Supporting Ubiquitous Location Information in Interworking 3G and Wireless Networks

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Abstract

Location-Based Services (LBSs) will be one of the main sources of revenue for wireless network operators. Emergency services, information services, fleet-monitoring services, tracking the location of vehicles, objects and users are some of the most promising location applications. The current interworking between the third-generation systems and the wireless networks, along with the spreading of the new mobile devices equipped with multi location sensing technologies, pave the ground to new and more favourable services. Wireless Internet Service Providers (WISPs) need to take into account several elements for ensuring valuable LBSs. The adopted location platforms should be able to leverage the different features of the wireless networks and of the existing positioning techniques in order to always provide ubiquitous LBSs with high accuracy across heterogeneous scenarios. Moreover, the adopted platform architecture and its protocols need to be carefully designed for providing highly scalable and interoperable services. For instance, the use of open standards can favour WISPs interoperability and hence multi-vendors LBSs integration. We first present the elements involved in high-quality LBSs provisioning. Then a possible two-tier open-standard based architecture for inferring and exchanging indoor and outdoor location information through heterogeneous wireless networks is presented. Privacy and security issues are also discussed.

1. Introduction

Location-Based Services (LBSs) are becoming one of the principal interests of Wireless Internet Service Providers (WISPs) and network operators [10, 16]. Positioning of mobile devices in the third generation (3G) of wireless communication networks (e.g., Universal Mobile Telecommunications System - UMTS) [17, 1], is crucial to many services, such as: i) location applications that utilize accurate positioning, including handset navigation tracking and locating points of interest; ii) public and private emergency services for calling out fire-fighters, medical teams, emergency roadside assistance; and iii) experimental or future applications, such as fraud detection services, location-sensitive billing services, information and advertisement services.

Current positioning techniques vary for level of accuracy, implementation cost, and typical application scenarios (e.g., indoor and outdoor). WISPs that wish to provide valuable LBSs should exploit the availability of these positioning technologies in order to locate their users in heterogeneous environments by using the most suitable positioning technique in a manner transparent to the user.

The recent interworking between the 3G systems and the current generation of wireless networks (i.e., IEEE 802.11, Bluetooth), has allowed WISPs to leverage wireless networks for localization purposes. The spreading of wireless hotspots into many public and private places (including homes, offices, airports, shopping malls, arenas, hotels, and libraries) [2], as well as the new generation of mobile devices (that support several positioning technologies, e.g., GPS, Bluetooth, Wi-Fi, RFID), has fostered the development of integrated positioning systems to be used by WISPs.

Proprietary architectural solutions have been proposed, as in [7] and [3], in order to provide ubiquitous location information, by integrating different positioning methods and infrastructures.

However, in order to design a solution that has low impact on the existing operator network infrastructures, and safeguards customers from risk of adopting a new technology, architectures, protocols, interfaces, and application environments should be based on open standards, to speed a multi-vendor deliverable framework for leveraging the interoperability among location platforms.
An open-standards based solution would allow and encourage this interoperability, enabling WISPs that adopt different positioning solutions to negotiate roaming agreements. A WISP could provide LBSs to its users across networks belonging to other WISPs that use different standard-compliant location platforms, enlarging the coverage area of its location services. This aspect would be advantageous for both the WISPs and the users.
In the following, we explore the elements involved in the provisioning of valuable LBSs; then we propose an open-standard based two-tiered architecture for inferring location information in heterogeneous wireless networks and ubiquitous personal networks (i.e., 3G, WLAN, Bluetooth). This solution is able to exploit multiple indoor and outdoor positioning methods and technologies at the same time in order to infer and provide location information compliant with LBS requirements, including accuracy, coverage, privacy, and security. It is designed as an user plane architecture, where the location information is part of the wireless user data and is transported over user bearers, such as the wireless data network (i.e., IP) or SMS.
The architecture is based on the OMA Secure User Plane Location (SUPL) [13]. SUPL acts as an enabler which utilizes existing standards where available and possible to exchange positioning information between the mobile terminal and the network.

In particular, the use of two levels in the architecture provides appropriate abstractions in order to support an extensible framework, so that new positioning technologies, supported by the network or by the mobile device, can be added without requiring any changes to the existing architecture. It increases performance scalability, allowing to balance the load among servers at different levels.
The logical separation between communication and positioning infrastructures allows to locate a user by a network different from the one to which it is connected. This feature enables positioning and communication technologies to evolve independently, keeping simple the integration between them in this architecture.

2 Location based mobile services

LBSs are any application service that exploits the position of a mobile terminal. There is a wide variety of LBSs, of which the following four kinds of services are considered the most promising in terms of global revenue [12, 5, 15]:

- *Information Services*: mostly refer to the delivery of information based on the target market, users' profiles and preferences. In particular, such services should be classified depending on the following relationships:
  - B2C: the user location information can be used by WISPs for launching promotions of local products or advertising campaigns;
  - C2B: the user can request its location to be calculated in order to gain access to precise information (e.g., information about local restaurants, gas stations, traffic information);
  - C2C: the user can locate friends, family members, or more generally members of a community to which it belongs (e.g., sport, music, cinema).
- *Monitoring Services*: services for monitoring and management of fleets, and for tracking the location of objects (e.g., cars, trucks, trailers, containers) and individuals (e.g., truck drivers, delivery personnel, maintenance technicians, security personnel).
- *Emergency Services*: this category includes public and private emergency services (e.g., services for calling fire-fighters, medical teams, roadside assistance). They do not require a subscription and can be accessed by any mobile user, in accordance with the regulations governing.
- *Operator Services*: the location information of devices or users can be used to significantly improve the performance of wireless network (e.g., for network planning, network adaptation, load balancing, resources optimization, handover).

LBSs can be classified in two service groups depending upon who begins the positioning procedure: i) *pull services*, in which device's location is estimated on the base of a direct user request (e.g., emergency services); and ii) *push services*, in which the positioning procedure is required by a network application (e.g., by an advertisement messages delivery service) or indirectly by user (e.g., through a subscription to a service of news).

3 Ubiquitous services providing

Since WISPs can provide LBSs ubiquitously through heterogeneous networks and scenarios, we claim that different elements have to be blended, including the wireless communication networks, the positioning systems, the location architectures and protocols, and the open location standards (Figure 1). The wireless network infrastructure

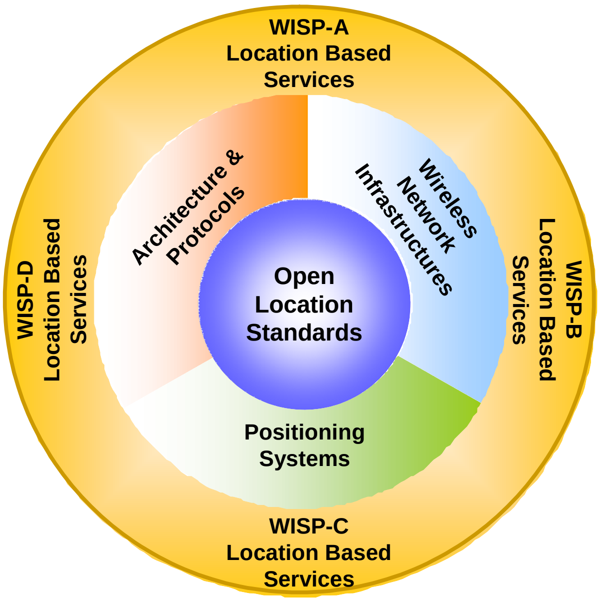

Figure 1. The entities involved in LBS delivery

allows delivering of LBSs as well as transferring of service requests and location information. The positioning system is the technology-specific subsystem that infers the user/object's location. The location architecture and protocols specify the responsibilities of the involved entities, and how to exchange location information among them (independently from the positioning technologies used). Finally, the standards are a set of technical specifications that allow multi-vendor's LBS interoperability.

3.1 The wireless infrastructures

Wireless communication networks can be classified by two means:

- the *network range*: in general, the coverage of a wide area cell is much larger than the one of local/personal wireless networks (i.e., WLAN and WPAN networks);
- the *network topology*: large infrastructures composed of fixed nodes (e.g., Wireless Wide Area Networks - WWAN), or self-configuring mobile nodes connected by wireless links, which form arbitrary topologies (e.g., piconet Bluetooth, IEEE 802.11 networks).

The 3G-wireless interworking network includes WWANs - e.g., UMTS and GSM/GPRS networks, and the local/personal wireless networks, that we call Home Networks (HNs). In the considered interworking architecture one or more HNs may reside within a single wide area cell. Each HN is connected to the 3G core network in the same manner as in the 3G radio access technologies. In this way, the 3G mechanisms for mobility and security can be reused [6].

3.2 The positioning systems

In order to locate user in every time and place, different positioning infrastructures have been used for indoor and outdoor location sensing.
For outdoor scenarios the most widely spread positioning systems are the Global Positioning System (GPS) and the Assisted GPS (A-GPS) [16].
In dense urban areas and inside buildings where GPS has its shortcomings, the Cell-ID based solution is adopted. It is the easiest but the most imprecise solution that is directly related to the physical position of the wireless base station. Typically, its accuracy is associated with the cell sizes, that vary from around 100 m up to several tens of kilometres. In order to increase the accuracy up to 100-500 m in urban area, solutions based on measurements of received signal strength (RSS), time of arrival (TOA), angle of arrival (AOA), and time difference of arrival (TDOA) from neighbouring base stations are used. Enhanced GPS allows higher accuracies (1-3m), covering most environments including indoors, without having to connect the A-GPS server to a Wide Area Network or having to wait several minutes as is the case with traditional GPS [11].
Since these solutions either do not satisfy accuracy requirements of several positioning services in indoor environments, or they are expensive due to the changes required to network elements, more attractive solutions based on standard wireless communication systems, such as IEEE 802.11 and Bluetooth, are considered [9]. For example, the Bluetooth network allows positioning of a Bluetooth enabled device very easily, with an accuracy related to the piconet's size (i.e., about 15 m), with an update rate in the range of a few seconds. The combination of RSS measurements (of the Bluetooth or the 802.11 signal) with triangulation or fingerprinting techniques [4] can increase the accuracy (e.g., about 3-10 m).
More accurate, but also more expensive, solutions are based on the ultrasonic, audible sound, and vision-based technologies. Cheaper solutions may be based on the RFID technology. Finally, data fusion techniques are considered to overcome the shortcomings of using a single positioning technology. It is based on combined measurements coming from different positioning technologies in order to improve the availability and the accuracy of the positioning service.
The choice of which positioning solution is best suited to locate a mobile device can be influenced by quality of position requirements of LBSs, such as accuracy, response time, privacy, as well as the device capabilities. Figure 2 sum-

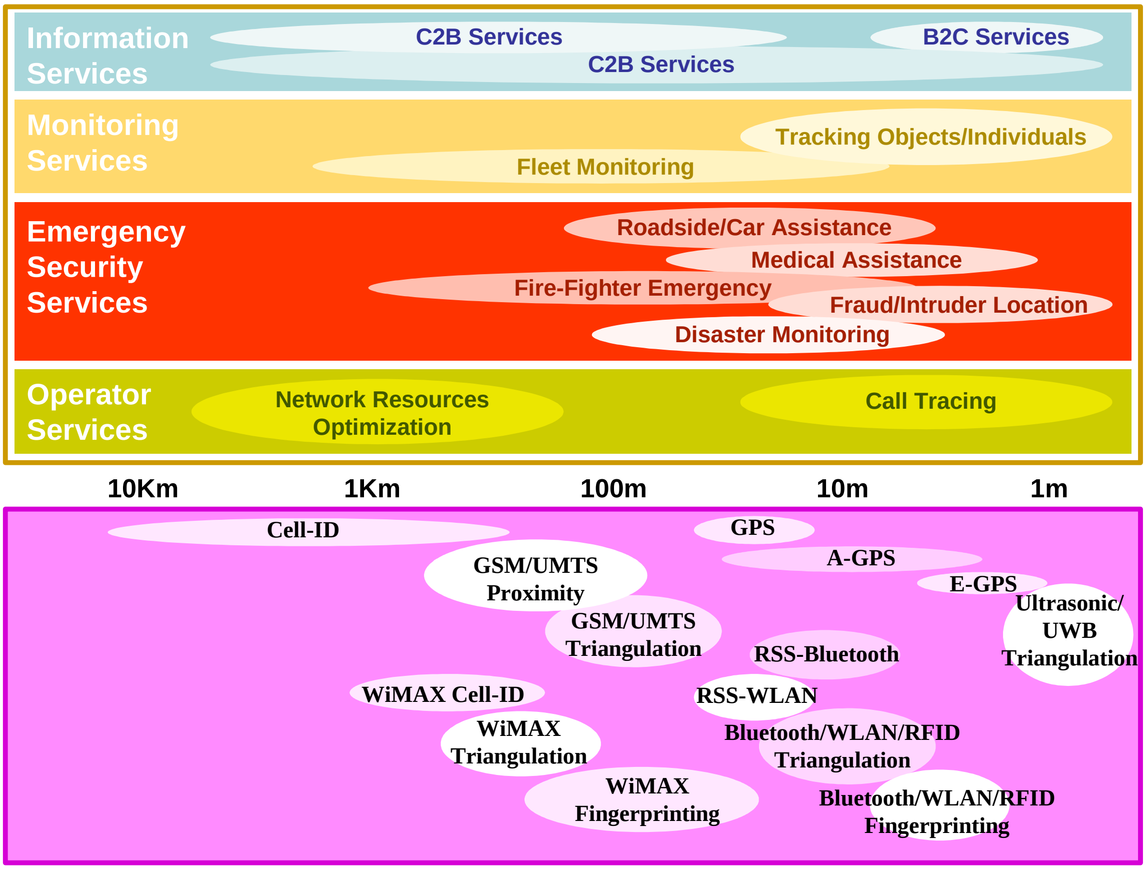

Figure 2. Location Based Services and Positioning Techniques

marizes the mentioned positioning solutions along with the LBSs categories.

3.3 The location architectures

As for location architectures, two standardized approaches have been adopted so far, namely *control plane* and *user plane* [13]. They are designed to meet different kinds of requirements, and the choice between them can influence the quality of provided services [8]. The main feature of a control plane architecture is the choice of exchanging location data through control channels, allowing voice and data communications to occur simultaneously. This feature made it tailored for voice-centric applications and emergency services. For this reason, it was adopted in the United Stated to develop E911 service. However this approach is not prone to consumer-oriented applications, because i) it does not allow to deploy handset resident location applications, and ii) it is expensive and not flexible (due to the required network infrastructural changes).
The need to have an application-centric solution integrated in heterogeneous networks, has led to the design of the user plane architecture. Its main feature is the use of IP bearers to transfer location information instead of control channels. In such an architecture, the location information is part of the wireless user data and it is transported via wireless data network (i.e., the Internet) or SMS (short message service). This feature does not imply the changes required by control plane architectures, and it simplifies the deployment of a wide range of applications.

3.4 Interoperability and open standard for location-aware computing

In order to realize and deliver LBSs, a number of different players ranging from technology providers to data providers have to be involved. This includes software and hardware developers, wireless communication networks and positioning infrastructure providers, wireless handset vendors, content and wireless service providers. Therefore, to ensure multi-vendor's LBS integration, common standards to interface and integrate different entities have to be considered or defined. In particular, the OMA SUPL specification [14] is a collection of specifications that aim

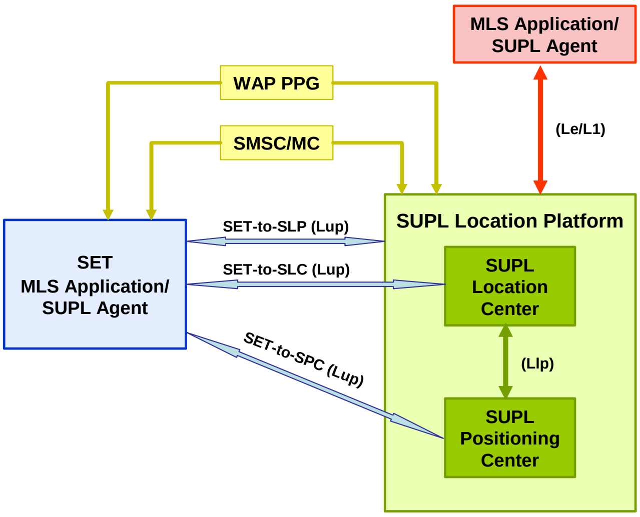

Figure 3. The SUPL architecture

to define a way of transferring location information among SUPL Enabled Terminals (SETs) and location applications. It utilizes existing standards where available and it employs user plane data bearers, requiring only IP capable networks and minimum modification to the network elements.
SUPL allows using several positioning solutions, based on A-GPS, Enhanced GPS, Enhanced Cell-Id, AFLT, EOTD and OTDOA. It defines how signaling and position information should be transferred between actors through wireless networks, independently from the positioning systems. It also defines security (as authentication and authorization), privacy and charging functions. Moreover, SUPL specifications define roaming functions that make it an effective solution to develop extensible and flexible LBSs for heterogeneous contexts.

3.4.1 The SUPL network architecture model

The block diagram shown in Figure 3 describes the SUPL network architecture model in terms of *network entities* and *reference points*. The reference points represent demarcations among entities. The architecture is characterized by several logical components: the *SUPL Enabler Terminal* (SET), the *Mobile Location Service* (MLS), the *SUPL Agent*, and the *SUPL Location Platform* (SLP):

- **SET**: It is a device able to communicate with a SUPL network.
- **MLS**: It is an application which requires and consumes position information in order to provide LBSs.
- **SUPL Agent**: It is the service access point, which accesses to the network resources to obtain location information.
- **SLP**: It is the core of the platform. The SLP is the entity responsible for estimating and delivering the SET position information. It is composed of (i) a SUPL Location Center (SLC), that coordinates the operations in the network and interacts with the SET, and (ii) a SUPL Positioning Center (SPC), that is responsible for all messages and procedures required for SET positioning.
- **WAP PPG** and **SMSC/MC**: They are used for communicating with a SET via WAP or SMS messages.

The MLS Application and the SUPL Agent can independently reside in the network as well as in the SET. If the SUPL Agent resides into the network, the services are named *Network Initiated SUPL services*; whereas if it resides into the SET, the services are named *SET Initiated SUPL services*.

4 An open-standard based architecture

In order to provide ubiquitous location information to both push and pull LBSs through 3G and HN interworking networks, WISPs can adopt the two levels hierarchical SUPL-based architecture showed in Figure 4. This architecture is designed to support interoperability among SUPL-compliant location platforms and to support several kinds of networks with different and complementary location-sensing features: the classical 3G infrastructure at the first level and the HN networks at the second level. Each level includes a number of positioning cells managed by a different kind of SLP. High level SLPs are responsible for managing user position information within WWANs, whereas low level SLPs, called **Local SLP** (L-SLP) are associated with HNs. The L-SLP may be either integrated into a HN or located in separate network entity. In the latter case, it may manage several HNs and may locate the SETs within their coverage area. For example, each L-SLP can manage correspondence between HN cell identifier (Cell-ID) and their geographic coordinates without involving wide area network provider. The L-SLP is free to choose the positioning method in accordance with the quality of positioning (QoP) requested by the MLS, as well as with the capability of the SET and of the positioning infrastructure. Each high level SLP may manage multiple L-SLPs within its coverage area. It can perform the role of the **Home SLP** (H-SLP) or **Visited SLP** (V-SLP).

- *H-SLP*: When the SLP performs the role of the H-SLP, it manages the SET's personal information (the subscription, the authentication and the privacy related data). It is responsible for the interface with the MLSs. It receives location requests from network-resident as

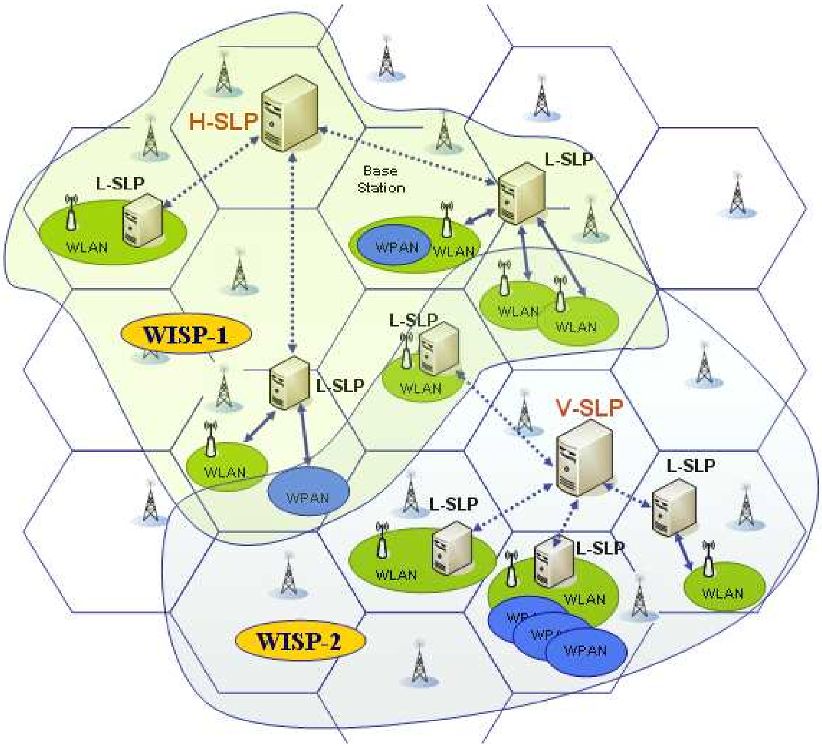

Figure 4. The positioning architecture

well as handset-resident MLS applications. If the request comes from a SET, it authenticates the SET, and checks that it is authorized to request the user location. It is also responsible for transmitting the required service quality (e.g., accuracy, response time) to the positioning network entities, and for converting the positioning results into the desired format (e.g., Cell-ID into location coordinates).

- *V-SLP*: When a SET leaves the service area of its H-SLP, a SUPL roaming may occur. In this case, in order to provide the SET position estimation, the H-SPL can contact the Visited SLP to which the SET is connected. The H-SLP may request the V-SLP to provide an initial position estimation (e.g., based upon Cell-ID), or fine-location estimation.

4.1 Push and pull delivery services

A *push service* is a MLS application, which requires position of a SET attached to an interworking 3G-HN network. For example, an advertisement information service which requires to be notified as soon as a specified SET enters within a specific area. Push sercive scenario can be summarized as follows:

- **Step 1**: The network resident MLS application requests for the position of the SET to the H-SLP of the target subscriber.
- **Step 2**: the Home-SLP (H-SLP) determines if the terminal is in roaming at one of WISPs infrastructures or at some public connectivity service, with which it has roaming agreements and that also support localization. In any case (roaming or not) the following basic steps need to be carried out:
  - **a**) The H-SLP creates a location session with the SET by sending a SUPL INIT message via a SMS or a WAP push message, which contains the positioning method it intends to use
  - **b**) The SET establishes a secure IP connection with the H-SLP; then it determines its location-id (i.e. the *lid*), based on Cell-ID and sends it to the H-SLP in a SUPL POS INIT message, including its supported positioning methods.

Step 3: If the SET is not in roaming (i.e., it resides in the H-SLP area and is attached to some of the H-SLP structures (3G or Wi-Fi/Bluetooth cell)), and the position computed by means of the received *lid* does not meet the QoP requirements:

- **a**) The H-SLP sends a SUPL START message to the L-SLP with which the target SET is associated (selected on the base of the received *lid*), in order to inform it that a finer SET position is required. The POS INIT message is forwarded to the L-SLP

  - **b**) On the base of required QoP, the L-SLP computes a SET fine position with a method chosen among those supported by the SET and by the network positioning infrastructure. The position is sent to the H-SLP. Note that some positioning methods can be used only if there are the necessary infrastructures in the L-SLP area (e.g. AP-based triangulation technique requires at least three access points). In some cases it may be necessary an agreement among WISPs to apply some techniques. For instance, it may happen that the SET receives signals from APs belonging to different WISPs; in this case, the confidential geographical information about APs belonging to other WISPs can be known only if there is an agreement with those WISPs that decide to expose information about some (or all) of their Access Points. Otherwise the L-SLP switches to another supported technique to carry out the estimation.
  - **c**) The H-SLP forwards the computed position to the requesting MLS application

- **Step 4**: If the SET is attached to a public/private entity providing an open connection service, with which the H-SLP has some agreements, and it resides in the H-SLP area:
  - **a)** The H-SLP requires this entity to collaborate in order to determine the SET position (through request/acknowledgement messages).
  - **b)** Then the H-SLP forwards the SUPL POS INIT message to that entity (referred to as a Visited SLP, V-SLP). This entity, based on the *lid*, will be in charge of carrying out the required estimation with its infrastructures or of providing the necessary information to the H-SLP (e.g., the geographic coordinates of the AP id), depending upon their agreement.
  - **c)** A different option is to let the terminal choose how to fill the *lid* field in the SUPL POS INIT message; for instance, by making it transmit the cellular cell *id* (because it resides in the H-SLP area) instead of the cell *id* of the entity to which it is attached, allowing for the H-SLP to choose the L-SLP and accomplish the estimation without the collaboration of the connection service entity. Other policies could be adopted depending on the agreement between the WISP and public/private entity.

- **Step 5**: If the H-SLP area does not cover the terminal and this is attached to another WISP or to an open connection service entity, it sends the SUPL POS INIT with its *lid* to the H-SLP, which forwards it to the V-SLP of that WISP/entity. The latter will be in charge of carrying out the required estimation based on that *id*, with its own infrastructures. Options like in the case of 4.c) are not allowed in this case, because the terminal is not in the H-SLP area.
- **Step 6**: Finally, if the terminal is attached to a network that does not have any agreement with the H-SLP, the terminal cannot be located.

The choices in the steps 4.b) and 4.c) are left to the specific implementation and depend on the business agreement.

A *pull service* is a service in which positioning data are required by an application that resides on the requester SET. Examples are C2B information services, which require user position in order to obtain information about points of interest around its location. In this case, it is the SET that has to contact the H-SLP and to start a positioning session. It sends to the H-SLP a SUPL START message, which contains its *lid*, supported positioning methods, and the MLSs QoP. Then the H-SLP determines if the SET is in roaming and the protocol proceeds as in the previous case (with slight differences in the name of the messages).

The described scenarios do not introduce any change to SUPL interactions, but only to the role of involved entities. In particular, the SUPL standard roaming scenarios in which a H-SLP forwards a positioning request to a Visited-SLP, are perfectly compliant with the described scenarios. When the SET is not in roaming, the L-SLP can be considered as a V-SLP specialization, i.e., a H-SLP has to treat positioning request as a SUPL standard roaming case, forwarding them to the L-SLPs.

The development of such an architecture can be done incrementally, i.e., a new L-SLP can be added in a transparent way for end users. End users devices implement in any case the same protocol, and they see always a SLP to which interact independently from its logical function (H-, V- or L-SLP), i.e., messages they receive and they send are always the same.

Finally, it is worth to point out that the use of a two-tier architecture makes the solution more scalable: the H-SLP has to only forward the positioning requests to the right L-SLP. It is not responsible for calculating each SET position, as in the SUPL standard.

5 Mapping of quality of position requirements

In order to provide proper services to mobile users at any time, the proposed solution allows MLS applications to ex-

ploit multiple positioning technologies and choice the most suitable one based on their QoP requirements. The QoP consists of a set of attributes associated with a LBS service request [18]. They include the required horizontal and vertical accuracy, the location age (i.e. the maximum tolerable age of cached position estimated) and the response time.
If the first coarse position based on *lid* does not satisfy the requested QoP, the SET and the SLP may perform several positioning procedures to determine finer position. On the base of the QoP, the SLP sends the positioning method that it intends to use to the target SET, in order to fulfill that requirement. It can adopt both a handset-side and a network-side approach. In the former approach, the mobile device can utilize the signals (e.g., Bluetooth, 802.11, satellite signals) transmitted by surrounding positioning infrastructure, in order to estimate its position through different technologies. In the network-side approach, by using the components of surrounding infrastructure, the SLP can track the position of devices when they are in its coverage area. Moreover, the SET may also adopt an infrastructure assisted approach sending a request to an external positioning system to calculate or to improve the position measurements (e.g., the Assisted GPS). The choice of the positioning method to be adopted depends on the provided accuracy, as well as on the structural modifications it may require, and on security and privacy issues.

6 Addressing privacy and security concerns

Privacy is a major concern when designing a system to locate user's portable devices. It concerns (i) how the user location information is used and logged, (ii) who (and how) controls access to location information, and (iii) how a location system should be implemented in order to allow different levels of access. In particular, a user has to be able to specify privacy preferences. For example, at home, a user may want to receive advertising about new promotions, whereas, at the office it may wish to receive an authorization request for sending these messages. These preferences have to be translated into polices for using or publishing user position. In particular, the privacy check may be done by the H-SLP after performing positioning, but before the user location is sent to the requesting entity. Other than user privacy, business privacy issues need to be addressed when positioning techniques may need the cooperation among WISPs and the disclosure of confidential information. To cope with this open issue, proper agreements among WISPs are needed.

Then, in order to address security issues, a mutual authentication between the network entities (the H-SLP) and the SET is needed. The authentication is performed with Pre-Shared Key Ciphersuites for Transport Layer Security (PSK-TLS) protocol, using security credentials associated with the SET user. After the SUPL INIT message, the SET has to establish a data connection with the H-SLP and has to initiate the PSK-TLS session. The data connection can be established through a cellular interface (GSM, GPRS, UMTS), or through one of its wireless interfaces (802.11, Bluetooth), depending on the handset equipment and on connection availability at a given moment. In the former case, the L-SLP is not implied during neither connection nor authentication, and the PSK-TLS session between the SET and the H-SLP can be created as in the SUPL standard. In the latter case, the connection is established by the SET toward the nearest L-SLP access point. The L-SLP has to manage the users connection requests, in order to allow SUPL registered users to start the PSK-TLS session with the H-SLP.

7 Conclusion

Ensuring multi-vendor's Location Based Services integration from a complex puzzle of disparate software, hardware, positioning and connectivity components presents several challenges.
Here, we outlined the main elements to be taken into account for a Wireless Internet Service Provider to offer valuable LBSs; we then proposed an integrated solution for inferring and providing indoor and outdoor user location information through heterogeneous networks and location platforms.
We described a two-tier SUPL-based architecture by which different WISPs can provide services tailored for each need by using in seamless manner: i) the most convenient positioning technologies, in terms of precision-cost trade-off; ii) the user bearer communication technology which is available in a given moment within the considered area, and iii) inter-WISPs roaming capabilities.

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References

[1] Akyildiz, I. F., McNair, J., Ho, J. S., Uzunalioglu, H., and Wang, W.: Mobility management in next genera-

tion wireless systems, in Proc. of the *IEEE*, vol. 87, no. 8, pp. 1347-1385, 1999.

[2] Axiotis, D.I., Al-Gizawi, T., Peppas, K., Protonotarios, E.N., Lazarakis, F.I., Papadias, C., Philippopoulos, P.I.: Services in interworking 3G and WLAN environments, in *IEEE Wireless Communications*, vol. 11, no. 5, pp. 14-20, Oct. 2004.

[3] Captivate a new generation, Autodesk Location Logic. Autodesk Inc, at http://images.autodesk.com/adsk/files/adsk_locationlogic_092006.pdf

[4] Darabi H.L., Banerjee H., Jing Liu P.: Survey of Wireless Indoor Positioning Techniques and Systems in *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 37, no. 6, pp. 1067-1080, Nov. 2007.

[5] Dru, M.A., and Saada, S.: Location-based mobile services: the essentials. Alcatel Telecommun. Review, 1st Quarter 2001, pp. 71-76.

[6] ETSI TR 101 957, Broadband Radio Access Networks (BRAN), HIPERLAN Type 2: Requirements and Architectures for Interworking between HIPERLAN/2 and 3rd Generation Cellular.

[7] Faggion, N., Leroy, S.: Alcatel Location-based Services Solution, Sep. 2005. Alcatel Telecommun.

[8] Gum, A., and Burroughs, K.: Wireless choices for LBS, in *GPS World Mag.*, vol. 17, no. 3, pp. 32-40, Mar. 2006.

[9] Manesis T. and Avouris N.: Survey of position location techniques in mobile systems, in Proc. of the *7th ACM International Conference on Human computer interaction with mobile devices & services*, pp. 291-294, Sep. 2005.

[10] Rao, B., and Minikakis, L.: Evolution of mobile location-based services, in *Communications of the ACM*, vol. 46, no. 12, pp. 61-65, Dec. 2003.

[11] Rowe, R.W.; Duffett-Smith, P.J.; Jarvis, M.R.; Graube, N.G.: Enhanced GPS: The tight integration of received cellular timing signals and GNSS receivers for ubiquitous positioning, in Proc. of the *IEEE/ION Position, Location and Navigation Symposium*, pp. 838-845, May 2008.

[12] SIRF Rep., Location-based services: Amplifying ARPU for carriers, Feb. 2007, at: http://www.sirf.com/sirfamplifyingLBS.pdf

[13] Spinney, J.: Wireless Location Uses in the User Plane and Control Plane, in *Directions Mag.*, Jul. 2005.

[14] The OMA Secure User Plane Location (SUPL) - v.1, at: http://old.openmobilealliance.org/release_program/supl_v1_0.html.
v.2 at: http://www.openmobilealliance.org/Technical/release_program/supl_v2_0.aspx

[15] UMTS Forum Rep. 17, The UMTS Third Generation Market Study Update, Aug. 2001, at: http://www.umtsforum.org

[16] Zhao, Z.: Standardization of mobile phone positioning for 3G systems, in *IEEE Commun. Mag.*, vol. 40, no. 7, pp. 108-116, July 2002.

[17] 3GPP. Functional stage 2 description of location services in UMTS. Technical report 3GPP TS 23.171 v3.9.0, 2002.

[18] 3GPP TS 23.032, Universal Geographical Area Description (GAD), Nov. 2007, at: http://www.3gpp.org/ftp/Specs/html-info/23032.htm