# Towards an implementation of Smart Hospital: a localization system for mobile users and devices

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***Abstract*— The advancements of wireless and mobile computing technologies and the diffusion of Pervasive Healthcare technologies are changing our perception of healthcare. In this paper, we describe how the Pervasive Computing technologies can be used to build a Smart Hospital. In particular, we propose a concrete implementation of a Smart Hospital and discuss how e-Health services and applications can be enhanced by location information. As a solution, we present semantic models, mechanisms and a system to locate diverse kinds of mobile entities in Smart Hospitals. The key feature of the system is the semantic integration of different positioning systems that not only enables the hospital to transparently handle such physical positioning systems, but also to reason on location information coming from different systems and to combine them in order to get higher context information or to resolve inconsistencies or conflicts due to sensing errors or limitations of the positioning systems.**

***Keywords-component; Smart Hospital, localization system, ontologies and rules.***

## I. INTRODUCTION

In the last decade, technology evolution in hardware design and development is leading towards the implementation of Smart Hospitals. As a matter of fact, the advancements of wireless and mobile computing and the diffusion of pervasive healthcare technologies are significantly changing our perception of healthcare. We expect that the everyday activities of clinicians in our classical hospitals can be extended with enhanced and customized healthcare services which can be delivered at any time and any place.

Pervasive Computing can tackle such changes by building Smart Hospitals, where highly heterogeneous hardware and software components can seamlessly and spontaneously interoperate, in order to provide a variety of services to clinicians independently of the specific characteristics of the environment and of the client devices.

Nevertheless, most of these services require different localization capabilities and, for this reason, a concrete implementation of a Smart Hospital requires that the environment be equipped with a multitude of different positioning systems capable of detecting presence and proximity of people and mobile devices.

Ideally, a positioning technology should provide complete and accurate location information for both users and devices. In the absence of an ideal solution, multiple technologies can be used and each of them can face specific requirements; i.e. a Wi-Fi based system can be used in order to locate mobile devices, whereas an RFID based system can locate tagged users.

In this paper, we describe how the Pervasive Computing technologies can be used to build a Smart Hospital. In particular, we propose a concrete implementation of a Smart Hospital and discuss how e-Health services and applications can be enhanced by location information.

As a solution, we propose a unique and unambiguous model to represent location information and integrate different positioning systems. This model integrates two specific positioning systems, respectively based on Wi-Fi and RFID technologies.

Moreover, we present a Semantic Location System that exploits the inter-working of several positioning systems utilizing Semantic Web technologies to localize mobile entities in Smart Hospitals. This system performs logic and reasoning mechanisms in order to generate semantic information from physical positions, ii) to give the location information with the finest granularity when a mobile object is located by more than one positioning system, iii) to resolve inconsistencies or conflicts due to sensing errors or limitations of the positioning systems.

The rest of the paper is organized as follows. Section 2 discusses the target scenario. Section 3 highlights our contributions and addresses related work. Section 4 overviews a proposal of location model for a Smart Hospital. Section 5 describes the localization system and outlines the implementation details. Finally, section 6 concludes the paper.

## II. THE TARGET SCENARIO

In this section, we present the application scenario of a Smart Hospital whose layout is depicted in figure 1.

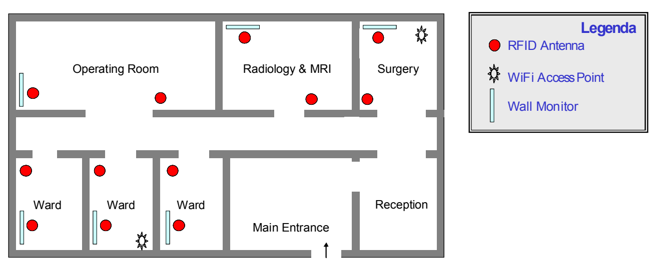


Figure 1. Hospital layout

Hospital consists of the following physical environments:

*Reception* – This is the place where the patient is accepted for hospitalization. Here a desk operator (Receptionist) registers the patient (i.e., a new Electronic Heath Record is created and the patient is given a bracelet with a RFID tag associated to an unique ID code). This room is equipped with desktop PCs for accessing system functionalities;

*Wards* – These are rooms where patients reside. Each ward is equipped with RFID readers and a wall monitor. Wi-Fi connection is also available;

*Operation room* – This is the room where surgeons operate. It is equipped with RFID readers along with a wall monitor for displaying Electronic Health Records;

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*Radiology & MRI* – This is the room where X-Ray images are produced. It is equipped with RFID readers and a wall monitor for displaying Electronic Health Records. Wi-Fi connection is available;

*Surgery* – This is the room where doctors perform specific check ups. This is equipped with a RFID readers and a wall monitor for showing Electronic Health Records. Wi-Fi connection is available.

In the following, some possible use cases are reported:

*Use Case 1* - whenever a patient is located within the Radiology, the system automatically retrieves X-Ray pictures and visualizes them through the wall monitor;

*Use Case 2* - as a patient enters the surgery, the system automatically retrieves and shows his/her Electronic Health Record through the wall monitor;

*Use Case 3* - when a doctor enters a ward with his/her tablet PC, the system automatically retrieves the patient Electronic Heath Record and shows it on the doctor's device. After that, if the doctor approaches the wall monitor, the system automatically re-direct its output on the wall monitor for a better resolution;

*Use Case 4* - when a doctor and a patient are both located in the surgery, the system automatically retrieves and shows the patient Electronic Heath Record either on the doctor's tablet PC or on the wall monitor depending on the doctor position within the surgery, similarly to US3. However, although the doctor is located in front of the wall monitor, if another patient enters the surgery, the system automatically re-direct the output on the doctor's tablet PC for privacy reasons.

These use cases highlight the need of different localization capabilities: as a result, a Smart Hospital should be equipped with a multitude of different positioning systems capable of detecting presence and proximity of people and mobile devices. The following open issues can be pointed out.

First, each positioning system provides location information in a specific format, but such an information is useless for the environment because it doesn't carry any semantic content. As a matter of fact, the environment doesn't care the AP a mobile device is connected to; on the contrary, the environment should be notified about which wall monitor the user and his device are in front of.

Second, conflicting location information can come from different positioning systems. Indeed, because different positioning systems can overlap each other in some areas, it might happen that more positioning systems locate the same mobile object (Es. a laptop equipped with Wi-Fi is located by two Wi-Fi APs in an overlapping region).

Third, incorrect location information can come from different positioning systems due to sensing errors. It night happen that a same user is located in two places that are disconnected from each other during the same time interval. (Es. An RFID tagged user moves bringing with him his Wi-Fi enabled PDA. The user is located by an RFID reader and a Wi-Fi AP in two different locations not related among them.).

Fourth, it is unthinkable that: i) application services (that need location information) deal with many and different positioning systems and their low-level protocols; ii) application services handle all specific representations, defined and used by different positioning systems and convert location information from each specific representation to an internal one; iii) application services are in charge of obtaining semantic location (which room, which wall monitor, etc.) from the ones provided by positioning systems (which access point the device is connected to, which RFID reader has identified the user, etc.) and resolving inconsistent location information.

## III. Contributions and Related Work

### A. Contributions

This paper proposes semantic models, mechanisms and services to make Smart Environments able i) to locate mobile objects by using diverse types of positioning systems and localization techniques; ii) to integrate location information characterized by a specific format and granularity; and iii) to infer better location information or to resolve inconsistencies by applying reasoning mechanisms. In detail, this paper provides the following contributions.

*Semantic integration of different positioning systems* - The location service exploits the inter-working of more than one positioning system hiding the format of location information coming from different positioning systems and granting both syntactic and semantic interoperability between services and positioning systems.

*Definition of a location model* - A specific location model has been defined in order to provide a unique and uniform representation for location information, independently of the particular positioning system and to represent both physical and semantic location.

*Logic and reasoning mechanisms* - We have also defined and built logic and reasoning mechanisms that enable the location service i) to generate semantic information from physical positions, ii) to give the location information with the finest granularity when a mobile object is located by more than one positioning system, iii) to resolve inconsistencies or conflicts due to sensing errors or to functional limits of the used positioning systems.

### B. Related Work

In the last few years the pervasive healthcare literature has not diffusely addressed either Smart Hospitals or the localization issues for these environments: indeed, a relatively poor systems-oriented research has been developed.

In [4] authors propose a Smart Hospital that uses this RFID identification technology to improve the patients' care, optimize the workflows, reduce the operating costs, help avoiding severe mistakes and reduce costly thefts. In particular, they realize an enterprise application for tracking entities within a predefined area, such as a building. This work contributes to Smart Hospital research highlighting different features, but, the proposed localization approach doesn't handle the inter-working of multiple positioning techniques and doesn't organize and represent location information in a formal structured model.

Differently, in the pervasive computing literature, a number of systems can be described by the term location-aware and in particular the approaches adopted in [6,7] are illustrated below.

In [7] the author presents a flexible platform for location-based services, which hides specific details of positioning systems and provides a uniform representation of both physical and semantic information. The corresponding infrastructure reflects a location domain model, which defines a semantic structure of the entire location space. This structure is composed of hierarchies that are built up of domains and logical links between domains. A domain represents a semantic location, whereas a link is the expression of a semantic relation between locations.

Differently, our approach relies on the Semantic Web technologies, and so it grants both the syntactic as well as the semantic interoperability between services and the positioning systems. Besides, the platform proposed in [7] doesn't provide a support for location reasoning, that is no logic mechanisms have been realized for obtaining semantic locations from physical ones or for determining the location information with the finest granularity when a mobile object is located by more than one positioning system.

CoBrA [6] is an architecture to support context-aware services in smart spaces. It locates mobile entities by using two types of positioning systems, respectively based on RFID and Bluetooth technologies. Besides, a set of ontologies has been defined for modeling context information. Semantic Web languages are used for representing them and for supporting context reasoning.

Nevertheless, CoBrA doesn't aim at realizing a semantic integration of different types of positioning technologies. As a result, the context ontologies don't model the location information coming from positioning systems but provide only a uniform and well-defined representation for the semantic locations which can characterize an environment. This choice is purely based on the type of context-aware applications to be supported in prototyping CoBrA.

## IV. THE SEMANTIC APPROACH

### A. *The location model*

The approach presented in this paper relies on a location model we have defined to provide a unique and uniform representation for location information, independently of the specific positioning system.

The model is based on the concepts of physical and semantic locations. These notions are not new in literature [5], but we have partially re-elaborated them. A physical location specifies the position of a mobile entity and it is characterized by different granularities and scopes, depending on the particular positioning system. Instead, a semantic location specifies the meaning of a location and usually groups more physical locations. As an example, GPS coordinates represent physical locations, whereas a semantic location can be a building, an office inside a building, a meeting room, an area in front of a wall-monitor and so on.

The proposed model describes physical locations as the proximity to well-known points. The technique of proximity is applicable when the environment is equipped with sensors to reveal mobile users presence, or with positioning systems to detect mobile devices position. In such cases, a sensor/positioning device, which covers a specific area, defines a physical location corresponding with the covered area. In the model, the covered area is called SensedArea.

We have adopted two specific positioning systems. The former relies on Wi-Fi technologies to locate Wi-Fi enabled mobile devices. The latter uses RFID identification systems to locate RFID tagged mobile users. Corresponding sensed areas are:

- WiFiSensedArea, which is identified by the physical area covered by a specific wireless Access Point (AP), i.e. the region in which the Access Point is able to grant access to a Wi-Fi mobile device;
- RFIDSensedArea, which is identified by the physical area covered by a specific RFID reader; i.e., the region in which the RFID reader is able to detect an RFID tagged user

In addition to these, a set of semantic locations, like Building, Floor, Room and Corridor, have been defined.

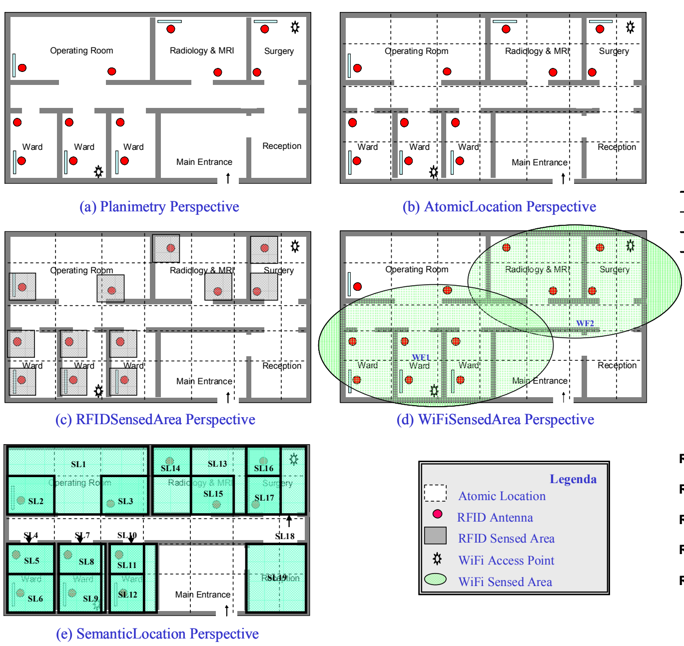



Figure 2. Representation of the location model

Finally, it has been defined the concept of AtomicLocation, which represents the linking element between physical and semantic locations. Its physical dimension corresponds with the one of the SensedArea of the finest positioning system in the environment. In the proposed example, an AtomicLocation corresponds with an RFIDSendedArea because an RFID reader covers a smaller area than the one covered by a WiFi access point.

As shown in figure 2, the concept of AtomicLocation is used to build a grid of locations in the physical environment (AtomicLocation Perspective). Therefore, some RFID readers are positioned in order to match with AtomicLocations. Not all the AtomicLocations are covered by an RFIDReader (RFIDSensed Perspective). Differently, each WiFi Access Point spreads signal over many AtomicLocations (WiFiSensedArea Perspective). Finally, semantic locations in turn group many AtomicLocations and correspond with well defined physical spaces (SemanticLocation Perspective).

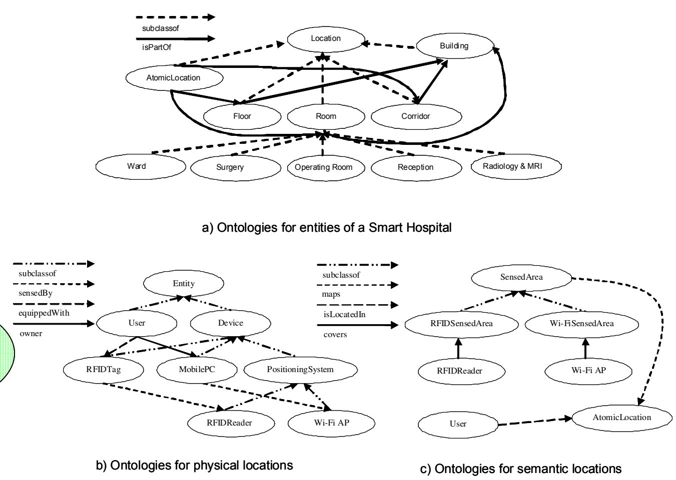
As a result, relationships between SensedAreas and SemanticLocations are built by means of AtomicLocations. This makes the model able to easily adapt to changes like introduction of new positioning systems or definition of new semantic locations.

### B. *Ontology and rules for the location model*

The location model defines location information in a unique and uniform way, but these information must be represented in a well-defined and unambiguous formalism and expressed in a machine-readable format. Besides, it has to provide a support to grant both the syntactic and the semantic interoperability between the environment and positioning systems.

Semantic Web technologies, which have been widely applied in many areas, can be used to face such needs because: i) ontologies and rules respectively enable the definition of domain vocabularies and allow declarative data processing, by providing a way to share knowledge without misunderstandings; ii) RDF, SWRL and OWL are semantic representation languages with high degree of expressiveness; iii) ontologies and rules can be reasoned by logic inference engines.

Ontologies and some rules that we have defined are shown in figure 3.




**Rule 1:** *IF (sensedBy(entity, RFID reader) AND covers(RFID reader,RFID SensedArea) AND maps(RFID SensedArea, AtomicLocation)) THEN isLocatedIn(entity,AtomicLocation)*
**Rule 2:** *IF (sensedBy(entity,Wi-Fi AP) AND notSensedBy(entity,RFID reader) AND covers(Wi-Fi AP, Wi-Fi AP SensedArea) AND maps(Wi-Fi AP Sensed Area, AtomicLocation) THEN isLocatedIn(entity,AtomicLocation)*
**Rule 3:** *IF (isLocatedIn(entity,AtomicLocation) AND isPartOf(AtomicLocation, SemanticLocation)) THEN isLocatedIn(entity,SemanticLocation)*
**Rule 4**: *IF (sensedBy(entity,Wi-Fi AP1) AND sensedBy(entity,Wi-Fi AP2) AND isNotEqual (Wi-Fi AP1, Wi-Fi AP2) AND sensedBy(entity, RFID reader) ) THEN sensedBy(entity, RFID reader)*
**Rule 5**: *IF (sensedBy(entity, RFID reader) AND covers(RFID reader,RFID SensedArea) AND maps(RFID SensedArea, AtomicLocation1) AND sensedBy(entity,Wi-Fi AP) AND covers(Wi-Fi AP, Wi-Fi AP SensedArea) AND maps(Wi-Fi AP Sensed Area, AtomicLocation2) AND isPartOf(AtomicLocation1,SemanticLocation1) AND isPartOf(AtomicLocation2,SemanticLocation2) AND isNotEqual(SemanticcLocation1, SemanticLocation2) ) THEN isLocatedIn(entity,SemanticLocation1)*
**Rule 6**: *IF (isLocatedIn(entity,AtomicLocation) AND isLocatedIn(device,AtomicLocation) ) THEN isNear(entity,device)*

d) Some example rules

Figure 3. Ontologies and rules for the location model

These ontologies identify all the concepts utilized to represent the entities participating the Smart Hospital and either physical or semantic locations.

Ontologies and rules have been used to perform location inferences. Let us consider the scenario described in the Use Case 1. As a patient enters the Radiology, information sensed by the RFID reader placed in the room are used by rule 1 to conclude that the patient is located in an atomic location. Because we have an ontology representing the relations existing among atomic and semantic locations, rule 3 enables to conclude that the patient is located in a semantic location, that is the Radiology.

Besides, if a patient is located by two Wi-Fi APs, it means that he is placed in an overlapping region existing among them and so we have two location information that conflict. This is due to the hand-off mechanism of disconnection of the Wi-Fi systems. In this case, if the patient is also located by an RFID reader, we can exploit this location information to outcome the Wi-Fi disconnection problem, resolve the conflict and identify soundly the location of the patient. Hence, in such a case, rule 4 enables to assume that the location of the patient is the one sensed by the RFID reader.

Moreover, reasoning about ontologies and rules can help to detect if there is any inconsistency about a user's location. Imagine that, due to sensing errors, a Wi-Fi AP detects the presence of a patient in the Surgery and a RFID reader informs that the patient is in the Radiology. Since the patient is known to be located in two semantic locations, and no person can be physically present at more than one semantic location during the same time interval, it is possible, by using the rule 5, to conclude that these location information are inconsistent. In this case, we consider more reliable the information produced by the RFID positioning system rather than the one produced by the Wi-Fi positioning system. So, we will conclude that the location of the patient will be the one sensed by the RFID reader.

Finally, let us consider this scenario described in the Use Case 3. If a doctor enters a ward and he is located by a Wi-Fi AP, rule 2 allows to conclude only his semantic location, but we don't know if he is in proximity of the wall monitor or not. If the doctor is both located by an RFID reader and a Wi-Fi AP, we can use the location information with the finest granularity. So, we can conclude, by using both the rules 1 and 2, that the doctor is located in the atomic location associated to the sensed area covered by that RFID reader. From this information and the atomic location in which the wall monitor is placed we conclude, by using rule 6, if the doctor is near the wall monitor or not. If the doctor is approaching the wall monitor, a patient Electronic Heath Record will show on the wall monitor for a better resolution.

## V. The Semantic Localization System

Current implementation of the Semantic Localization system provides both location and locating functions. A location function is a mechanism to identify objects active at a specific physical location, whereas a locating function is a mechanism to identify the location of specific objects [1].

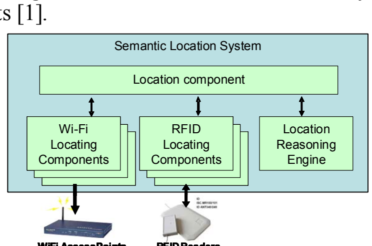



Figure 4. The Semantic Localization System architecture

Currently, we have developed two locating components that identify the location of mobile objects by using respectively the Wi-Fi and RFID based positioning systems. New locating components for other positioning technologies, such as the Bluetooth technology, can be realized and easily integrated in the service.

The Wi-Fi Locating Component is in charge of locating Wi-Fi enabled mobile devices, by periodically interrogating Wi-Fi APs. Indeed, each AP writes an event into a log file whenever a device becomes active into its area. By comparing such logs and by handling global states, it is possible to detect location changes. A similar approach has been realized in [2]. This technique can not be used to recognize when a device becomes inactive, because hand-offs are not reported in the log file. It has been adopted a strategy based on heartbeats to detect device disconnections. Current implementation uses 3Com Office Connect Wireless 11g Access Point.

The RFID Locating Component is in charge of locating RFID tagged entities, by periodically interrogating RFID readers. When an entity is sensed by a reader, we can conclude that it is located in the atomic location covered by that reader. A similar approach has been described in [3]. Current implementation uses the passive, short-range (30 cm), Feig Electronic RFID, model ISC.MR 100/101.

The Location Component is in charge of handling global location states obtained by combining information coming from Locating components.

The Location Reasoning Engine is the core-component of the Semantic Location System and it is in charge of managing the location OWL ontologies and SWRL rules. First of all, it deals with location ontologies and rules to specify location information in a uniform representation. As a result, it is able to grant both the syntactic as well as the semantic interoperability between the environment and any positioning system. Therefore, it integrates and combines location ontologies and rules in order to perform reasoning mechanisms about the location information in a complete and sound way.

## VI. Conclusions and Future Work

In this paper we presented a Semantic Location service that locates active mobile objects, such as Wi-Fi enabled devices and RFID tagged entities, in Smart and Intelligent environments. The key feature of the service is the use of ontologies and rules i) to define a uniform, unambiguous and well-defined model for the location information, independently of the particular positioning system; ii) to perform logic and reasoning mechanisms to provide physical and semantic locations of mobile objects and to give the location information with the finest granularity when a mobile object is located by more than one positioning system. This facility provides the environment with support for customizing services depending on the user location, as well as enabling mobile users to get access.

Future work will aim to realize locating component for integrating new positioning technologies, such as Bluetooth. As a result, the location model will be extended by defining the concepts related to these new positioning systems, and in particular the new types of physical locations provided by them.

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