POSITIONING AND LOCATION SERVICES FOR INDOOR AREAS IN NEXUS

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The research project „NEXUS" is currently being carried out within a so-called research group supported by the Deutsche Forschungsgesellschaft (DFG, German Research Foundation) in cooperation between the Institute for Photogrammetry, the Institute of Parallel and Distributed High-Performance Systems and the Institute of Communication Networks and Computer Engineering of the University of Stuttgart. It aims at the development of a platform for spatially aware applications. A prerequisite for such applications it is to determine the location of mobile users within different areas. As users also will act in buildings, a research aspect is the acquisition and representation of location information indoors. In the paper also problems will be discussed, which indoor sensor systems are suitable in case of NEXUS as well as the management of position information indoors.

1 Introduction

Within NEXUS the world is represented by spatial models, which describe the outdoor and indoor world as well as virtual objects. The virtual objects – the real world is augmented with – act as brokers between the platform and external information sources and services. Interactions between mobile users and the virtual or real world objects are realized by using the actual location/position information. The platform's job is the acquisition of position information to be able to provide Location Awareness. Especially indoor areas are points of interest because outdoor positioning tools usually fail there. A topic of the research project is to show mechanisms and concepts for positioning in indoor areas. The filed of main application of NEXUS are cities. Here pedestrians move in outdoor and indoor and access to location aware information by contacting the Augmented World Model (see Fig. 1) using small devices like PDAs (**P**ersonal **D**igital **A**ssistant).

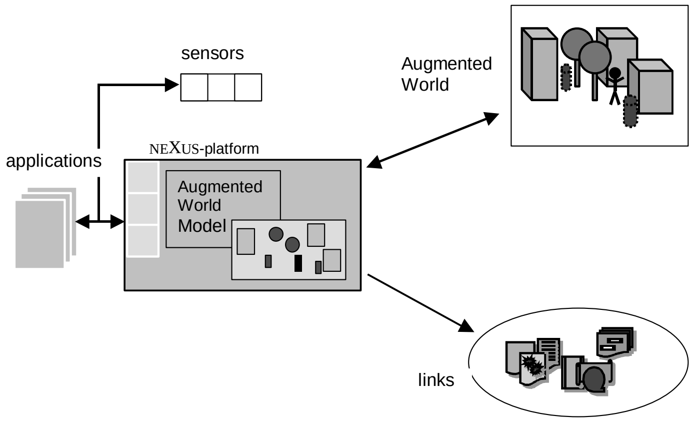

Figure 1-1: Augmented World Model in NEXUS

To determine the actual indoor position of the mobile user, it is necessary to use positioning techniques, which facilitate self-positioning. In self-positioning the positioning receivers themselves determine where they are. In remote positioning systems receivers at one or more locations measure a signal originating from, or reflecting off, the object to be positioned. These signals are communicated to a central site where they are combined to give an estimate of the position of the object. Remote positioning only in limited applications is of interest and would require a marking of users, e.g. marking with an active badge. NEXUS should support a big amount of users; therefore an active location is not the main topic of research. Passive location is favorite, so any user of NEXUS will be able to determine the actual indoor position autonomously, e.g. with his PDA. For this purpose it is important to ensure that the location services and the location-based data are accessible with any PDA.
To solve these problem in NEXUS research is done, in what way infrared, radio and imaging sensors are applicable. Additional research topics are the structuring and preparation of location aware information for indoor areas.

2 General Aspects

2.1 Applications

Different applications and areas are able to benefit if position information in indoor is available. To show all of these applications would be a large area, so only a view of them will be pointed out. Ubiquitous Computing, initiated from Mark Weiser [Weiser 91] aims at the integration of mini-computers into everyday objects, which are communicating to each other using a wireless network. In that way they expand the environment with intelligent objects. The concept supposes that any mini-computer knows its actual position.
The use of augmented reality systems also requires position information. In augmented reality or mixed reality systems the real environment is augmented with virtual objects. For the visualization of virtual objects they are back projected into the environment, e.g. using data glasses. Augmented reality systems therefore need a relatively exact positioning.
Nomadic Computing supports the user in a different way. Here the computers are fix and the user is moving around. The idea is, that the application – the user is working with – is moving respectively the user. This offers the possibility to work on any computer using the same ap-

plication. To identify which devices are close to the user, location information of the user as well as that of devices are required.
Applications with privacy aspects benefit of the positioning of mobile users. If confidential data are printed out e.g., the system could be instructed to print out the data not before an authorized person is in front of the printer [Hadley 95]. Also a system is thinkable that offers the possibility to login to the computer if someone enters the office room. More important than the login would be the logout or to lock the computer when the user is leaving the office room.
The NEXUS platform is arranged in a field, where different location aware applications get in touch, see Fig. 2-1. It is important to point out, that NEXUS is not a single application. It is a platform that will give the possibility to manage and combine several applications and services.

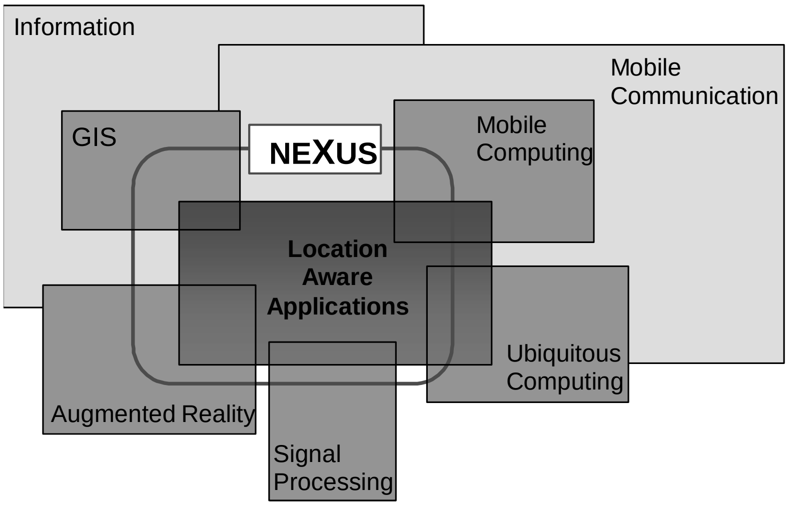

Figure 2-1: NEXUS in the filed of different location aware applications

So far only applications were pointed out, where position information is required. To illustrate the idea of NEXUS in more detail (especially for indoor areas) in the following section a scenario shall give the reader an impression.
Let us accompany Mr. X, a businessman who is on the way to Munich. Imagine, he is a person who has never been before in town arrives at the airport. There he has to go to a conference room, because he is in a hurry it would be fine to be guided to the location where the meeting takes place. As a service for travellers the airport had decided to prepare the indoor area for locating and guiding people. So Mr. X takes his small PDA and registers for that service. Within a few seconds he is able to select the preferable language and the service he needs. He decides for the navigation service and tells the application the room number, where the conference takes place. Because the airport is equipped with an indoor positioning service, the device locates the user’s position stand-alone. On the PDA a general map of the indoor area appears and guides Mr. X to his destination. Pleased to attain in time he imagines that such an indoor positioning and information service is very useful.
The scenario only describes a small extract of possible location aware applications that will be supported by the NEXUS platform. Generally it will be able to support various services and the architecture of the system enables to tie on different positioning tools.

2.1 Location Information

Location systems provide position information to applications. Basically they are special information systems. Position information often is a relative term, it depends e.g. on the area, where these information is required to describe the actual location. For evaluating positioning systems therefore the required information for an application should be considered in more detail. As one aspect it is important to know the required quality of data for the particular application. Generally there exist two types of location data, the relative and absolute position information. Absolute positions are required to determine objects and relative to describe the relationship between them. The relative information could be subdivided into two parts. The exact distance between two objects and secondly the collocation. Two objects are described as collocated when they could be identified at the same position, e.g. conditional on the inaccuracy of the position information. As example a predication could be, that several persons or objects are in one room, with no further information about the exact position. Relative positions e.g. are important for augmented reality applications [Starner et.al. 98], but also for nomadic computing [Brown 96].
A short overview about positioning systems with the aspect of data that occur will be discussed in the following paragraph. At this more the characteristic of data and not the contents will be viewed. In order to be able to manage position information and to be able to explain queries on them, positioning systems need an internal data view. The determined information therefore is mapped into a suitable data format, which is called "sighting" [Leonhardi & Kubach 99]. The "sighting" provides information about the position of an object to a given timepoint. That means it brings an object into relation with position and time. The formal definition of the position date (PD) is describable the following triple:

PD = f (o,p,t)

$-o \in O$	O … set of the objects to be positioned	(2-A)
$-p \in P$	P … set of all determinable positions	
$-t \in T$	T … set of all determinable times.	

In order to work with position data, often it is necessary to consider more than one individual date. The well-defined position data base $\det Pos_t$ is the following set.

$$\det Pos_t = \{(o_1, p_1, t_1), (o_2, p_2, t_2) \in Pos_t \mid (((o_1 = o_2) \wedge (t_1 = t_2)) \Rightarrow (p_1 = p_2))\} \qquad \text{(2-B)}$$

That means no object can be at the same time simultaneously on more than one location. However, the condition e.g. can be hurt through inaccuracies in the time measurement or the representation of the position. It is the task of the positioning service to prevent such conflicts.

In (2-A) the axiomatic definition for position information is given. The representation of location information generally could be indicated in two classes: The geometrical and the symbolical model [Leonhardt 98]. The positioning process could be subdivided into two categories, self-positioning and remote positioning, dependent to the system that carries out the position. As objects in remote positioning are tracked these process is also called "tracking" [Leonhardt 98]. Methods for self-positioning within buildings are basically distinguishable in contact afflicted and contact-free methods.

Positioning method	Data model
triangulation	geometric
cell based	symbolic
relative motion	geometric
recognition of environment	symbolic
physical event	symbolic

Figure 2-2: Positioning method and required data model

Triangulation methods using the running time of the signal or the signal strength e.g. are used in positioning GSM system applications. The triangulation using several measurements yields to an approximate position.
For cell-based methods the spatial environment first becomes divided into cells. The cells are equipped with devices broadcasting information. The location occurs via the determination of the cell, in which the object to be positioned is located at. Mostly this happens if non-ambiguous IDs are received/sent and assigned to a position. For each cell an own infrastructure is required, where the ID is propagated.
During an observation of the environment it is attempted to determine a position, when sensors recognize characteristic features of the environment. For this purpose the colour of the walls of a room or the noise level is determined and tried to map these to one room or location. These form of the positioning reminds strongly onto the type, how people determine their own position.
Events in the physical world always have a spatial relation, a place where they occur. Objects can be positioned, when the events are identified and the location is mapped between them. This positioning method completely manages without own infrastructure.
Movement measurement using e.g. a gyro is a relative positioning method, where directions and distances between starting and actual point are traced. Adding the traced path to the position of the starting point – which is well-known – new or updated location information can be processed. Since measurements are relatively, errors are added over the time.

2.2 Management of Location Information

The up-to-date location information of mobile objects, which is a very important aspect of the Augmented World Model (AW), has a very different characteristic from the much more static spatial model data, especially if the information is required with a high accuracy. As it is very volatile (in case of a walking person it has to be updated about once per second to achieve the above accuracy), updates will have to be very frequent. Existing databases are not well suited for these requirements, as they assume a low number of updates and the extensions required for performing spatial queries are not yet able to perform a higher number of transactions. Therefore, mobile objects are managed in the NEXUS platform by a special distributed component, the Location Service (LS, see Fig. 2-3), which primarily stores for each mobile object its current location. This location is given as a coordinate.

The Federation Layer contacts the LS, whenever a query to the AW-model concerns the current location of a mobile object. To this end it provides three main types of queries that are reflected in the AWQL (Augmented World Query Language):

(a) position queries return the current location of a certain mobile object
(b) range queries determine all mobile objects inside a certain area
(c) nearest neighbour queries return the mobile object nearest to a given position.

For security reasons the LS allows the user to set an upper limit on the accuracy with which it handles his/her position information. The semantics of the queries were designed to handle this issue.

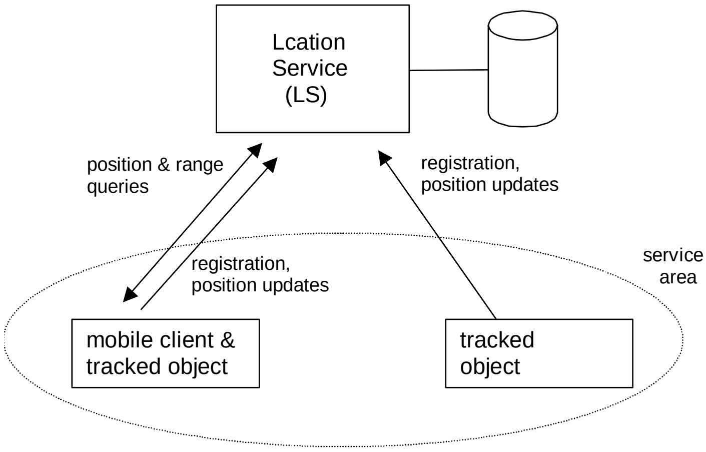

Figure 2-3: Basic components and interactions of the LS

To achieve the scalability necessary for a large-scale deployment of the platform, the servers that constitute the LS are organized in a hierarchical fashion, similar to that of the globe location system for software objects (see [v. Steen 98]). Leaf servers in this hierarchy are responsible for managing the position and registration information for the mobile objects inside their disjunct service areas, while the higher-level servers are responsible for forwarding queries and handovers. As a fast processing of queries and especially updates concerning location information is of great importance, the location information will be managed in a special main-memory data-structure based on a Quad-tree (see [Samet 90]), while the registration information is stored in a traditional database. The volatile position information, which will be out-of-date after a server failure anyway, can be recovered from the mobile objects.

3 Indoor Positioning Systems and Concepts

3.1 Tagging Systems

Most of the indoor positioning systems available at the moment are so called tagging systems. The idea of tagging systems is to mark objects in a special manner, so they can be identified precisely. Tagging systems do not locate persons or objects they locate only the tags. The location process is cell based. Each tag is assigned with an ID, which propagates the tag

in the environment or cell. If there is a sensor in the cell, it can identify the ID of the tag and create a collocation information (see Fig. 3-1). The created collocation information first is relative position information and the used positioning model is “symbolic”. Symbolic means that the position is described, e.g. as following: “You are in room A, of building B”. If necessary the received location information can be transformed into an absolute position.
Tagging systems are made up of different components. The basic element is the “tag”, which work is to propagate the assigned ID in the environment. The propagation is contact free and can be differentiated into active and passive tags. Active tags own a broadcast unit to send their ID, what can happen via infrared or radio signals. Passive tags do not send their IDs actively, they only allow reading it, e.g. barcodes (cybercodes) are passive tags.

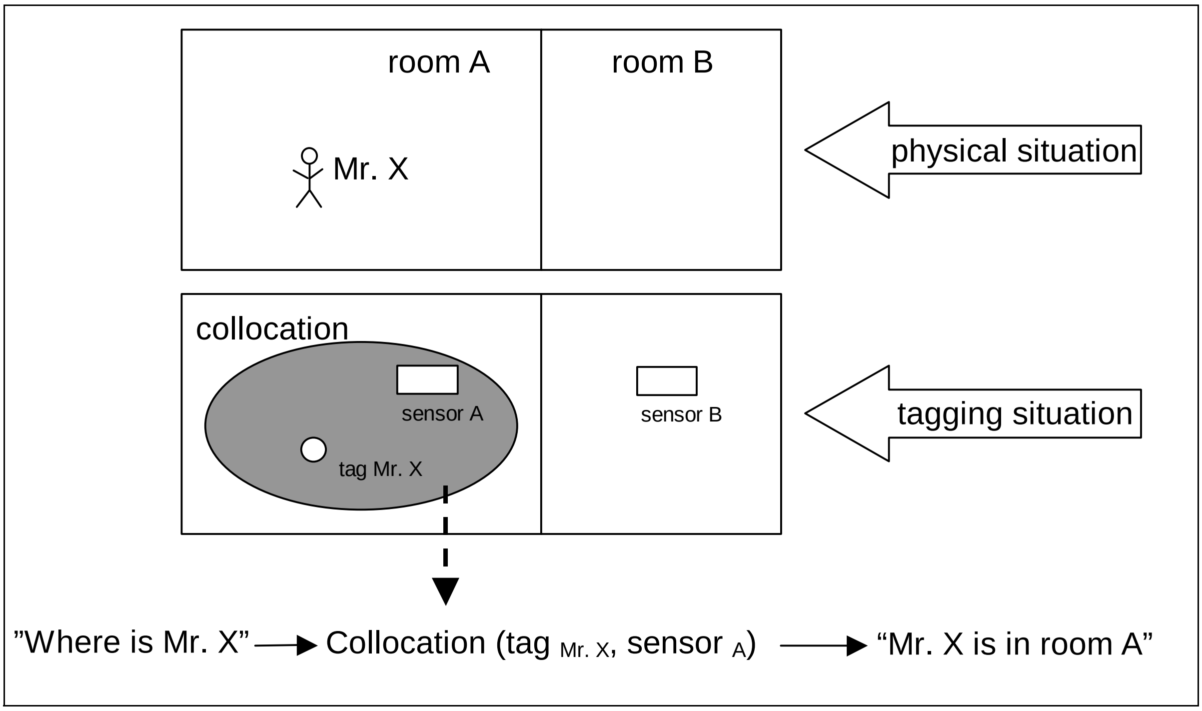

Figure 3-1: Functioning of a Tagging System

3.2 Implementations of Indoor Positioning Systems

There exist several implementations of positioning systems for the indoor use. Especially the technology of two of them is interesting for NEXUS and will be pointed out. The Active-Badge System of AT&T Laboratories Cambridge, which principle is ‘tracking’ resp. remote positioning and the Locust Swarm System of the MIT Media Laboratory, which principle is self-positioning.
Olivetti & Oracle Research Laboratory (ORL) started in 1989, in cooperation with the University of Cambridge to develop the Active-Badge System. In the beginning it was a pure tagging system, but over the years it grew more and more to be a cell based infrared network. As mentioned the structure is that of a tagging system and the tags exist as “Active Badges” (AB) for persons and “Equipment Badges” (EB) for objects. The ABs commemorate to name tags and are also worn as such. An AB or EB is made up of a small memory chip, a simple processor and an infrared receiver/transmitter. In intervals of 10 seconds it transmits its ID.

Also the environment resp. the building is equipped with fix “Base Sensors” (BS) that are able to communicate with the ABs. Each BS is linked to a location server using a local network. If any BS receives an ID of an Active Badge, it transmits the BS-ID and the AB-ID to the location server. Using this information and a database, it is able to provide the location of the AB or of the person wearing the badge. The communication sequence between the AB or EB, the Base Sensor and the system is illustrated in Figure 3-2, [Harter&Hopper 94].

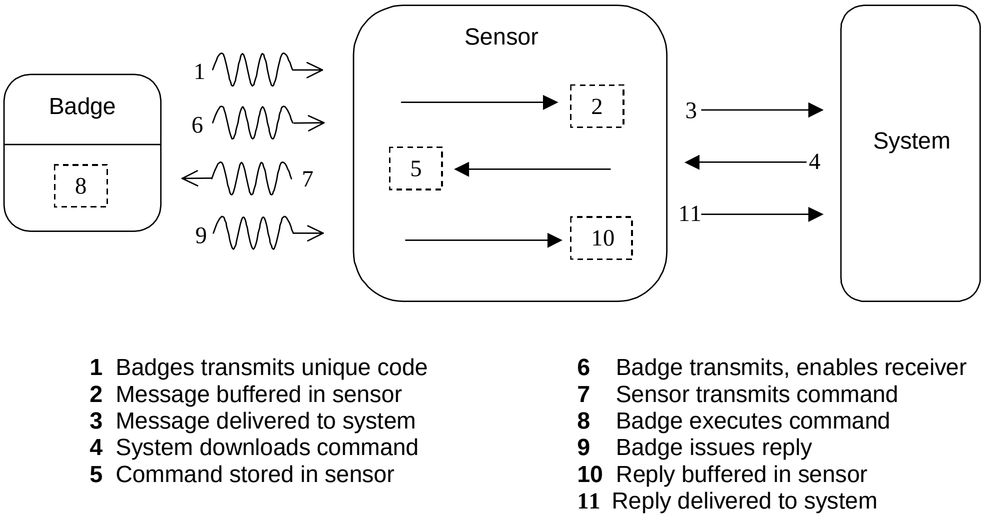

Figure 3-2: Active Badge communication sequence

The “Locust Swarm” system which is a self-positioning based tagging system provides different advantages in opposite to the AB system. Locust Swarm was developed at the Media Lab of the M.I.T. in 1997 within the scope of testing wearable computers. The aim was to generate a test bed where wearable computers could determine their position in indoor areas. Also Locust Swarm generally is a tagging system. Here the tags are called “Locusts”. They are installed fix on strategic locations, sending their ID to the environment via infrared. The user is equipped with a receiver and a small computer, which is able to absorb the ID of the Locust. In cooperation with the computer and the ID a location information can be computed. The advantage of “Locust Swarm” is, it is not a remote positioning system what offers several possibilities. Within such location environments the user locates autonomously. Also he/she can decide when a location process should be carried out and need not to transfer data to the infrastructure, what would offer new security and privacy problems. The disadvantage maybe, the user must carry a small mobile computer to locate himself.

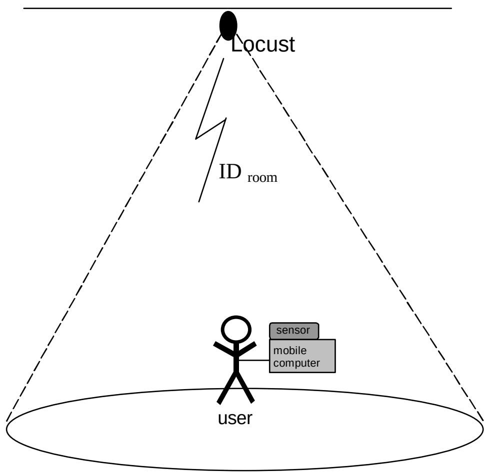

Figure 3-3: Principle of the Locust Swarm System

3.3 Concepts for Indoor Positioning in NEXUS

As described there exist several indoor positioning implementations but they are not suitable for the use in NEXUS. Often the implementation is not scalable enough or too cost intensive (scalable means the possibility to split a geographical area into sub-areas).
For the indoor positioning in NEXUS first the requirements and the system environment should be considered in more detail. The idea is that any user will be equipped with a PDA (a small mobile computer) and a wireless connection to the Internet (e.g. wireless LAN or GSM). Further the mobile user should be able to locate himself in any indoor area providing a positioning service. Also he should be able to determine the position stand-alone using his own device. To fulfil this, it is not necessary to develop a completely new technology for indoor positioning, but it is necessary to configure existing systems and concepts for the use in NEXUS.
The idea of the Locust Swarm system fits best for NEXUS, because the functioning is that of a tagging system and the principle is self-positioning. The problem of Locust Swarm is the scalability, which is not provided as is. To overcome that, the system must be extended with the possibility to unite sub areas into one domain. A system of grouped cells must be built up therefore (see Fig. 3-4). In NEXUS e.g. a building can represent a domain, wherein the domain ID is propagated via radio or infrared signals. For the positioning process in indoor it is necessary to propagate two types of IDs:

(1) The domain IDs specify the domain of an object. They are globally non-ambiguous.

(2) The cell IDs specify the actual location in more detail. In combination with the domain ID the location of an object can be specified relatively to that. Cell IDs are only in combination with domain IDs globally non-ambiguous.

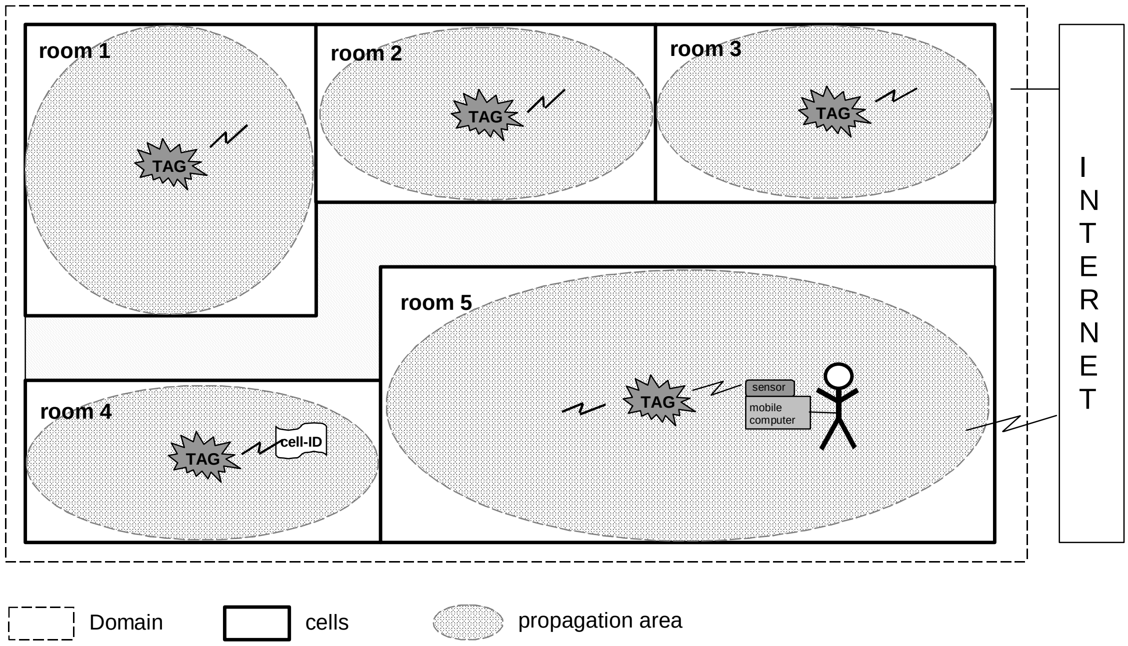

Figure 3-4: Domain concept in indoor

As two ID types were propagated (domain ID and cell ID) it is necessary to distinguish them. For this purpose the structure of the ID, e.g. bit pattern or ID length can be utilized. Considering that, it is necessary to equip any room with one or more stationary tags, sending their ID periodically. To propagate them infrared transmitters (IR) should be used, because common PDAs are usually equipped with IR-devices. To reduce the amount of transmitters, any tag is sending both, its domain-ID and cell-ID. The propagation frequency depends on the type of the ID, cell and domain. Because the local domain management knows the environment best, the responsibility about propagation frequency belongs to it. In case of a building e.g. the domain ID can be transmitted once per minute and the cell ID in intervals of 15 seconds.
One or several Information Services (IS) are assigned to the domain. The IS manages all the information about the domain and cells contained. Also it allows queries about the cell-/domain ID and provides the contained information. This information particularly provides the transformation of the ID into an absolute position (location). That means symbolic information is transferred into geometric information. For the transformation the IS can receive the necessary data about the building using a CAFM-system (Computer Aided Facility Management), wherein the building is modelled.
If the carried hardware component (sensor, mobile computer and wireless connection to internet) receives the propagated ID it contacts the IS, for being able to determine the position indoors. For this purpose instances of a positioning, a management and a query software tool have to be installed on the user's PDA (see Fig. 3-5).

Figure 3-5: Software instances for location

To use availably infrastructure the IS is realized as a WWW server. Queries to the IS are performed in the following way: A XML file is transferred via HTTP to the IS. The contents of the XML file describes the required information, as well as details of the cell ID the user is located at. Providing these information the IS is able to generate answers. So straight away any HTTP demon is applicable as an IS. To search for a particular domain Information Service also an index is provided by Internet. Here the IS is determined using the domain ID. The IS index is distributed to overcome bottleneck problems or single-points-of-failure. The distribution is feasible due to the hierarchical structure of the domain IDs.

4 Conclusion

Within the NEXUS project a subtask is to provide techniques and concepts for indoor location. As location information enables several new services, it legitimates the requirement of an indoor positioning service. Beneath the provision of overall information the service contains also the possibility for locating users in indoor. Within the paper the concepts for indoor positioning have been evaluated and specified. It was pointed out which data models and location services are necessary for indoor areas. Also some implementations of indoor systems have been described. Especially a case study for an indoor location in NEXUS was performed, where the technical environment and some solutions were shown.

References:

[Brown 96] Brown, M. G.: Supporting User Mobility; Proceedings of the IFIP Conference Mobile Communications, Canberra, Australia, Chapman and Hall, 1996.

[Drane & Rizos 98] Drane, C., Rizos, C.: Positioning Systems in Intelligent Transportation Systems, Artech House, Boston, 1998.

[Hadley 95] Hadley, C.: Using Location Information about People and Computers to Personalize the Working environment; Privacy Law and Business Conference, Cambridge 1994.

[Harter & Hopper 94] Harter, A., Hopper, A.: Distributed Location System for the Active Office; in: IEEE Networks, Special Issue on Distributed Systems for Telecommunications, Vol. 36, Nr.1, 1994.

[Hohl et. al. 99] Hohl, F., Kubach, U., Leonhardi, A., Rothermel, K., Schwehm, M.: NEXUS – An Open Global Infrastructure for Spatial-Aware Applications; Fifth Annual International Conference on Mobile Computing and Networking (MobiCom 99), Seattle, USA, 1999.

[Leonhardi & Kubach 99] Leonhardi, A., Kubach, U.: An Architecture for a Universal, Distributed Location Service; European Wireless ’99 and ITG-Conference on Mobile Communications, München, Deutschland, 1999.

[Leonhardt 98] Leonhardt, U.: Supporting Location-Awareness in Open Distributed Systems; PhD Thesis, Department of Computing, Imperial College of Science, Technology and Medicine, University of London, 1998.

[Samet 90] Samet, H.: The Design and Analysis of Spatial Data Structures, ISBN 0-201-50255-0, Addison-Wesley, Reading, MA, USA, 1990.

[Schiele 99] Schiele, G.: Positionierung von Benutzern innerhalb eines Gebäudes; Diploma Thesis Nº 1739, Faculty of Computer Science, University of Stuttgart, 1999.

[Starner et.al. 98] Starner, T., Mann, S., Rhodes B., Levine, J., Hearley, J., Kirsch, D., Picard, R., Pentland, A.: Augmented Reality Through Wearable Computing; in: Presence, Vol. 6, Nr. 4, 1997.

[v. Stehen 98] van Steen, M., Hauck, F., Homburg, P., Tanenbaum, A.: Locating Objects in Wide-Area Systems; in IEEE Communications Magazine 36, 1, p. 104-109, 1998.

[Weiser 91] Weiser, M.: The Computer for the 21st Century; in: Scientific American, September 1991.