Exchanging Information in Decentralized Location-based Services

Hendrik Witt
University of Bremen, Germany
Center for Computing Technologies
hwitt@tzi.de

***Abstract*— This paper introduces the Location-to-Location-Network (L2L-Network), a peer-to-peer based architecture for location-based services. The L2L-Network uses a qualitative approach of spatial relevance derived from a peer-to-peer network topology and annotated location-based information to determine relevant information for a physical location. We introduce a distribution mechanism for localized information that automatically exchanges relevant information between network peers. Beside the discussion of spatial reasoning methods used for information distribution, the architecture of a L2L-Network is presented.**

I. Introduction

Location Based Services (LBS) were seen in their hype phase as the next "Killer Application" for mobile infrastructures. Today, after overcoming this hype phase a more realistic view on LBS is established. However, the development of real added value LBS applications that provide users only with relevant information at a certain location is still challenging.

Present commercial LBS applications often achieve location-awareness by simple polygon-based methods with a rigid allocation of information and geographical regions. Typically, proprietary protocols and monolithic approaches are used to build these systems [1]. Key issues such as openness, flexibility, and extendibility are rare. And also only a few systems already use semantic annotations for location-based information. But understanding the relations between information and physical space that can be encoded in annotations is crucial to get appropriated results from a LBS.

The L2L-Network that is introduced in this paper is based on a flexible and extendable hybrid peer-to-peer (P2P) infrastructure [2] which allows for an arbitrary arrangement of geographical regions and relations between them by associating peers with physical space. The general idea of this approach is that each peer offers only information that is spatially relevant inside a certain region a peer is responsible for. To achieve this, we developed a special information exchange mechanism. It uses spatial relevance measures computed from geographical regions that are related to the P2P network structure. Additionally, semantic annotations of location-based information are used by the mechanism also.

A. Outline

The organization of the paper is as follows. Section II gives some background information and a brief overview of related work in the field. Section III motivates the distribution of localized information in a distributed infrastructure. In Section IV we discuss in detail our approach of exchanging location-based information in P2P networks and gives a formal description of the proposed distribution mechanism. In section V the architecture of the L2L-Network is introduced. Section VI concludes the paper and section VII is pointing out some future work.

II. Background and Related Work

With the growing importance of location-based services, a lot of research is focused on LBS and location-based computing [3]. As mentioned by other research (e.g. [4], [5]) a central problem of LBS is the description of a location model which models environmental characteristics of physical space. As discussed by Leonhardt in [6] there are different approaches to model physical space, i.e. symbolic, geometric and hybrid approaches. Although location is the most important context information for LBS, there are other context information useful, e.g. environment conditions such as time or temperature [7]. In [8] an approach is introduced that collects a motion pattern from a user to describes his behavior in physical space. However, the quality of the motion pattern relies on the accuracy of location information, which is still a challenge for academia and industry [3].

Besides location modelling and localization, the design of an open and extendable LBS architecture should not be disregarded. As pointed out by [9], LBS architectures should not follow a design assumption that merges information sources and information providers to a single instance - a service provider. Thus, distributed network infrastructures such as P2P networks are useful in LBS research as an approach towards extendibility and flexibility issues. The use of such distributed networks for LBS has been applied, e.g. by the FETISH project [10].

For annotating location-based information with semantic information several description languages such as RDF exist. However, approaches that focus on an annotation of location-based information with information about spatial information derived from network topologies (e.g. relations between P2P nodes) are rare. Therefore, our work differs from other research in the way that we focus on hybrid P2P-based LBS architectures. Our location models are derived from a P2P network structure and spatial service regions in physical space that are managed by peers. To overcome the problems of providing users with location-based information in high quality, we developed a distribution mechanism that is able to automatically exchange relevant information between network peers.

III. Exchanging Spatial Relevant Information

The starting point of our research on LBS was based on the question of how it is possible to provide spatial relevant location-based information at a certain location in a decentralized LBS environment.
Our approach for such a decentralized environment is based on a P2P network structure. The idea is that each peer offer only information that is spatially relevant inside a geographical region. Thus, an exchange mechanism is needed that automatically exchanges relevant information between different peers.

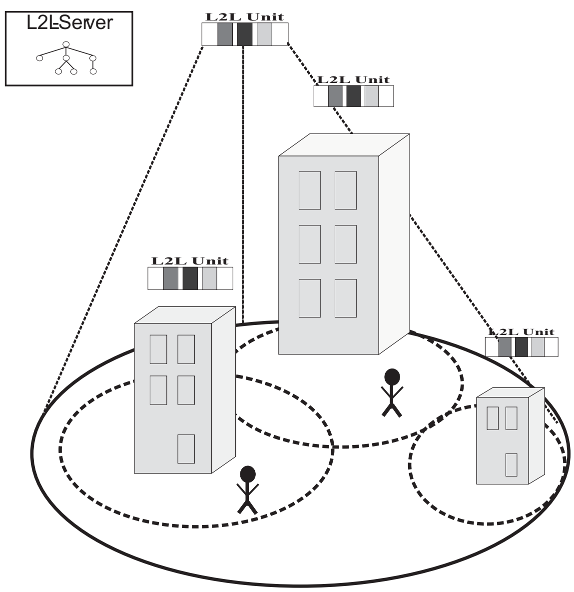

Fig. 1. Decentralized LBS Network Environment

The network environment shown in figure 1 is such a decentralized LBS environment. It consists of a number of different *L2L-Units* and a *L2L-Server* forming a hybrid P2P infrastructure [2]. The L2L-Server is the initial access point to the L2L-Network and manages, e.g. an overall location model of the entire network and the assignment of users and peers. L2L-Units represent single peers responsible for serving client request within an assigned service scope, which is a representation of a physical region.

IV. The Content Exchange Mechanism

The Content Exchange Mechanism (CEM) for location-based information is a mechanism that implements the exchange of spatially annotated information in a P2P network infrastructure. The mechanism allows for the exchange of location-based information by using their *spatial relevance* in such way, that each L2L-Unit manages only information that has a high relevance for its assigned service scope. Figure 2 illustrates an exchange sequence in principle.

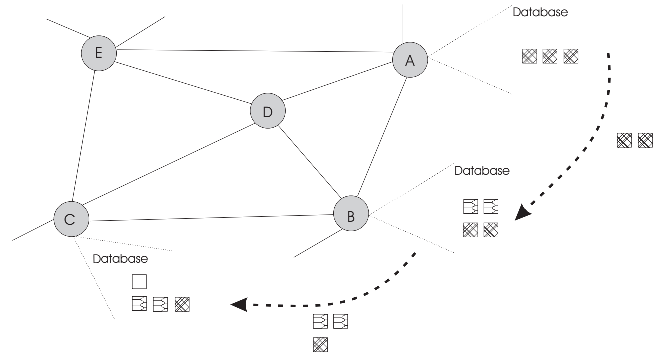

Fig. 2. Information Exchange Sequence

As shown in figure 2, a specific set of information items is exchanged between L2L-Units A, B and C, if their spatial relevance is above a certain threshold. The spatial relevance is computed based on a combination of spatial relations between L2L-Units and semantic annotations of location-based information (indicated in figure 2 by different shadings).

A. Components of the Mechanism

Figure 3 shows that the CEM basically consists of two components, a *Filter-Component* and a *Modify-Component*.

The Filter-Component of L2L-Unit A is responsible for the extraction of *relevant* information for L2L-Unit B from its database. For this, the spatial relations between A and B and the annotations of a location-based information are evaluated. For resolving spatial relations between the L2L-Units the location model is used. After this, the gathered information is send to L2L-Unit B in case it is above a relevance threshold.

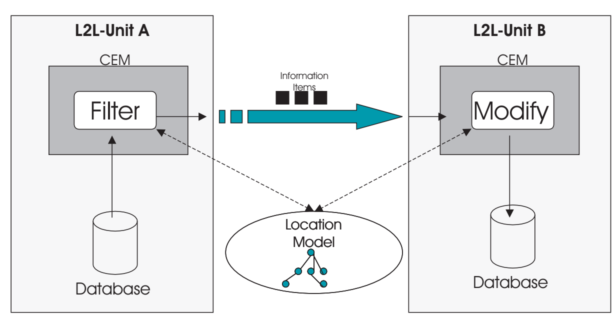

Fig. 3. Information Exchange Components

The Modify-Component receives the information items from A, modifies them and stores them to the local database of B. The modification process adapts meta data of an information item to store, e.g. pathways or relevance values.

B. The Mechanism

In analogy to the main components of the exchange mechanism we describe the mechanism in two steps: First, we show how spatial relevant information is gathered by calculating the so-called *extended spatial relevance* (ESR). Second, we describe how meta data annotation of exchanged information is modified to assure a controlled exchange that does not exceed propagation boundaries.

Our mechanism uses a qualitative spatial relevance approach introduced by [11]. The spatial relevance is defined as a measure to describe how relevant objects are for a certain location. The general assumption of this approach is based on Tobler's opinion that "everything is related to everything else, but near things are more related than distant things" [12].

***Definition** 1 (*Spatial Relevance*):* The spatial relevance σ measures the distance D between two objects r_q and r_i and is defined by

$$\sigma(r_q, r_i) = \frac{1}{D(r_q, r_i)} \ where$$

$$D(r_q, r_i) = \alpha \cdot h(r_q, r_i) + (1 - \alpha) \cdot v(r_q, r_i), \ \alpha \in [0, 1]$$

The distance D is computed by a linear combination of the *horizontal* distance h and the *vertical* distance v of a request object r_q and a current location r_i. The horizontal distance describes the spatial distance between two objects by using neighborhood graphs [13]. The easiest way to compute h is the euclidian distance, e.g. by using coordinates gathered from a location sensor. The vertical distance is computed through the distance of r_q and r_i in a hierarchical decomposition tree, which encodes the partonomic structure between spatial objects [11]. This decomposition tree (see figure 4 b) is created from a polygon standard reference tessellation (pSRT) of an environment (see figure 4 a).

The pSRT of the L2L-Network is formed by the service scopes of all L2L-Units and is derived from the network topology and associated service scopes.

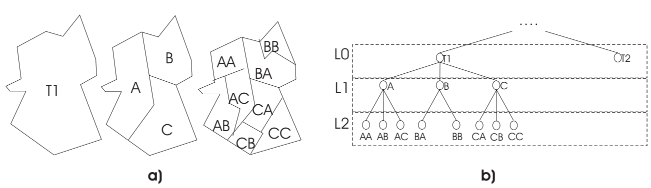

Fig. 4. a) pSRT of Service Scopes b) Resulting Decomposition Tree

1) Declared Relevance: Because the exchange mechanism works on single information items, we extended the definition of the spatial relevance to assign σ to each information in the network. To fulfill this, we introduced a measure that encodes the relevance of an information for other L2L-Units. This measure, which is some kind of meta information attached to each information item, we call *declared relevance* δ.A simple example definition of δ is given by table I.

***Definition** 2 (*Declared Relevance*):* The declared relevance δ is a mapping that assigns to each information item $d \in D$ of a L2L-Units database D a certain relevance value:

$$\delta : D \mapsto [0, 1]$$

The given mapping in table I defines some sort of "spreading range" of an information. The assumption in the example is similar to the earlier introduced approach, that information in general is less relevant at locations faraway from there initial source. Therefore, the maximum relevance (1.0) is mapped to the relation *regional* which enables maximum spreading. If information spreading is unwished, the *local* relation can be used to indicate that an information is not relevant for any other L2L-Unit in the network.

2) Extended Spatial Relevance: To apply the spatial relevance concept to the exchange of information items, we combined the existing spatial relevance σ with δ to form the extended spatial relevance (ESR) σ^*. Doing this, we adopted the used linear combination approach suggested in [11] to get a weighting factor β that can influence the outcomes of σ^*. With the existence of β we can decide, dependent on the environment configuration (arrangement of service scopes), if the outcomes of σ^* should be more influenced by σ or by δ. This allows for controlling the amount and balance of exchanged information. It provides a useful tool to influence the quality and characteristic of available information at a certain location in the L2L-Network.

TABLE I

EXAMPLE MAPPING OF δ

Relation	δ
local	0
surroundings	0.5
regional	1

***Definition** 3 (Extended Spatial Relevance):* The Extended Spatial Relevance of an information $d \in D_A$ from L2L-Unit A with a database D_A to L2L-Unit B is defined by

$$\sigma^*(A, B, d) = \beta \cdot \sigma(A, B) + (1 - \beta) \cdot \delta(d)$$

$$with \ d \in D_A, \beta \in [0, 1]$$

Based on σ^* we defined a measure for the relevance threshold (see equation 1) that is needed by the filter component to determine the relevant set of information items Δ to be exchanged from L2L-Unit A to L2L-Unit B (denoted by $\Delta_{A \to B}$).

$$\Delta_{A \to B} = \{d \in D_A | x \leq \sigma^*(A, B, d)\}, x \in [0, 1] \qquad (1)$$

After knowing the exchangeable set of location-based information Δ, we need a possibility to modify exchanged information to document their new meaning for other L2L-Units.

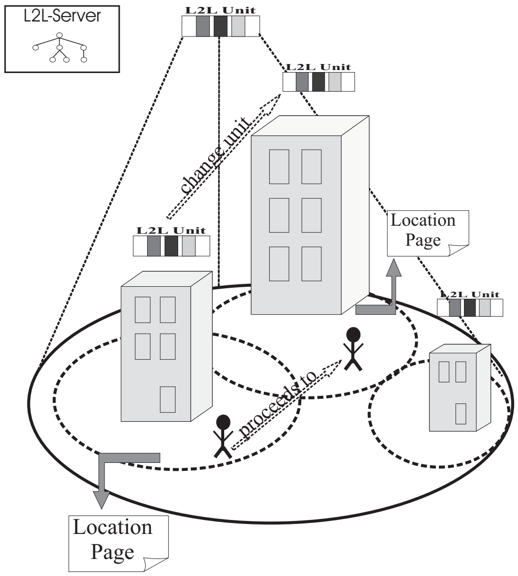

Fig. 5. L2L-Network Infrastructure

However, with the existence of δ we already have a measure to describe such relevance. Therefore, we combined δ with σ to encode history information about information spreading on the network. By subtracting a certain part of σ from δ we modelled the situation of reducing relevance of information every time an information exchange took place. Equation 2 describes the explained behavior.

$$\forall d \in \Delta_{A \rightarrow B} : \delta'(d) := \delta(d) - \gamma \cdot (1 - \sigma(A, B)), \gamma \in [0, 1] \quad (2)$$

With the definition of the modification process we finished the description of necessary parts of the CEM to implement the Filter- and Modify-Component.

The remaining part of this paper will describe in detail how the decentralized LBS architecture of the L2L-Network is designed.

V. The L2L-Network Architecture

The architecture of the L2L-Network is based on a hybrid P2P network. The L2L-Network environment shown in figure 5 consists of a number of different *L2L-Units* and a *L2L-Server* forming a hybrid P2P infrastructure.

A. L2L-Server

The L2L-Server is the central access point of the L2L-Network. Besides an initial network access service, the L2L-Server basically manages a *location model* with spatial representations of real world objects and provides a *contextualization process* which determines the L2L-Unit that is (for a given location of a user) responsible for user requests. This follows the idea of serving only spatially near users by a certain peer. Thus, the L2L-Servers role in the architecture is to offer basic system operations. Authentification and contextualization allow for basic management and security restrictions that are crucial for LBS [14]. In the current version of the L2L-Network authentification is achieved via MAC addresses or SIM id's, dependent on the used mobile device and the available network infrastructure, e.g. WLAN or GSM. Although, a central authentification is necessary for commercial use of a LBS, there are drawbacks. First of all, if the server crashes in a hybrid P2P infrastructure no new users can login to the system unless there is a second backup server available. Due to the contextualization process the L2L-Server is responsible for, it could temporarily represent a bottleneck in the system. However, the server only initially assigns users to L2L-Units when they login to the system. Thus, utilization of the L2L-Server is manageable.
Beside this, the most important task of the L2L-Server is the management of an overall location model describing a spatial model of the entire L2L-Network environment. The used location model is a combination of a symbolic and geometric model in analogy to the suggestion in [6]. According to this, the model is defined as a symbolic abstraction of the geometrically orientated service scopes. Each symbol is assigned to at least one service scope and thus indirectly to a L2L-Unit. The symbolic view of the used location model is interpreted as a *location context*. If an object is inside a geometrically described service scope, its corresponding symbolic name, e.g. "Building A", can be interpreted as the current location context in a qualitative manner. Figure 6 illustrates such a used structure.

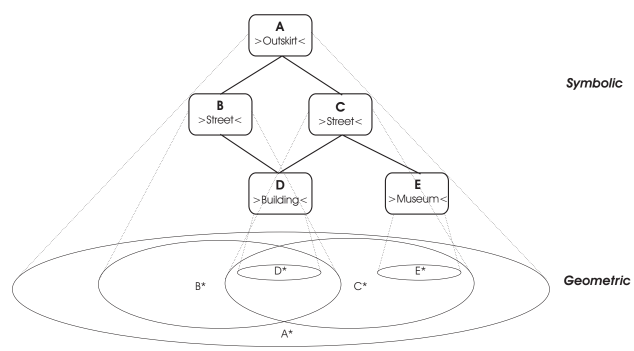

Fig. 6. L2L-Network Location Model

Additionally to the determination of a location context, the location model is also used to determine the responsible L2L-Unit for a given client request by inferring spatial relations. The best L2L-Unit for a client request (in terms of smallest service scope around a request object) is found by the evaluation of *part-of* relations.

B. L2L-Unit

The L2L-Unit is a peer in the L2L-Network and acts as a location information supplier and/or a client. It processes requests, displays gathered location-based information and

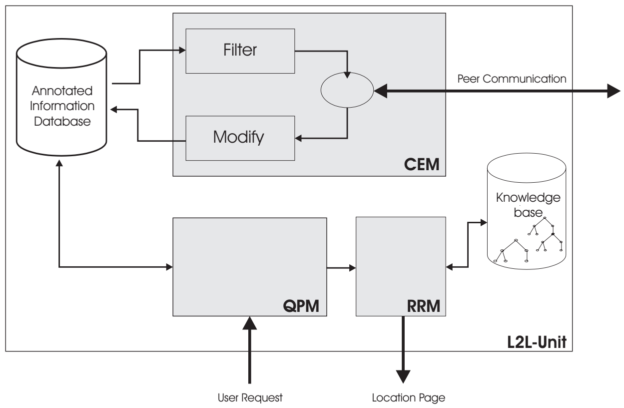

Fig. 7. L2L-Unit Architecture

manages the automatic information exchange with other L2L-Units. Each L2L-Unit represents a geographical region or object. This region can be an arbitrary physical region at any size, e.g. a building, an entire town or a small region around a moving L2L-Network user. The physical region is represented by a (so-called) service scope every L2L-Unit is responsible for. The physical location of the L2L-Unit is not necessarily related to the geographical region managed by the L2L-Unit. The L2L-Unit must not be physically placed inside the geographical region their service scope refers to. This allows for a flexible management of the L2L-Network by a spatially separation of physical network peers (IT infrastructure) and their controlled physical regions.
Requests inside a service scope are only managed by the L2L-Unit that is registered for the service scope. Therefore, user queries are not processed by one default service which prevent from bottlenecks. Additionally, this decentralization ensures a dynamic growth of the network and prevents the system from performance loss. If necessary, a handover to another L2L-Unit is performed for seamless connectivity according to suitable spatial relations (e.g. neighbor or superior). This procedure is similar to a handover in GSM networks [15].
Location-based information is accessible inside the L2L-Network environment through a kind of homepage of the current location - the *location page* (see figure 5). The content of a location page depends on a user context which includes among other parameters the current geographical position. The location page itself is not static for a certain service scope, but location-aware and depends on more detailed context information given by a motion pattern [8]. The motion pattern contains data about, e.g. pathways or the current heading of a user, which allow for an adaptation of the location page according to different situations, e.g. while walking the location page shows less detailed information that is easily readable, e.g by adjusting font sizes. To implement a dynamic adaptation, the location page is pushed to the users mobile device each time context information changes.

To implement the functionalities described above, the L2L-Unit consists of three main components as shown in figure 7.

Query Processing Module (QPM) The QPM processes requests of a client that basically consists of a tuple containing a motion pattern and a user profile. The user profile defines special static properties that describe a user, whereas the motion pattern describes a dynamic behavior of the user in space. A user profile contains properties such as user id, name, etc. and information about personal interests, e.g. “Sports” or “Special Offers”. The motion pattern is a 5-tuple of spatio-temporal parameters describing the users activity in space [8]:

```
(position, heading, moving direction,
        distance, duration)
```

The properties *position* and *heading* describe the results of a users movement by the current position and line of sight of a user. The rest describes the users movement itself and is measured against previous movement.
The information derived from the heading property is used, e.g. to display information about objects a user is looking at in more detail. For evaluation of the motion pattern we use several techniques, not issued in this paper.

Resultset Rendering Module (RRM) The RRM is responsible for rendering queried spatial relevant information on the users display. The main challenge of the RRM is the presentation of information for a given device category. To achieve this, the RRM uses device ontologies and categorization strategies to aggregate similar information under a common topic. For example, Italian, Spain and French restaurant information are summarized under the topic ”Mediterranean Gastronomy”.

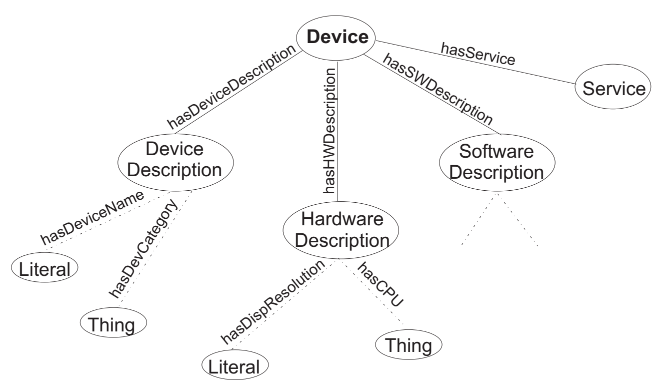

Fig. 8. Device Ontology

A device ontology is used by the RRM to derive information about existing capabilities or limitations of a client device. Recently, there have been proposed similar ontologies for the semantic description of devices in the field of Semantic Web [16]. Figure 8 shows a part of a device ontology used by the L2L-Network. The properties described in the ontology that are most important for the rendering process are hardware restrictions, such as display resolution, CPU power, and software restrictions. Software restrictions are important if some information items require pre-installed software on the device, e.g. a JAVA applet.

Content Exchange Module (CEM) The CEM is the core of the L2L-Network. As mentioned in section IV, the aim of the CEM is to achieve a network state where client requests can be processed on the local database of a L2L-Unit without the need for remote requests. For this, the CEM exchanges automatically the location-based information between L2L-Units. This exchange process is based on the evaluation of the spatial relations between L2L-Units in the network as well as the semantics of the location-based information to be exchanged.

The initial population of the databases of a L2L-Unit is done by the administrator/carrier of a L2L-Unit for privacy reason. Since each provided location-based information is annotated with the declared relevance δ which defines the spreading of an information in the network, complete control is given to the information owner.

VI. Conclusion

This paper presented the current results of the L2L project. It introduced the general architecture of the L2L-Network and its main services based on a hybrid P2P approach.

In the beginning a general refection of related work in LBS research was given to motivate the use of P2P networks for LBS architectures. We explained in detail the idea of the content exchange mechanism that allows for an automatically propagation of spatial information between network peers. To describe the functionality of the CEM we introduced a formalism based on the definition of spatial relevance given in [11].

By using the CEM we showed how to model an exchange component that exchanges location-based information between L2L-Units according to their spatial relevance in the distributed network structure. We described the overall architecture of the L2L-Network and discussed design decisions, such as the use of a central authentification service and their need for LBS that are used in commercial environments. However, we have not discussed issues such as reliability due to peer failure or server crashes or management of imprecise or trustworthy information in much detail, but gave some assets and drawbacks of chosen approaches.

VII. Future Work

In order to evaluate our L2L-Network approach, we are currently developing an evaluation scenario, able to give us a deeper understanding of the behavior of the L2L-Network. In particular, we want to answer the question of how the system scales for large environments as well as what the limitations of the exchange mechanism we introduced are.

In this paper we have not explained how the rendering process for different device categories is done in detail. The paper also gives only a few answers how query processing is managed in detail. This aspects we leave to forthcoming papers about the L2L-Network.

References

[1] P. Ibach and M. Horbank, "Highly available location-based services in mobile environments," *International Service Availability Symposium, Munich, Germany*, May 2004.

[2] R. Schollmeier, "A definition of peer-to-peer networking for the classification of peer-to-peer architectures and applications," in *IEEE 2001 International Conference on Peer-to-Peer Computiong*, Linkping, Sweden, August 27-29 2001.

[3] M. Hazas, J. Scott, and J. Krumm, "Location-aware computing comes of age," *IEEE Computer*, vol. 37, no. 2, pp. 95–97, February 2004.

[4] U. Meissen, S. Pfennigschmidt, K. Sandkuhl, and T. Wahnfried, "Context- and situation-awareness in information logistics," in *Proceedings of the Workshop on Pervasive Information Management held in conjunction with EDBT 2004*, Germany, 2004.

[5] R. Jose, A. Moreira, F. Meneses, and G. Coulson, "An open architecture for developing mobile location-based applications over the internet," in *Proceedings of the 6th IEEE Symposium on Computers and Communications*. Hammamet, Tunisia: IEEE Computer Society, July 2001, pp. 500–503, iSBN 0-7695-1177-5.

[6] U. Leonhardt, "Supporting location-awareness in open distributed systems," Ph.D. dissertation, University of London, May 1998.

[7] A. Schmidt, M. Beigl, and H.-W. Gellersen, "There is more to context than location," *Computer & Graphics*, vol. 23, no. 6, pp. 893–902, Dec. 1999. [Online]. Available: http://www.elsevier.com

[8] C. Schlieder and A. Werner, "Interpretation of intentional behavior in spatial partonomies," in *Spatial Cognition III: Routes and Navigation, Human Memory and Learning, Spatial Representation and Spatial Learning*. Germany: Springer, 2003, pp. 401–414, iSBN 0302-9743.

[9] R. J. P. Jose, "An open architecture for location-based services in heterogeneous mobile environments," Ph.D. dissertation, Lancaster University, England, April 2001.

[10] M. Vidal, J. Snchez, and J. Aparicio, *Core FADA*, FETISH Project, 2002, http://fetish.t-6.it.

[11] T. Vögele, "Spatial information retrieval with place names," Ph.D. dissertation, University of Bremen, Germany, March 2004.

[12] W. Tobler, "A computer movie simulating urban growth in the detroit region," *Economic Geography*, vol. 46, pp. 360–371, 1970.

[13] C. Schlieder, T. Vögele, and U. Visser, "Qualitative spatial reasoning for information retreival by gazetteers," *Conference on Spatial Information Theory (COSIT)*, 2001.

[14] U. Leonhardt and J. Magee, "Security considerations for a distributed location service," 1998. [Online]. Available: citeseer.ist.psu.edu/leonhardt98security.html

[15] A. S. Tanenbaum, *Computer Networks*, 3rd ed. New Jersey: Prentice-Hall, 1996.

[16] A. Bandara, T. Payne, D. de Roure, and G. Clemo, "An ontological framework for semantic description of devices," in *3rd International Semantic Web Conference (ISWC2004)*, November 7-11 2004.