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Ubiquitous Sensor Networks in IMS: an Ambient Intelligence Telco Platform

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Abstract: Ubiquitous Sensor Network (USN) concept describes the integration of heterogeneous and geographically dispersed Wireless Sensor and Actuator Networks (WS&AN) into rich information infrastructures for accurate representation and access to different dynamic user's physical contexts. This relatively new concept envisions future Sensor-Based Services leading to market disruptive innovations in a broad range of application domains, mainly personal (lifestyle assistants), community (professional users) and industrial domains. The support for this broad range of innovative Ambient Intelligence services urgently demands a standardized access to different WS&AN, and Telco Operators have an opportunity to lead this technological challenge as they evolve towards future Next-Generation Networks. Telefónica Research and Development is a leading innovation company that provides communication services for businesses and consumers. Networks and Service Platforms is a major Telefónica I+D innovation area where new Service Architectures and Platforms concepts are essential for the development of services with a high differentiation value. This contribution describes Telefónica I+D activities directed to the design of an Ambient Intelligence Platform integrating USN concepts over NGN architectures. In our view IP Multimedia Subsystem (IMS) concepts can enable and promote a first generation of Sensor-Based Services where multimedia interactive sessions are enriched with contextual information from WS&ANs. To this end three major design criteria are addressed at three different levels. At the application layer, OMA Service Environment and OGC Sensor Web Enablement are combined to define a specific USN Service Enabler. At the communication, management and control level WS&AN Gateways are defined for integrating WS&ANs infrastructures into all-IP IMS environments. While at the lower level, data and meta-data exchanges with different WS&ANs entities are homogeneously represented using OGC® SensorML standard. Finally this paper concludes by discussing some preliminary business opportunities we foresee for the proposed Platform.

Keywords: Ubiquitous Sensor Network, Wireless Sensor Network, Ambient Intelligence, IP Multimedia Subsystem, OMA Service Environment, OGC Sensor Web Enablement, SensorML, Sensor-Based Services.

1. Introduction

WS&AN capabilities for sensing enriched user's contexts provide a huge potential for developing revolutionary context-aware AmI services built between the physical and digital worlds. Recent economical forecasts reveal [1] an increasing number of business opportunities expected for a wide range of industries: medicine, agriculture, energy, environmental, telecommunications and defence among others.

The relatively new concept of Ubiquitous Sensor Network (USN) [2] depicts a framework for ambient sensor networks not as simple sets of interconnected networks but as intelligent information infrastructures. In this challenging technological environment, as innovative AmI services are being conceived [3], major Telecom Operators are committed to design and develop Ambient Intelligence Platforms to support real ubiquitous AmI applications over Next-Generation Networks (NGN). IP multimedia subsystem (IMS) environments [4] represent one of the most innovative, although also controversial, approaches to drive telco service creation strategies into Web 2.0-styles (see, for example Telco 2.0 www.telco2.net, or Teleco 2.0, teleco2.blogspot.com). We believe that AmI Platforms, as the one this work describes, will make future Sensor-Based Services integrating the physical with the digital world relevant drivers in promoting the Telco 2.0 view.

This paper presents the Telefónica I+D on-going research, partially funded by the European Union through the IST FP7 project SENSEI, towards the design of an IMS-based AmI Platform integrating WS&ANs. At the application level, our efforts are directed towards the definition of an IMS Sersor Enabler thus resulting in a Service Oriented Architecture that could be open to Third Part Service Provides, similarly as in OSA/PARLAY, but with higher degrees of flexibility as well as with more powerful security and access control mechanisms.

The proposed IMS USN Enabler combines, in an innovative way, OMA specifications with the Sensor Web Enablement (SWE) family of standards OpenGIS® from the Open Geospatial Consortium (OGC®) [5]. At the access level, specific WS&AN Gateways are defined over SIP-based communication protocols and directed to provide sensor data format adaptation facilities. Although the sensing technology we are considering is based on ZigBee [6], the AmI platform is agnostic to different wireless/wired communication protocols.

The rest of the paper is organized as follows: Section 2 presents a general overview on the integration of USN into next-generation networks. Section 3 describes sensor data homogeneous representation and communication into Telco networks. In Section 4 main enabling components for developing future context-aware intelligent Sensor-Based Services are presented. Finally, some business benefits (Section 5) and conclusions (Section 6) are discussed.

2. Ubiquitous Sensor Networks in IMS

2.1 IMS in Sensor-Based Service Scenarios

To motivate our AmI Platform we describe an illustrative scenario of a Sensor-Based Service for urban spaces integrating context information from different WS&ANs: traffic road, public transportation, parking lots, commercial centres, restaurants, car sensors, etc. While John is driving downtown to do some shopping he receives traffic information on the access to the commercial area. As John is trapped in a traffic jam, he uses his interactive car system (ICS) for watching some pictures from traffic cameras and the ICS informs that it would be better to park outside the commercial centre and take public transportation to get into the commercial area ICS also informs that, according to updated sensed information, the subway line to the commercial area is not very crowded. After parking, while walking to the subway station the mobile phone informs John that a group of his friends are in near restaurant. John starts a voice chat session (PoC, Push to Talk over Cellular) with them while the phone display guides him to where they are. As he is engaged in the conversation, the mobile phone interrupts and warns John about an alarm event from his car. John immediately starts a video call to watch the car's video camera, he checks its car is safe (only a false alarm) and gives an order to re-start the alarm system.

The scenario above describes a type of Sensor-Based Service where context information from different public and private WS&ANs entities is integrated into several multimedia mobile sessions. At the moment we are not considering application scenarios where high levels of interactivity are required, as, for example, interactive sensor-based games. We think this highly dynamic scenarios will be better managed through ad-hoc networks policies, although we hope that, in the near future, they could complement and be integrated in our platform. So far, our AmI platform is intended to enable what we consider a first generation of services where broad dynamic context information is managed through three main strategies: 1) Context Information

Repositories, to store and timely update large amounts of context data, making sensor information accessible to high segments of users (for example: users interested on traffic, parking or public transportation); 2) Subscription, Publication and Notification Policies to specific, and mainly private, data and context-driven events (John's car alarm event); and 3) Situation inference from presence discovery and context processing, in the urban scenario, an application proactively proposes John to meet his friends based on their presence, location and availability for a chat session.

Although several research efforts in middleware definition for context-aware applications have been already proposed, only few have been focussed on IMS-based Service Architecture possibilities [15]. As stated in [16] three major problems can be identified for deploying context-aware applications in IMS: 1) scalability for context delivery; 2) absence of specific data models for enriched personal context information; and 3) lack of mechanisms for fusing low level context information to derive higher context abstraction levels. Nevertheless, apart from those common benefits of service-oriented architectures, there are also important benefits that can be foreseen for IMS architectures:

- As the urban scenario illustrates, this type of sensor-based services can be strongly benefited by integrating WS&AN data exchanges into IMS multimedia sessions; for example, watching road traffic pictures while receiving parking and public transportation sensor data; a car alarm reception while engaged in a phone conversation; or controlling an alarm actuator while receiving car's video camera stream. IMS can also be particularly important for seamless multimedia sessions across different mobile devices and environments (car, mobile phone, office, house,…).
- IMS offers a horizontal and flexible service oriented architecture providing a service execution environment with support for large number of concurrent context information requests from sensor-based services. Our IMS Context Information Repository can be implemented over distributed physical architectures providing scalable access to heterogeneous and disperse sensor data.
- SIP-based session control and management in IMS can be efficiently and easily extended to provide access-independent connectivity for a wide range of WS&ANs.
- The extended SIP session control can also be very useful to keep track of context-information provided by WS&AN, for example to combine user's situation inferred from WS&AN information and other users' presence in the IMS domain (John's activity or situation is combined with his friends location and their availability for a chat session).
- Context-aware scenarios involving both public and private data demand specific policies for privacy and accounting. IMS can provide privacy and accounting through its basic services: Authentication, Authorization and Accounting (AAA) and billing.
- Finally, WS&AN are usually unaware of the final application and billing services, so an IMS platform can be an effective solution for both final user charging and accounting of third part sensor-based service providers.

2.2 Ambient Intelligence Platform: High Level Architecture

NGN (Next-Generation Networks) presents horizontally layered network architectures to decouple services and networks, so services can be separately deployed and evolve independently. The 3rd Generation Partnership Project (3GPP) has introduced the IP Multimedia Subsystem (IMS) [4] as one of the main drivers for NGN cores supporting any multiservice environment. IMS can be considered a good candidate for USN as it provides global access-independent connectivity to a wide range of network technologies (3G, Wi-Fi, WiMax, DSL,…) as well as IP mobility support to WPAN (Wireless Personal Area Networks). IMS also offers a service-oriented architecture where access, control and application/service horizontal layers not only enable a rapid development of services, but also provides, security, scalability, high performance, end-to-end Quality of Service (QoS) and high availability. Our approach to extend a generic IMS platform to support Sensor-Based Services mainly acts on application and access layers (see Figure 1).

- At the service layer, our Platform defines a Ubiquitous Sensor Network Service Enabler (USN-Enabler) designed to assist Application Servers (AS), located on top of the IMS application layer, to access WS&ANs entities. Our USN-Enabler design follows OMA Service Environment (OSE) [7] enablers' specifications, already used for several standardised components (presence, call conferencing, transcoding, billing, …).
- At the access layer, WS&ANs entry points to the IMS core will be implemented through specific components called WSN-Gateways. They will provide two main functionalities: a) Communication Protocol Adaptation: bridging specific WS&AN communication protocols to the SIP environment; and b) Data Format Adaptation: converting WS&AN messages to a standard SensorML/O&M description language that will be presented in the following section. These two functionalities are key issues to make our AmI platform sensor-technology independent.

3. Sensor Data Modelling and WSN-Gateways

3.1 Sensor Data Modelling

In order to have a unique homogeneous model to represent data and measurements from heterogeneous WS&ANs we choose the OGC® SensorML standard format [5]. SensorML [5] presents a XML encoding for describing any process or process chain including the process of measurement by sensors and instructions for deriving higher-level information from observations. SensorML also represents a rich collection of metadata (identifiers, capabilities, characteristics, location, references,...) that will be stored, processed and managed in the USN-Enabler and accessed by the Sensor-based Services. Complementary to SensorML, OGC®'s has also defined the Observations & Measurements (O&M) standard [10], as flexible and extensible XML schemas for representing and exchanging different sensors' data (measurements) and results generated by different processing algorithms (observations). It is important to point out that harmonization of sensor standards is a current trend where SensorML can play an important role extending a global framework for integrating other standards such as the IEEE 1451 and ANSI N42.42.

3.2 WSN-Gateway

WSN-Gateways are logical entities acting as sensor data producers towards the USN-Enabler component (see Figure 1). In our view WSN-Gateways are implemented as IMS User Equipments (UE) [11], so they can be integrated into a wide range of devices (mobile phones, PCs, PDAs, ADSL routers, etc). Furthermore three important benefits can be derived from the IMS environment. Firstly, implementing basic IMS authentication and authorization procedures WSN-Gateways, as UEs, can control critical issues of security and privacy when accessing public and private WS&ANs. Secondly, Home Subscriber Server (HSS), or User Profile Server Function (UPSF) can be also used to gather WS&AN subscription-related information (as if they were user profiles). Finally, although not implemented in our Platform, subscription, publication and notification resources in the IMS Presence Service could be applied to mobile and not always accessible WS&ANs entities, so far and Presence Service could be extended to include enriched sensors/actuators information.

In terms of functionality, a WSN-Gateway implements two different adaptation procedures:

- Communication Protocol Adaptation. As a connection point between two networks, a WSN-Gateway implements the SIP stack protocol for communication with the IMS network and services, and it is also responsible for applying routing procedures to any message send/received from each particular sensor/actuator in the WS&AN. As an UE, a WSN-Gateway performs IMS registration, requesting authorization to register sensors into the

Observation Entity of the USN-Enabler (see Section 4), and implements data publishing mechanisms to provide updated information on sensors' data availability.

- Sensor Data Format Adaptation. This functionality is intended to provide USN-Enabler both SensorML (meta-information) and O&M (observation & measurements) data from specific WS&AN data (for example ZigBee format). That way the USN-Enabler is independent from particular WS&AN communication protocols or sensor technologies.

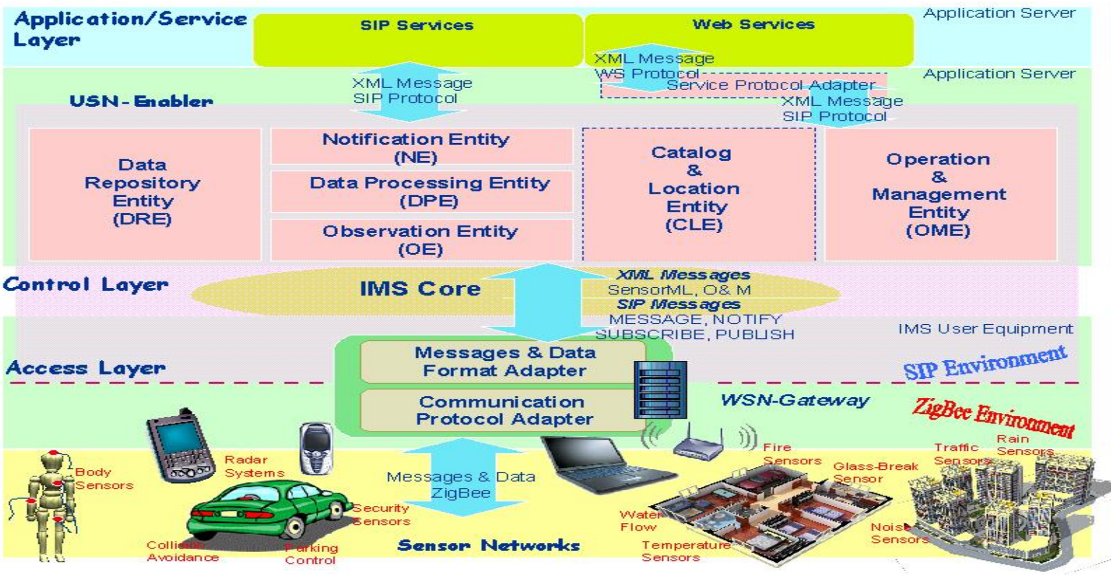

Figure 1: AmI Telco Platform: Reference Architecture

4. USN Enabler

4.1 Reference Architecture

USN-Enabler communication to services can be implemented both in a direct way (using the SIP protocol) and through the Service Protocol Adapter (that converts Web Services messages to SIP messages). USN-Enabler and WSN-Gateways are connected to the IMS Core Network using the SIP protocol and XML-based messages. Several standards and recommendations have been considered during the USN-Enabler design, among them the more relevant are: 3GPP TS 24.229 [11] for SIP protocol used in an IMS network; OMA, Presence SIMPLE Specification. [13], for publish and subscribe mechanisms to sensor information; OMA, XML Document Management (XDM), for XML information modeling in Service Enablers; and the OGC, Sensor Web Enablement [14] environment specification for sensors and Web Services.

4.2 USN-Enabler Entities

USN-Enabler entities (depicted in Figure 1) provide several coordinated capabilities for implementing the three main strategies of our AmI Platform (presented in Section 2.1): context information repositories; 2) subscription, publishing and notification; and 3) context processing.

Observation Entity (OE): implements a SIP interface with WSN-Gateways (sensor producers or providers) mainly through sensor registration, sensor data publishing and basic subscription and notification capabilities.

Notification Entity (NE): provides interface with any sensor data consumer (sensor-based service) demanding filtering or information processing. To receive sensor information, NE must be subscribed to an Observation Entity. NE provides the following functions: Intelligent Subscription for clients willing to receive a subset of the information produced by sensors, or information obtained by applying filtering processes to the original information.

Data Repository Entity (DRE): offers basic storage facilities (data base functionality) to all USN-Enabler information. DRE mainly encloses context information repositories but it also gathers information on subscribed services, privacy/security policies, filters and processes. DRE also offers other entities subscription to modifications in the stored data, usually necessary for administration or management purposes. DRE subscription and notification capabilities can be considered optional, since entities have direct access to the stored information.

Data Processing Entity (DPE): is responsible for applying rules, processing or filtering processes to information from different WS&ANs. By applying specific filter/rules to sensor data DPE can infer and notify enriched context events to sensor-based services

Operation & Management Entity (O&ME): is responsible of providing management and maintenance functions acting also as an interface between client applications, willing to perform management operations, and other entities of the system.

Catalog & Location Entity (C&LE): provides resource discovery facilities for distributed computing environments. C&LE will be a key entity for scalability issues, i.e. when large amounts of WS&AN data is distributed over different physical and distributed Data Repository Entities.

4.3 USN-Enabler Protocols

Main USN-Enabler protocols are applied in a strict way when they are used in a Distributed Computing Platform (DCP), both basic HTTP and SIP protocols are supported. One of the benefits of our IMS environment is that most USN-Enabler protocols can be implemented using basic SIP primitives: PUBLISH, SUBSCRIBE, NOTIFY and SIP messages containing XML documents. Besides, basic capabilities sensor-based services usually demand from USN-Enablers are mainly subscriptions to specific sensor information and notifications of sensor data availability, therefore we implement similar mechanisms to those in standard enablers like OMA SIMPLE but managing different types of information. Main SIP messages header fields we have implemented are:

- *Event*: state information to be reported from the notifier to the subscriber. Two kinds of events for subscription and notifications have been implemented: events for observations and measurements publishing, and sensor registration events.
- *Content-Type*: a SIP message header to describe the payload (content) inside the message. Specific types for sensor data and information have been defined, in a similar way as it is done in the OMA SIMPLE enabler (application/pidf+xml). However, it is advisable to make the content independent from the transport protocol header.
- *From*: header field referring to the entity that produces or generates sensor events (mainly WSN-Gateway identifiers).

Figure 2 shows an example of the sensor data publishing and notification protocols. The flow starts at the Sensor Data Publisher with a SIP-PUBLISH InsertObservation request *from* a particular Sensor Data Publisher (WSN Gateway, user_user_gw@home.net) *to* an Observation Entity (OE, oe@home.net). XML-InsertObservation includes sensorId, observationType and observation data in O&M format. After receiving the InsertObservation request, OE inserts observation data into the Data Repository Entity (DRE) using HTTP-POST. Once observation has been properly inserted into the DRE (HTTP-OK), OE notifies, using SIP-NOTIFY, to a previously subscribed Consumer (Sensor-based Service, consumer@home.net) the availability for this new published data.

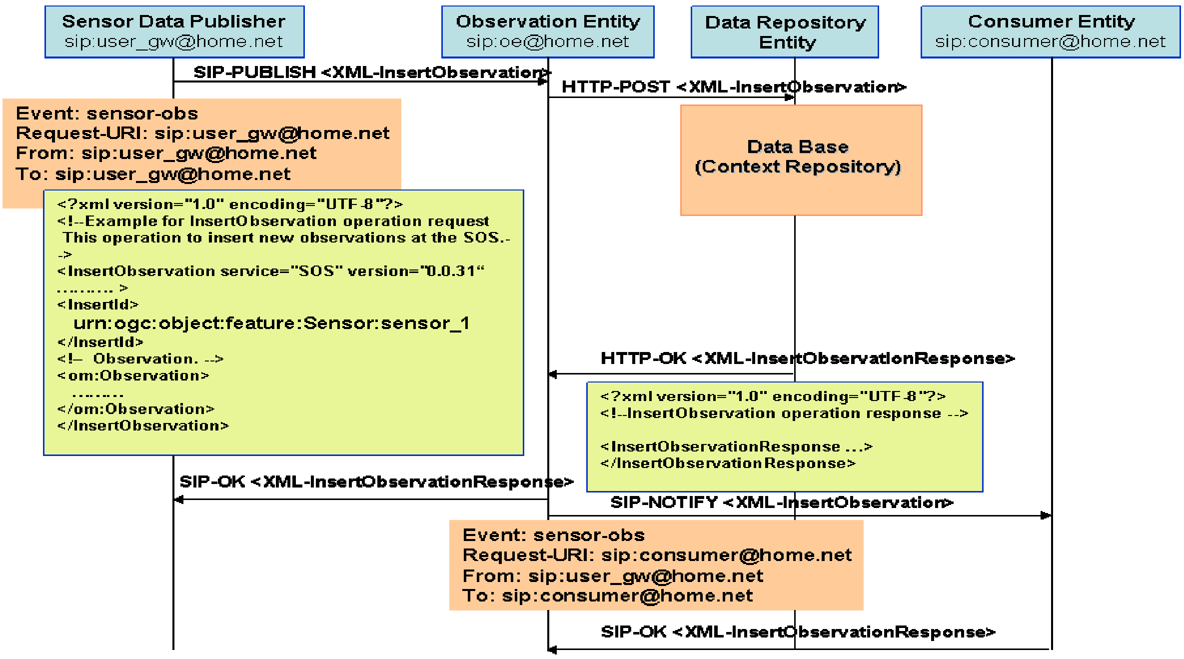

Figure 2: Sensor Data Publishing and Notification Protocols

5. Business Benefits

The development of an AmI Telco Platform is conceived as an evolved technological infrastructure leading to totally new business models for a first generation of sensor-based services integrating heterogeneous and geographically disperse WS&ANs into current ubiquitous Telco networks. We believe that IMS environments can importantly promote Telco Operator's role in future sensor-based services deployed on multimedia mobile applications demanding high levels of security, privacy and quality of service. Moreover, the USN-Enabler described in this work is intended to open the capabilities of our IMS horizontal service oriented architecture to third part companies as, for example, sensor-based service providers and Web 2.0 application developers. Thus considering the AmI Telco Platform as a technological middleware between sensor data producers and physical-context representations consumers, the following 3rd part key stakeholders can be identified: Communication Gateway Companies, WS&AN Industry, and Ambient intelligence service providers.

It is also important to point out that, although the proposed USN Telco AmI Platform could bring the added value that is missing in current isolated WS&AN applications, the evolution in the way markets are to emerge is difficult to forecast. Business opportunities will strongly depend on the speed at which context-aware services will become useful in the eyes of users and sensor technologies profitable in the opinion of manufacturers and their partners along the value chain. To this end Telefónica I+D maintains a continuous prospective activity over different markets, industries and exploitation scenarios.

6. Conclusions

In this paper we have presented our on-going activities towards an Ambient Intelligent Telco Platform for supporting future Sensor-Based Sensors over NGN. Our Platform relies on the ability to integrate several WS&AN over an IMS all-IP framework and it can be considered as an innovative infrastructure to progress towards the abstract concept of Ubiquitous Sensor Network.

The preliminary definition of our Platform has been mainly focussed on representing the underlying user's physical environment. However to completely accomplish Ambient Intelligence requirements there are still important issues to research. Among them, it will be necessary to perform a detailed analysis on the management and processing capabilities of our Platform as function of the number of different WS&ANs and sensor data dimensions. Furthermore, as our Platform mainly describes the user's physical context, future extensions will be necessarily directed to combine it with personal and social contexts.

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