Handling Heterogeneity in Context Aware Services

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Abstract. The increasing number of context aware applications, sensing technologies and positioning algorithms ask for a generic framework that is able to handle the large heterogeneity in contextual information. Thereto, we propose a layered context model that describes the heterogeneity in location information and a reference architecture that contains Distributing Servers and Location Operation Servers. The proposed framework can support location services in a heterogeneous environment. Finally we demonstrate the viability of our framework by implementing parts of our architecture related to a location service. Our service makes use of two different positioning technologies, based on WLAN and Bluetooth infrastructures respectively.

1 Why is there a Need for Handling Heterogeneity?

The present variety of positioning technologies for indoor as well as outdoor settings is large and the diversity of targeted end-users, devices and applications they have been developed for is growing as well. Originally many specific user groups and professions have required highly limited and restricted navigation tools. These technologies have been developed according to specific application requirements but after being implemented they have found broader use, i.e. use by other types of applications. However, the applications are specifically proprietary and not easy to use in other network environments. Furthermore, for these different environments other positioning technologies, e.g. based on wireless local area network or mobile phone base station networks have been developed. There is extensive literature about positioning technologies, location information representation and how to deal with location information. For an overview of positioning technologies we refer to [1] and [2]. An excellent overview of location modelling work can be found in [3]. A few important research results will be discussed here.

The solutions mentioned here are not technology and application independent. Therefore, we will define a framework that is both technology and application independent. Our solution will be capable of dealing with the whole process of sensing the location, processing and combining location information and distributing it to interested entities. In our view there are two major functional requirements that have to be satisfied by our envisioned generic framework, namely:

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- Handling heterogeneity of sensing technologies, among which are those for positioning, e.g. positions may be calculated from the network or determined from sensors or beacons.
- Sustainability of contextual parameters, e.g. parameters describing the situation of a group of users being in a meeting

In line with these functional requirements we aim in this work to combine two positioning technologies that are not compatible with each other, i.e. they do not support the same coordinate system and their methods for determining and representing location information are significantly different. However in many future scenarios some of these technologies or like in some cases, all of them, are embedded or attached to the same physical device, e.g. a PDA or laptop. In other words different applications running on one device have to be able to use different technologies or even combine location information that comes from these different technologies. This can only be done if the details of the technology are shielded from the application, and location information is always communicated in a way that the application understands. This makes it a challenge to develop an application or a service that is able to use all possible positioning technologies to acquire location information in every situation and as accurate as possible in a generic way that is independent of the technical details of the positioning technology.

In the next section we propose a context model that is required to describe and model the heterogeneity in location information. When location information has to be communicated between clients and servers, intelligent Distribution Servers and Location Operation Servers have to be defined. Therefore, we propose a reference architecture for intelligent location handling in section 3. In section 4 we describe our implementation of a Location Service to demonstrate our ideas. This service makes use of two totally different positioning technologies and shows how our framework can handle heterogeneity in location information caused by various positioning technologies. In section 5 we draw conclusions on our ideas and our implementation.

2 A Five Layer Context Model

In order to share contextual information with other applications and users, contexts need to be represented in a generic way to a certain degree. This requires knowledge modelling with respect to contexts. Dey et al. [5] pointed out that context models have always been application dependent. Hence, there are not really generic context models suitable for all kinds of applications. For our purposes we will use a context model in order to define context levels (different levels of abstraction); mappings and operations on contextual representations; reuse in applications; roaming between different positioning technologies.

In particular we follow the context model given by Ailisto et al. [9] and apply their context model for location information services using different positioning technologies. In their model different abstraction levels are defined for context processing objects and the location information that they produce (see Fig. 1). In this model information is processed and combined by objects at different levels as follows: (1) On a physical level, position is measured by hardware equipment, e.g. by a terminal or sensors observing signal strengths or Cell Ids, respectively. (2) On the data level, this information is processed and new data is computed, e.g. the absolute location of an object in x,y coordinates. (3) On the semantic level semantic information is collected (for example references to other places in the world) and used to enrich the location data and produce location information that is more meaningful and understandable to both applications and human users. (4) On the inference level, information is used from the semantic level, history information and inference rules, possibly dynamically learned, to make educated guesses what the user is doing and what kind of services he might want. (5) On the application level, decisions are made about taking actions triggered by situations defined at the inference level.

It should be noted that location information on a higher abstraction level may combine input from one or more sources of information defined at lower levels. This is indicated in Fig. 1 by input arrows.

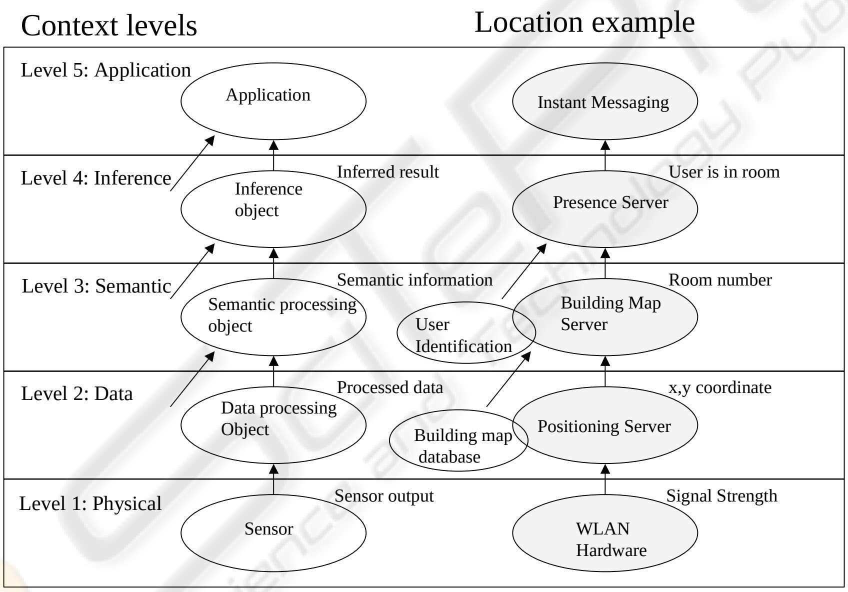

Fig. 1. Layered context model. Adapted from [9].

3 A Reference Architecture for Location Information Handling

Because high-level applications and users cannot deal with low-level sensor data, it is necessary to introduce a reference architecture that collects raw sensor information, translates it to an application-understandable format, and disseminates it to interested applications or end-users. In this section we present such a reference architecture that makes use of our context model presented in Section 2. Note that other reference architectures are possible that could support our same context model, because our model is not dependent of any architecture.

First, we describe the components of a physical frameworks and their functionality. Second, we describe in more detail the two main architectural components: *Location Operation Servers* and *Distribution Servers*. Finally, we give an example to illustrate the roles of the components in an intelligent location handling system.

3.1 System Architecture and its Functional Components

For our system architecture we were inspired by the layered architecture of the TEA-system [4] and the Context Toolkit [5]. The following components form the basis of an architecture that can be used to determine position, to exchange location information and to present it to users and applications:

- **Positioning units**. For example the user’s device itself that has a hardware interface to perform measurements or that can receive information from sensors in the environment. These units produce physical information, e.g. signal strength. Two ways are possible (and might even be mixed): sensory data coming from the user's device and sensory data coming from devices in the user’s neighbourhood (e.g. WLAN access points).
- **Location Operation Servers**. Servers that can transform, adapt, pre-process and do calculations on location information.
- **Distribution Servers**. These servers have the task to collect, store and distribute location information according to queries.
- **Client devices**. The client device will be equipped with different communication interfaces (GPRS, WLAN) and different positioning technologies (GPS, WLAN, Bluetooth beacons).

Together, these entities are part of an architecture, in which location information is requested, obtained, forwarded, processed etc. The roles of Location Operation Servers and Distribution Servers will be explained in more detail now.

Location Operation Servers. In our reference architecture the heterogeneity in location representations and positioning technologies can be handled by what we will refer to as “Location Operation Servers” where the transformation and adaptation process is done in one or several specific instances that could function in a distributed manner. A Location Operation Server can for example enrich location information with references to other information, e.g. a map, and thus convert it to a more semantic level according to our context model (see Fig. 1). Another example is calculating the distance between two objects.

Distribution Servers. Because applications require different forms of location information about a specific client, it should be possible to receive different types and formats of location. In order to realise this the Distribution Server can send information in the right format and to the right interested entities. Only when location has been described in a rich way, the Distribution Server can carry out queries for different levels of accuracy, granularity and richness of location information. Such a Distribution Server can be a moving object database [11] for example. This server may communicate with Location Operation Servers to perform operations on location information.

3.2 Handling Diverse Location Information in a Guidance Service Scenario

Let us define a scenario in which a maintenance service person equipped with a PDA searches target objects that need maintenance. The terminal that the maintenance person is using is carrying one or several technology modules that can be used for location determination, e.g. GPS, WLAN or Bluetooth modules. This person is guided though a large building using a guidance service. This service must receive the user's location in the form of logical indoor location, i.e. the user is in room 224 or the user is on the stairs between floor 2 and 3. Obviously the service does not know or care about the technology used to actually determine the user's location. Indoors the GPS cannot be used, but then the service still has to deal with two different technologies that may be used: the WLAN based or the Bluetooth based positioning technology. As data and information is passed from the mobile host to the route planner server, it is adapted to the needs of the service. First we describe the two technologies used for deriving the user's location and then we present the architecture that can deal with those different technologies.

WLAN based positioning. In case of a WLAN positioning technology (see [7] and [8]), a Location Operation Server will work in the following way. The client device is equipped with a WLAN interface and a positioning unit that collects signal strength information of at least two, preferably three, WLAN access points. These signal strength measurements are sent to the user's Distribution Server. The Distribution Server determines which other servers need to receive the user's location information and use one or more Location Operation Servers to convert the raw data into the required format. Our Location Operation server uses a method called location fingerprinting, which is based on learning. The signal strengths associated with a number of locations are measured in the learning phase and recorded into a table containing the coordinates of each location, the signal strengths and possibly some related semantic information, such as the name of the room. In this case, the signal strength values are used to calculate x,y,z information. Then, the x,y,z coordinates are used to determine the logical location information. The logical location information is then forwarded to the Distribution Server of the guidance service.

Bluetooth based positioning. The mobile hosts with a Bluetooth interface work in a different way. The Bluetooth positioning unit collects signal strength information about available Bluetooth location providers. The best location provider, selected using the measured signal strengths, supplies the logical location information to the user's Distribution Server. This server can now send the information to the

Distribution Server of the guidance service, without adaptation (so, without using a Location Operation Server).

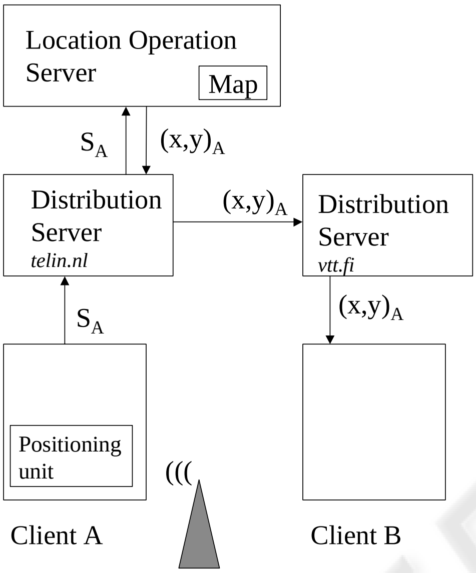

Fig. 2. The main entities in a reference architecture that handles location. SA = Signal strength data for client A. In this example client B is subscribed to (x,y) coordinates of client A.

Fig. 2 illustrates this example. This figure shows how client B, in our case, the guidance service, requests the position of a client A, the maintenance service person. These can be two users interested in each others position or, as in our scenario, one user and an application that is interested in the position of that user. Client B wants to have this position as an x,y coordinate. However, client A can only provide signal strengths. So in this example a mapping from signal strength to x,y coordinates take place. This is a transition from physical level to data level.

Fig. 2 also shows how the flow of information takes place. From this figure one can see that it is the Distribution Server that is responsible for providing coordinates and thus it will access the Location Operation Server to convert the information. The advantage of letting intelligent Distribution Servers communicate with the Location Operation Servers instead of the client is that the client now only has to communicate with the Distribution Server for sending physical data. This limits the amount of wireless communications. Disadvantage of this approach is that the Distribution Server has to be aware of the context of the client. But probably the Distribution Server is located close to the client and has access to local maps, service directories and organisational information related to the user.

4 Implementation of a Location Information Handling Service

Two existing positioning technologies, both using different wireless techniques and both with different ways of determining the actual position of a mobile client have been used for implementation of part of the proposed solutions. To illustrate our ideas we started with implementing a generic, i.e. technology independent location handler interface and a generic location representation format. This section will be concluded with a description of an exemplary application: the location service.

4.1 The Positioning Technology Independent Location Handler Interface

We have limited our scope by selecting two positioning systems based on WLAN and Bluetooth technologies respectively to make it easier to implement quick trials to proof our conceptual framework. In this architecture the positioning hardware itself is wrapped and hidden from the applications and application developers. Instead the system provides them a more generic interface to communicate with positioning technologies to help the design process of the applications and services using positioning information for their purposes, e.g. tracking or adapting them to user needs. A well-defined interface layer between hardware and applications provides the necessary freedom to application engineers to develop location aware services that are able to use any of different technologies possibly even simultaneously.

4.2 Location Format Compliant to the Mobile Location Protocol

A generic location format at the data level enables the description of location information at different levels and makes the information useful for different location aware applications. Main constraint to this format is that it should be technology independent and that it should be shareable with all possible other applications. For each level presented in Fig. 1, more parameters are added, but by embedding basic data in the new enriched format, backwards compatibility should also be sustained. Finally, a generic location format allows one to match location information to the different requirements of applications, for example, in terms of accuracy and granularity. We propose to use the following parameters: (1) Name of the technology used to obtain this position, (2) Coordinates and a reference to the corresponding coordinate system, (3) Date and time (to indicate freshness of location) and (4) Accuracy.

In implementations of our reference architecture a XML based location presentation language can be used for creating the final location information presentation in the application layer. In our implementation the presentation form used in carrying the location information from client to server and further to the subscribers is based on a subset of the Mobile Location Protocol (MLP 3.0.0), which was defined by the Location Interoperability Forum (LIF) and is expected to be supported and developed by the Open Mobile Alliance (OMA, see [12]). It's structure and parameters make this protocol well suited not only for describing location but also for querying it. Another important advantage is its extensibility, simple format and readability.

4.3 Implementation of the Positioning Technology Independent Location Service.

In both positioning technology cases the location information is stored in a PLIM (Presence and Location Instant Messaging) server. The PLIM server is a slightly modified version from the original Instant Messaging (IM) [6] server where just the presence information was available for clients to subscribe to. In the current modified PLIM architecture the location information is updated and subscribed as the presence information in basic IM platform. The PLIM server stores the location (XML based) presentations in its database and provides them to clients. All the PLIM clients log into one of the PLIM servers and provide their location information (if capable) to the server where it is stored in the form of a Mobile Location Protocol (MLP) presentation. Then other clients are able to access this information if their permissions are set to allow browsing of location information. The PLIM server is administrating these user restrictions. In other words, we have used PLIM as a *Distribution Server*. Using a publish-subscribe mechanism in the Distribution Server, each interested entity receives information that is in a format that is suitable for carrying out its own task. For example, one client might only be interested which room a user is in, while a tracking application might want to have building coordinates. Nevertheless, they can subscribe to different sets of location information that is related to the same physical position of that particular user.

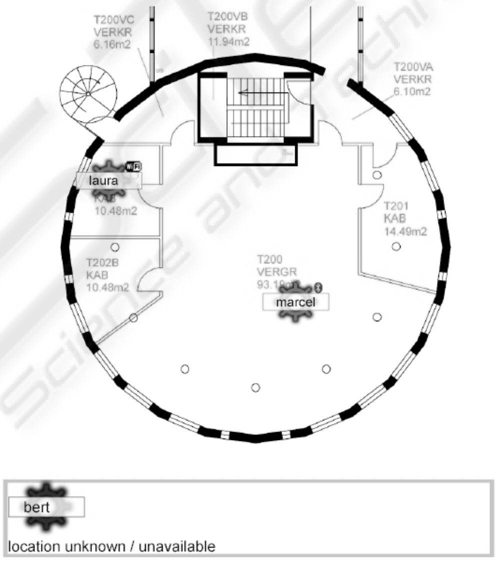

Fig. 3. Map of a large meeting room showing the position of two users equipped with PDAs. To determine and provide their position, one user is using WLAN technology (WiFi) and the other is using Bluetooth technology

Then we used the positions of two clients and showed them on a map. This map is a client of the Distribution Server and receives updates of two users, one using the Bluetooth positioning technology and one using the WLAN positioning technology. The complete concept of the map application is presented in Fig. 3.

Depending on the hardware the client software picks the right positioning method and executes the initialization process accordingly. The technology specific location handler launches a location update process to acquire the latest position of the device and delivers it to the Distribution Server that can forward this information to other clients or entities. Distribution of the location information to other users makes it possible to see each other on the same map. Distribution to other interested applications makes it possible to reuse the position in other applications, for example an Instant Messaging application that wants to know if a user is in his office and thus available for a chat session.

In the case of WLAN positioning the update process is measuring the signal strength values from the base stations and delivering them to the location server for calculations of the location. The location server could also act as an information source for multiple intelligent services, e.g. tracking or distance calculation services but the only function currently implemented is a basic service providing xy-coordinates from signal strengths.

When Bluetooth access points are used, the position is acquired directly from the BT access points. The client device determines its position (a room) based on the strongest signal it receives from one of the access points. This means that the access point functions both as positioning unit and Location Operation Server, because it maps to a physical location.

Note that this application is now able to use two different technologies to position the user. This has been made possible because the terminal has a generic interface and because the application uses the same location format and both technologies share the same coordinate system, i.e. the same map of the room.

5 Conclusions

A generic framework has been proposed that handles simultaneously the heterogeneity of both positioning technologies and location representations. The main characteristic of the framework is a strong functional separation of functionality for distributing and for processing location information. Location Operation Servers have been defined to do operations to add information to a location information object enriching it and bringing it to a higher more meaningful level (from physical level to data and semantic level). We defined Distribution Servers based on a publish/subscription mechanism to deal with exchanging location information between different users or entities. This means that the intelligence that is required for location handling is not in the Distribution Server nor in the client device, but in specialized functional components, i.e. the Location Operation Servers.

Our implementation of a location service proved that our context model and reference architecture are a good basis for building a system that can deal with heterogeneity of location information. In this case an application was build that made use of two totally different positioning technologies.

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