10cm to 1m) and properties of the system. Commonly available tags have an operating frequency in the range from 60kHz to 5.8GHz depending on application.

Transponder systems have recently started to become major players in the field of electronic identification like electronic article surveillance, container tracking, personal access, vehicle access and control, sports timing, document authentication, dairy tagging, etc. The reason for this popularity being its contactless and powerless operation (no power supply needed in the tag),low cost packaging, unlimited lifetime, ISO standard compliance (14443 A/B and 15693-2), a wide choice of qualified packaging (Smart Cards, tags, inlets, smart labes, etc.), short range, proximity and vicinity communication with the same chip, single card/chip/transponder for various types of applications, cryptographic security (i.e. the protection against unauthorised product copies or data modification), and, last but not at least, low investment level for contactless technology integration.

In CampusSpace, a vast of 125KHz magnetic coupled transponders are used to tag objects in the various (physical) campus workspaces. The corresponding readers are integrated into the MS as a PCMCIA hardware add on. See Figure 3 for an example of a CE-device simultaneously holding an IEEE 802.11b adapter and a magnetically coupled RFID reader in its back:

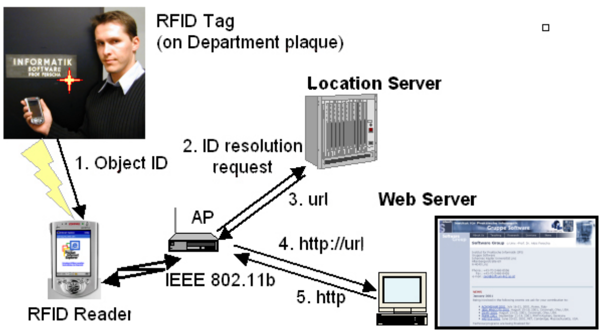

Figure 3: MS senses RFID tag in door plaque

Operating at frequencies in the order of 125KHz, the tags are characterised by antenna systems that comprise of numerous turns of a fine wire around a coil former to collect energy from a reader's magnetic field. Figure 4 shows the three phases a 125 KHz magnetic coupled passive transponder performs: During the first phase (energy loading) a carrier signal is propagated via a magnetic field from the reader to the coil. In phase 2 a level detector detects the end of the carrier and gives signal to the code transmitter, which propagates the unique ID in phase 3. Due to the magnetic method of coupling, reading range is limited generally to 20-30 cm in our setting. In a second generation of experiments we are using 13.56 MHz contactless technology allowing for considerably larger object IDs and reading ranges (approx. 1 meter). By having a continuous energizing field applied by the reader during the scanning which is used to power the tags, those tags can use time for seperating replies as well as use onboard receivers on the tags for addressing specific tags. Moreeover, these tags generally are read/write and have two way communications between the tags and the reader, opening the perspective of logging user visits at certain points on campus on the tag itself.

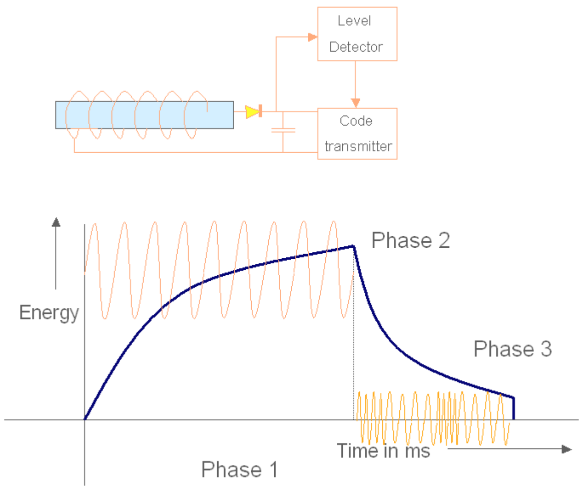

Figure 4: ID transmission of 125 KHz transponder

3. Wireless Campus Service Platform

In CampusSpace, a central server collects location information from the MSs and the APs, or at least logic link to information describing their properties, location, etc. Organizing position data within a central server, also called *location server*, does not imply that data should be stored and managed in a centralized way, but suggests to act like a broker among different clients as shown in Figure 5. It is also possible to keep information local at the client-side, while the location server just manages URIs and URLs respectively to this information. Another very important requirement to the software environment is to store information in a structured and platform independent way. We have decided to use RDF [RDF 00] as generic description format for this purpose.

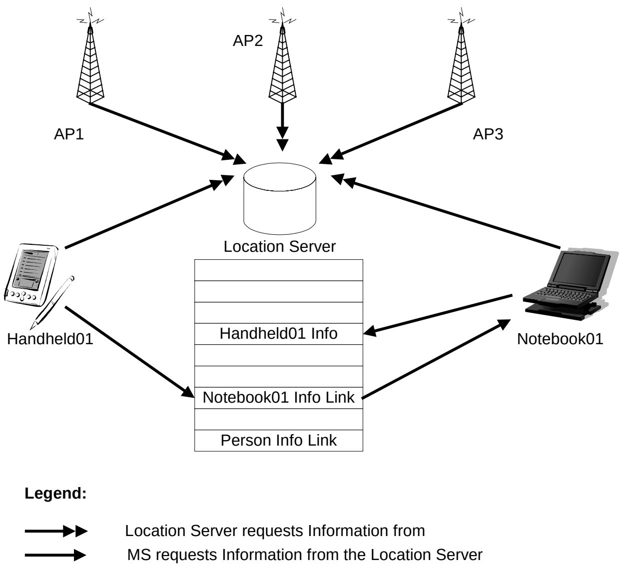

Figure 5: Software Architecture

The example in Fig. 3 now shows how the location server acts as an information broker between different CampusSpace clients. The MS via its embedded RFID reader senses the tag's ID from the department door plaque. With this Object-ID information (1) the client requests additional information about the environment around this location from the *location server* ((2), ID resolution request). The location server performs a hash table lookup in the campus tag location map, describing a static map of the position of tagged objects in physical campus spaces. The location server the responds back the corresponding URI or URL to the MS (3), allowing the client to access the internet with dedicated http request ((4) and (5)). In the example, the mobile iPAQ client requests the homepage URL of the person working in this office.

Figure 6 shows an example of the RDF description of a staff member who is the owner of two *things* listed in an RDF-Bag [RDF 00] and that his current location is in the seminar room called *HS1*. The *isIn* Attribute always tells where the resource is at the wireless campus. This information is updated on the fly by the location server, if new information were received from the clients or from the access points.

Due to device heterogeneity of MSs in Campus-Space, a critical aspect of delivering information from the location sever to the mobile clients is a very simple access protocol. We achieve platform independence in via the use of HTTP as information request protocol. (e.g. HTTP GET/PUT requesting over e.g. socket connections or RMI registries).

```
<rdf:RDF
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:s="http://wireless.uni-linz.ac.at/schema/">

  <rdf:Description about="http://wireless.uni-linz.ac.at/People/beer.rdf">
    <s:ownerOf>
      <rdf:Bag>
        <rdf:li resource="http://wireless.uni-linz.ac.at/Things/34.rdf"/>
        <rdf:li resource="http://wireless.uni-linz.ac.at/Things/35.rdf"/>
      </rdf:Bag>
    </s:ownerOf>
    <s:homepage>
        wireless.uni-linz.ac.at/Staff/WB/index.html
    </s:homepage>
    <s:phoneOffice>073224687132</s:phoneOffice>
    <s:phonePrivate>072585924</s:phonePrivate>
    <s:isIn resource="http://wireless.uni-linz.ac.at/Places/HS1.rdf"/>
  </rdf:Description>
</rdf:RDF>
```

Figure 6: RDF description of a staff member

4. Use-Case Scenario

As a demonstration for the location awareness abilities of CampusSpace consider a work progress meeting among researchers A (the host) and B (the guest) in A's office at the department. For the gathering of geographical position information of a moving MS within a campus building the accomodating AP is responsible to log position information of the client at the location server beforehand. For awareness at the task level, the precision of this location data (more or less of the kind "first floor of building P") is just not enough. The RFID based proximity sensing mechanism now allows for a more precise mapping of MSs to particular physical campus spaces.

The handheld MS of B in Figure 7, once passing the door to room P111, in a contactless way collects the ID

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Figure 7: RFID tag in office door frame

of the transponder on the door frame and registers the new position of the MS, and thus the position of B, at the location server. From this moment on, the location server supports context aware CampusSpace applications by the information that B is in A's office. The tagged objects in the office of A now allow for an even more detailed mapping to subspaces (Figure 8). Since B as well as A are working at the side table, both the MSs of B and A read the tables object-ID tags, and register the respective positions at the location server.

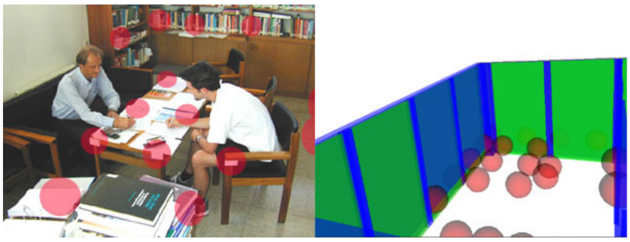

Figure 8: Virtual RFID tag mapping

Even the object-ID tags of the chairs are read and registered, thus allowing for a mapping of a persons position on campus down to a particular chair that person is currently seated on. (In previous work [Fers 01] we have exemplified how the physical presence of a person in a certain "sphere of objects" can be exploited to map this information into the task agenda of this person, i.e. implement task awareness in cooperative multi-user environments. In the example the "availability for interaction" service of CampusSpace would answer requests by other users that both A and B are unavailable for the expected duration of the meeting.)

5. Conclusion

Motivated by the disregard of multi-user cooperation software with respect to awareness issues, we have developed a context-aware multi-user environment, CampusSpace, to serve a manifold of awareness demands in a university campus scenario – ranging from group, to workspace, to task and location awareness.

For the latter, we have exploited and developed an automated position tracking mechanism for MSs roaming in an IEEE 802.11b wireless campus LAN. AP data has been used to gather the geographical position of an MS. To extend the tracking precision down to personal workspace areas, we have proposed and implemented a spatial proximity sensing system based on RFID technology. The combination of these to technologies is unique and has a manifold of advantages, among which the most prominent ones are that almost any physical campus space can be tagged almost invisibly at any desired density and in any desired shape, operating reliably and securely without wiring or power supply, collision free at short range, at low cost, etc. In the design of CampusSpace we have isolated the context sensing components from the components that utilize this information to implement context-aware applications. As such, CampusSpace represents a generic architecture for context-based computing environments with potentials in many other fields of application.

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