Retrieving Position From Indoor WLANs Through GWLC

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Abstract

Enabling context-aware applications requires the incorporation of users' and objects' location. Retrieving location data has been a field of on going research for both the outdoor and indoor wireless/mobile systems. The results in the cellular scenario are already matured and location architectures have been standardized. The cellular-based positioning mechanisms have similarities with the wireless LAN mechanisms, but are not appropriate to be operated in indoor scenarios. Resent research is ongoing for indoor positioning mechanisms, resulting in implementations that vary in several factors and offer specialised APIs. A platform that enables the deployment of Location Based Services in heterogeneous WLAN-based positioning systems will address difficulties cooperating with different systems. We have designed a novel entity, called Gateway WLAN Location Center (GWLC), which hides the heterogeneous functions of the indoor positioning architectures, illustrating a unified framework for retrieving location data of users and objects. The article discusses and categorises the different positioning architectures, it elaborates on the design principles, and the functionality of the GWLC platform. The GWLC platform is designed to meet objectives such as modularity, scalability, extensibility, portability, and to facilitate open interfaces.

I. Introduction

During the last years, cellular operators, service and content providers, and software developers have been trying to identify the needs of a fully connected user, facilitating pervasiveness communications and ubiquitous computing concepts. One of the most promising directions seems to be the context-aware applications. These applications are based on the contextual information of a mobile or nomadic user and they can lead to highly customized personal communications. The location of a user is thought to be the most important attribute of the contextual information. Thus it is expected that the services provided to the users, which are based on his location, will exhibit high market penetration, worldwide. Examples of Location Based Services (LBS) are:

- Emergency services as defined by the E911 and the E112 recommendations in North America and EC countries, respectively
- Point of Interest (POIs) such as find location and proximity services
- Navigation and routing
- Geocoding and reverse Geocoding

In order to support such services, operators that offer cellular access and organizations that offer wireless access have to use location-tracking mechanisms and to deploy specialized platforms, which will execute the service logic and provide the user with the required service. Until now, these platforms were highly customized for specific applications, and as a result the application deployment has been evolving at a slow pace. In order to accelerate the deployment of new services, the network operators have decided to open their networks borders to application developers and service providers through well-defined Application Programming Interfaces (APIs). One of the most accepted APIs standard is the Open System Architecture/Parlay (OSA/Parlay) [1]. Applications and service providers that reside outside of the core network infrastructure can take advantage of the OSA/Parlay gateways in order to have access and use the required service elements from the underlying network. As far as LBS applications and services concerns, the 3rd Generation Partnership Project (3GPP) has specified a standard configuration of location services entities in a GSM/GPRS and UMTS Public Land Mobile Network (PLMN) [2]. To support LBS services the 3GPP initiative has defined the Gateway Mobile Location Center (GMLC) [2]. GMLC is the node that an external location application accesses in the PLMN in order to gather location coordinates. Although introduction of the OSA APIs and the facilitation of specialized gateways are key steps to accelerate LBS applications' deployment, the current solution for providing them is still closely bound to each application's semantics. The Information Society Technologies (IST) project PoLoS intends to specify, deploy and demonstrate a middleware platform that will cater for the provisioning and the delivery of LBS services in a uniformly fashion [3]. For providing LBS services the PoLoS platform incorporates a Positioning Component (POS) generic enough to communicate with differentiated types of network infrastructures and to retrieve the location information of the required user [4]. The POS component inter-operates with different types of networks, such as cellular (e.g., GSM, UMTS), wireless LANs (e.g., IEEE 802.11), Bluetooth and others. In the case of cellular networks the entity responsible for retrieving the position of a user is the standardized GMLC. On the other hand, in the case of the WLAN networks, which will be operated by public hot-spot providers or private organizations, there is no standardization process for the methods and the mechanisms to obtain the location of a nomadic user. However, during the last years there has been ongoing research for such mechanisms and methods, whilst indoor positioning prototypes and commercial products have been made available. The major disadvantage of such mechanisms and implementations is that they require specific hardware and/or software to be deployed. To provide a platform that hides the different location tracking methodologies and architectures of the WLAN scenario, we propose a novel platform, the Gateway WLAN Location Center (GWLC). GWLC integrates different positioning methodologies and architectures, giving to middleware entities, such as the POLOS platform, capabilities to obtain users', assets' and objects' location without taking into account positioning methods and architectures. Beyond any convergence of the location tracking methods, the GWLC incorporates service discovery techniques. This feature is essential to indoor nomadic users, providing the means to exploit services that are offered, to configure end-devices automatically and to register on LBS applications with the minimum human intervention.

This article describes our ongoing research for the design and the implementation of the GWLC entity, and is structured as follows. In Section II we discuss the different mechanisms used for positioning in indoor environments, which are already in use as prototypes-products or they are under research. We provide a brief categorization of these location schemes, which will reveal the need for a unified integration and accessing these mechanisms from a uniform platform. Section III introduces the features of the GWLC entity, and Section IV identifies the design objectives. The architecture of the novel GWLC entity and its modular design is presented in Section V. The services publish and automatic configuration capabilities of the GWLC platform are illustrated in Section VI. Finally we summarize on the advantages and possible enhancements that might be applied to the GWLC functionality.

II. Positioning Technologies In Indoor Wireless Networks

During the last years, considerable research effort has been elaborated for the development of techniques that estimate the position of an object that is either semi-static (e.g. a printer that may change sparely position) or is moving within an indoor area (e.g. a laptop user). Indoor premises have the disadvantage of absorbing and diffusing the radio waves of systems like GSM and UMTS. This introduces difficulties to use cellular systems' positioning mechanisms (i.e., Time Of Arrival, Observed Time Reference, Angle Of Arrival, etc.) to provide the location of a user inside buildings. In the cases that this might be possible, the provided accuracy is of the magnitude of tenths of meters, which is not useful for the applications envisioned to be deployed for the indoor scenario. A necessity exists for positioning mechanisms that will provide the accuracy required by the context-aware applications that will be deployed in indoor premises.

The positioning techniques are based on sophisticated mathematics and physics to "sense" the location of an object. There are three main techniques that can be used to provide this information: **triangulation**, **scene analysis** and **proximity** [5]. These techniques can be used either on their own or jointly. The latter case can further enhance the accuracy and precision of the positioning method.

Triangulation is a technique that uses the geometric properties of triangles to compute objects location. There are two triangulation approaches:

- **Lateration** measures the distance from a number of multiple reference points. Measurements are through:
  1. **Time of flight** measures the time that takes for an emitted signal to be reflected by the located object.
  2. **Attenuation** measures the emitted signal's decrease as the object's distance from the transmitter increases.
- **Angulation** uses angles measurements for determining the position of an object.

The scene analysis technique uses features of a scene observed by a reference point in order to draw conclusions about the location of the observer or of objects in the scene. It usually requires a database of signal measurements that is used from the positioning system for location estimation.

Finally, proximity, determines when an object is "near" a known location. The object's presence is sensed using a physical phenomenon with limited range. Proximity sensing can be done through:

- **Physical contact** through pressure sensors, touch sensors and capacitive field detectors.
- **Monitoring** wireless cellular access points for determining when an object is in their range.
- **Observing** automatic ID systems, through the proximity of systems like credit card point-of-sales terminals, computer login histories, landline telephone records, etc., which can be used to infer the location of a mobile object.

The information concerning the location of an object that these systems return can be either **physical** or **symbolic**. Physical location is expressed as a mathematic magnitude, like for example our building is positioned at $38^0 14'49"$N by $23^0 31'94"$W, at a 10.5-meter elevation. The symbolic position information encompasses abstract ideas for the position of an object, e.g. in the office, in Athens. Another classification of the location information supported by the positioning systems is whether this information is **absolute** or **relative**. Absolute information is depicted on a shared grid or on a geographic coordinates system for all the located systems. This information for a located object is the same and unique for all the observers that are using the same grid or coordinates systems. Unlike, the relative position information, represents the position of a located object in reference to the observer and thus it is not unique and definitely not the same for all the possible observers.

Positioning systems can be divided in two primary categories. The first category includes the systems that use a specialized infrastructure, apart from the one that is used for wireless data communication purposes. This infrastructure is specifically deployed to provide location information. The second category includes the systems that are relying in the wireless communication network to infer the position of a served object (e.g., laptop, PDA).

First category includes systems like:

- Active Badge, a proximity system that uses infrared emissions emitted by small infrared badges, carried by objects of interest. A centralised server receives the emitted signals and provides the location information [5], [6].
- Active Bat system resembles the Active Badge using an ultrasound time-of-flight lateration technique for higher accuracy [5], [6].
- MIT's Cricket system relies on beacons, which transmit a RF signal and an ultrasound wave, and on receivers attached to the objects. A receiver estimates its position by listening to the emissions of the beacons and finding out the nearest one [7].
- SpotON is a location technology based on measuring RF signal strength emitted by RF tags on the objects of interest and perceived by RF Base Stations [8].
- Pseudolites are devices emulating the operation of the GPS satellites constellation, and positioned inside buildings [9].
- Pin Point 3D-iD is a commercial system that uses the time-of-flight lateration technique for RF signals emitted and received by proprietary hardware [10].
- MSR Easy Living uses computer vision to recognize and locate the objects in a 3D environment [6].
- MotionStar Magnetic Tracker incorporates electromagnetic sensing techniques to provide position-tracking [6].
- Smart Floor utilizes pressure sensors to capture footfalls in order to track the position of pedestrians [6].

Systems of the second category are, among others:

- MSR RADAR system, which uses both scene analysis and triangulation based on the received signal's attenuation [11].
- Nibble uses scene analysis to estimate the location of the user that requires location information and it provides to him/her symbolic and absolute positioning information [12], [13].
- Ekahau's Positioning Engine is a commercial product that combines Bayesian networks, stochastic complexity and on-line competitive learning, to provide through a central location server, its clients with positioning information [14].

The main advantage of the methods of the first category is the high accuracy that they support when estimating the position of an object. However, the disadvantage is that it requires additional equipment to be carried by the located object, which although, in most cases is small and economic, doesn't help in the user-friendliness envisioned for these systems. Moreover, a main drawback is associated with the deployment costs and the operation-maintenance of a second location-specific infrastructure that runs in parallel to the wireless data communication infrastructure. The GWLC platform integrates representative systems of the second category, although, as it will be shown in Section V, any location mechanism can be easily added to the platform.

III. Introducing GWLC

To provide a unified framework for the indoor location issue, facilitating a pervasive concept to the context-aware paradigm, it is essential to integrate the different location systems to a generic platform. Such an innovative platform will hide the heterogeneity of the indoor location systems. For these reasons, we have designed a novel framework, which provides positioning of objects to LBS applications, transparently of the different indoor positioning mechanisms. The idea resembles the architecture that has been standardized for cellular systems. For these systems the ETSI (European Telecommunications Standard Institute) and the 3GPP specifications define a gateway entity, the GMLC, which exists within the PLMN of the network operator. The GMLC entity is responsible to provide the location information of subscribers that have been registered to the PLMN network and have decided to permit their location tracking. Following the recent trend for open telecommunication infrastructures, the GMLC can be accessed through a standardized OSA/Parlay API interface, which permits to an application or service that is running outside the PLMN to request predefined types of location positioning functions. The Request-Response (RR) type of function is the simplest; the GMLC entity returns to the requesting application or service the current position of a user. The Periodic Request (PR) type of function registers a request to the GMLC entity for periodic forwarding of the position of a user to the requesting application. The Event-driven Request (ER) registers a request to the GMLC, which replies with a signal indicating that a subscriber is entering to or departing from a predefined geographical area. These types of functions are incorporated with additional attributes, such as accuracy, time to respond, priority, and reliability.

The GMLC standardized functional features are used as a basis for the design objectives of the novel GWLC entity. As in the GMLC case, the designed GWLC entity receives and manipulates the location requests arrived from external to WLAN clients, such as third-party applications, and service providers. The GWLC entity will provide the location information of WLAN nomadic users that have been registered to the WLAN network and have decided to permit their location tracking. We also envisioned an OSA-based interface between the external clients (LBS platforms), such as the POLOS platform, and the GWLC entity. In **Figure 1** we depict the proposed architecture of the entities that should cooperate with the GWLC to provide indoor WLAN-based location tracking. As an external client we illustrate the PoLoS platform paradigm. Other external clients that might be considered include, among others, content providers, GIS providers, application providers, and commercial companies.

IV. GWLC Design Objectives

The design of the GWLC platform is based on a modular, object oriented, approach. The development is based on state-of-the-art tools, which are provided by the various Java^{TM} frameworks, and especially the Java^{TM} 2 Enterprise Edition (J2EE) [15], [16]. The GWLC platform was designed to fulfil:

- **Modularity**: GWLC adopts a fully modular architecture (see Section V) where its components have a discrete, and well-defined functionality.
- **Extensibility** that stems out from the modular design, which allows new location mechanisms to be integrated easily to the platform. Moreover this allows the addition of mission-oriented components in future releases, such as Customer Records' objects.

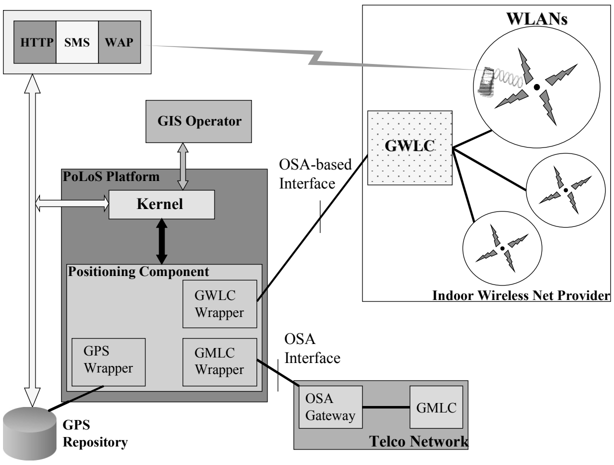

Figure 1: Configuration of GWLC in PoLoS context**.**

- **Scalability**, as far as the number of concurrent sessions that can be supported by the platform.
- **Efficiency** by integrating load-balancing mechanisms and the clustering capabilities (e.g. server farm) as provided by the J2EE framework.
- **Independency** from the underlying networking systems that are used for providing indoor location, the various positioning techniques, and the terminal capabilities of user's equipment.
- **Portability** between contexts illustrating different characteristics and architectures (e.g. Windows, Linux), due to the use of the Java^{TM} language.
- **Openness** since all the interfaces between the GWLC and the LBS platforms that will be its clients are based on open standards such as the OSA API and the Location Interoperability Forum's (LIF) Mobile Location Protocol (MLP) [17].
- **QoS orientation** through the incorporation of Quality of Service (QoS) techniques, at the scheduling of requests level and at the selection of the appropriate location system.
- **Reliability,** taking advance of the clustering characteristics of the J2EE framework.

The QoS capabilities and the management interface, are to be further elaborated in conjunction to the authentication and security mechanisms, which will be based on the Java^{TM} Authentication and Authorization Service (JAAS) framework [18].

V. GWLC Architecture

Figure 2 illustrates the architecture of the GWLC platform. In this Section we describe details of each component of the architecture.

A. Communication Interfaces

In order for the GWLC platform to receive requests and to send the results to the requesting clients (e.g. PoLoS platform), we use open and standardized communication interfaces like the OSA/Parlay's API and the LIF's MLP protocol. However, a proprietary legacy interface can be easily integrated as a subsystem in the GWLC platform.

B. Dispatcher

Dispatcher's task is to receive the requests from the Communication Interfaces, and to parse them, in order to determine the semantic and syntactic correctness. It assigns a unique identifier to each incoming request, which is used throughout the GWLC platform. It determines the scheduler's queue that should forward each incoming request, based on the attributes that are associated with it. In the opposite direction, the Dispatcher retrieves the location information from the Kernel, and forwards this information to the appropriate Communication Interface module for respond formulation. The Dispatcher maintains a table that associates pending requests identifications and the Communication Interfaces that these requests originated.
Dispatcher is the first module where authentication and access restrictions are taken under consideration upon reception of a service request.

C. Requests Schedulers

Each type of request (i.e., RR, ER, PR) is processed by a discrete scheduler, which is responsible to handle priority queues, and to schedule the requests based on their QoS constraints. The scheduled requests are forwarded to the Kernel of the platform. The RR scheduler's discipline is FIFO for the current release of the platform, but future direction might impose more sophisticated disciplines, such as WFQ [19], based on priority levels that are introduced by the external clients, or on time to response laxities. The ER and PR Schedulers use timers to trigger the scheduling of the events, according to the requested periodicity. They have similar design but the ER Scheduler can incorporate advanced characteristics that will prevent the platform from flooding the underlying WLANs with location requests. In future releases, the ER Scheduler will be able to back-off periodic positioning requests for a user that illustrates low mobility.

D. Router and Capabilities Broker

The Router and Capabilities Broker entity determines the positioning mechanism and system that is appropriate to serve a location request. GWLC might be deployed in an environment where various types of positioning technologies and architectures might coexist (e.g., the Nibble and the Ekahau's systems might coexist on a WLAN infrastructure), offering different type of service, in terms of accuracy, precision, reliability, time to respond and first time to fix. To determine the appropriate Positioning Module, the Router and Capability Broker is based on the users' terminal equipment, as well. Moreover semantics such as **localized location computation**, the **ability to identify** the objects (i.e., unique identifications), the **coverage** of the geographical area and the **cost** of the positioning processing are taken under consideration [5]. Furthermore, as indicated in Section II, some systems support physical coordinates, whilst other might provide symbolic locations. The Router and Capability Broker, based on the location requests' arguments and attributes, identifies the appropriate location system to handle the incoming request, and passes this information to the Kernel.

E. Users DB

This database stores the information that is relative to the registered users of the platform. Each user is assigned a unique identifier at the time of registration. Users are classified as occasional (e.g., visitors) or permanent users (e.g., working stuff). Users' DB records are valuable for accounting and charging purposes, including post and pre-paid options.

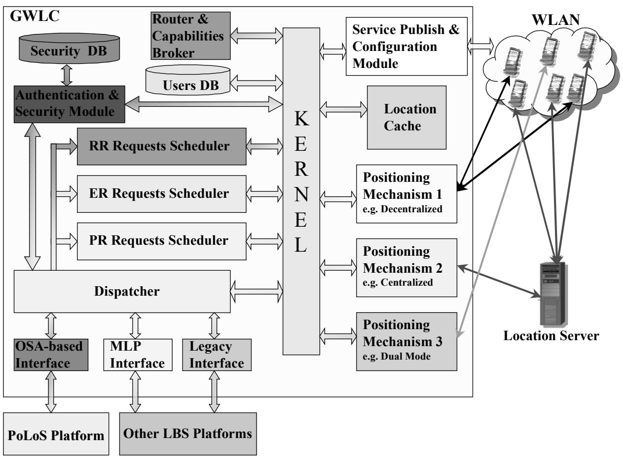

Figure 2: GWLC Platform's Architectural Layout.

F. Service Publish and Configuration Module

This module advertises the location services that are offered. It manipulates the service discovery and the service configuration for end users, which is performed transparently and with the minimum human intervention. We further describe the used mechanisms of this module at Section VI.

G. Authentication and Security module

The authentication and the security policies that apply to the GWLC platform are enforced from this module. It uses the JAAS security framework, and it provides authentication and security services to the other modules of the platform [18].

H. Security Database

This database holds all the required information that enables the Authentication and Security module to enforce the security policy for the GWLC platform. Typical records of this database include access permission rights, authentication tokens and lists of permitted operations and services for each user (permanent or occasional).

I. Location Cache

To minimize location-signalling overheads and to avoid power consumption phenomena of wireless terminals we have introduced a Location Cache that keeps the location information of the recently tracked users and objects. Moreover, several WLAN-based location systems, such as the Nibble, introduce a predefined refresh period, which imposes lower bounds on the "time to respond" requirement. Storing location data in the Cash, the GWLC platform avoids the "time to respond" limitations, introducing different levels of responds thresholds that are applicable to location request that require fast position resolution with medium location accuracy.

J. Positioning Mechanisms

Each Position Mechanism resides in a discrete module. Since there can be more than one positioning systems and mechanisms available at the same time, the GWLC platform incorporates the logic to decide which one of the candidates fits better for processing the request. The platform supports the integration of WLAN-based location mechanisms and systems of different type. Positioning mechanisms are classified as centralized (e.g. Ekahau's Positioning Engine), decentralized, (e.g., Nibble) and dual-mode (e.g., MSR Radar). Modules that implement other positioning mechanisms can be integrated to the platform, enhancing its capabilities and providing a generic functionality to different LBS semantics.

K. Kernel

The Kernel is the centric entity of the GWLC platform. It incorporates all the logic that is required to orchestrate the other components. Kernel receives requests for service execution from the Schedulers. It is the only module that is permitted to re-insert a request in Schedulers' queues or to delete a PR or ER request from the corresponding queues when a message to stop the periodic and event-driven reports arrives. It activates the appropriate Positioning Module for servicing a request, based on information obtained from the Router. Finally, upon receiving the position data of a user or object from a Positioning Module, it forwards them to the Dispatcher, in order to be returned to the LBS platform that issued the corresponding request.

VI. Service Discovery and Configuration

A success factor for a platform such as the GWLC concerns its ability to publish the services that it offers, the convenience to be discovered by end-users, as well as the incorporation of mechanisms that dynamically configure end-user's terminal equipments. The Service Publish and Configuration module, that is included in the GWLC design, advertises the services that are offered to end-users. The service advertisement mechanism could be based on the Jini framework provided by the Java™ language [20]. Every user that enters the WLAN area supported by the GWLC gets a message that advertises the existence of positioning capabilities within the WLAN domain. The user has the choice to register in GWLC, enabling his/her tracking or to decline this opportunity. Other candidate systems to carry out the service advertisement process include the Service Location Protocol (SLP) and the Universal Plug and Play (UPnP) protocol [21], [22]. An important aspect of the GWLC is the effortless reconfiguration of the end-users' equipment, performed in an automatic and transparent fashion by the Service Publish and Configuration module. This module integrates mechanisms, like Mobile Execution Environment (MExE), that retrieve information for the terminal equipment capabilities [23]. Service configuration module forwards the required and compatible to terminal's platform configuration files of the location system (e.g., Nibble client software), as well as application files. In this way, any required file can be pushed to end terminals, and the positioning mechanisms can be executed in a centralized or a decentralized fashion, without requiring extra effort. The Service Discovery and Configuration module is at this moment under further research.

VII. Conclusions

The GWLC platform is an innovative brokering entity that provides a unified interface and a generic mean to access the positioning services that are offered by wireless location tracking systems. The GWLC hides the heterogeneous and complexities of the various WLAN-based location architectures, whilst integrates different positioning systems already in the market or under prototype development. In this paper we have described the design objectives, the architecture, the functional characteristics and the services that the GWLC offers to external middleware platforms, location information clients and providers. The GWLC platform is based on state-of-the-art software tools and is developed on a modular fashion that adds portability, flexibility, and scalability. Using standardized interfaces (OSA/Parlay, LIF's MLP) the platform provides an open framework for location data retrieval. Enhanced features of the platform deal with the capability to handle the QoS of the location requests, the enforcement of authentication and security policies, the manageability and the brokering efficiency to route requests based on underlying positioning capabilities and on location request's semantics. An advanced feature of the platform is its Service Publishing and Discovery capabilities. Service discovery will enable users to identify the services offered by the GWLC, whilst reconfigurability options will allow the automatic configuration of users' terminal equipment for accessing location services.

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