Enabling Innovations in Mobile-Learning: A Context-aware and Service-based Middleware

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Abstract— **Development of mobile learning projects involves addressing many challenges, from pedagogies (e.g., what must students learn? and how?) to technical issues (e.g., use of context-awareness, use of communication or collaboration methods, mash-up of information). This paper introduces a framework intended to provide different educational tools and information to mobile learning programmers and designers in order to simplify and reduce the project development. The paper offers an overview of the state of the art of mobile learning applications, focusing on some of its problems: lack of interoperability and difficulty of using advanced technologies, such as location-based systems. It also addresses why most of the m-Learning applications do not make use of the existing services and knowledge of the Learning Management Systems, which are in fact the real pillars of the e-learning methodology. The framework design is guided by a new paradigm for development of e-learning tools and platforms: Learning as a Service (LaaS). The main contribution of this framework is to provide contextual information from different sources and sensors (e.g., geographical, motion); and integration of many existing services from e-learning platforms.**

Keywords- context-awareness, e-learning, framework, location, LMS, mobile learning, ubiquity

I. INTRODUCTION

Nowadays mobile technologies are being applied on educational environments quite successfully. One of the main reasons of this success is the improvement of the technical features of the devices. New generations of mobile devices have wider and touchable screens; built-in digital cameras; and connectivity not only with GPRS but also with Wi-Fi or 3G. In some of them it is even possible to find GPS receivers, RFID, NFC readers or smartcards integrated.

All these new technologies inside a small and portable device are giving rise to a new generation of applications in all kind of environments. These kinds of applications are called mobile learning (M-Learning) inside the educational environment. Here, mobile devices are supporting collaborative and mobile work and enabling students to learn anytime anywhere, especially through games, applications or courses designed for these small devices.

Actually location-based and context-aware systems can give a very interesting added-value to M-Learning, because they allow the creation of mobile context-aware application that lets students interact with their environment in a totally new way. For instance, a student in a canteen will have different needs than in a laboratory or in a secretary; or a teacher in a classroom will need different information than in an office. It is possible to offer personalized learning through the mobile device depending not only on his/her profile but also on the moment and his/her location.

The other focus of the paper is over the integration and interoperability of the existing e-learning tools and applications with the mobile learning environment, giving rise to a complex mobile digital ecosystem of educational applications.

The paper might be of interest for those involved in the development of mobile learning applications, since the introduced framework could become a powerful and useful tool for them; for those also designing supportive tools to simplify the development of mobile learning applications; and in general for those involved in the development of any kind of e-learning or m-learning application, since the paper introduces a service-oriented methodology for the development of applications.

The paper is structured as follows: Chapter II offers an overview of the main goals of the system. Chapter III describes what the authors consider m-learning, and provides a mobile learning classification. This chapter is complemented with the learning theories and methodologies of Chapter IV. In chapter V, the necessity of the integration of the new technologies related to location systems into the m-learning environment is addressed. Chapter VI offers an overview of the Learning as a Service (LaaS) methodology used in the project design. Chapter VII shows the importance of the interconnection between the e-learning platforms and the m-learning applications, according with the LaaS paradigm. Finally, chapter VIII describes the design of the proposed middleware. Chapter IX offers an

overview of related works; and Chapter X some conclusions.

II. GOALS

The aim of the paper is the description of a framework developed recently by the authors that supports and simplify the creation of M-Learning applications: M2Learn [1].

The main contribution of this architecture is the combination of ubiquitous and context-aware technologies with the Learning as a Service (LaaS) paradigm, which will be introduced in the following chapters. The result is an easily-extended framework that offers useful services and information to high-level applications. Thus, developers using this framework will see their work considerably reduced.

Although there are many other frameworks to help in the creation of context-aware systems and mobile applications, this development supposes an improvement of the state of the art. The reason is because M2Learn is particularly focused on the learning environment, as its design is closely related with the existing e-learning platforms and tools. As a summary, the main features that the framework includes are:

- Context-awareness. Developed mobile applications will easily incorporate information about user's geo-location, which is useful for personalizing the services and activities offered to students; or for having a log of their movements in certain activities. Currently the location methods supported by the M2Learn framework are Global Positioning System (GPS), triangulation of Wi-Fi access points, and identification through Radio Frequency Identification (RFID). The framework also monitors student's hand movements through motion sensors. It offers a more natural way of interacting with technology, giving rise to a new kind of engaging applications. Other relevant piece of information to compile the student context is the academic profile (e.g., degree, subject, or preferences), since it can be used to personalize services and information according with their interests. Finally, the user's context contains the user's activities history (log), which can be useful to study user preferences (e.g., applications used, information accessed, etc), and movements in an environment (Figure 1).

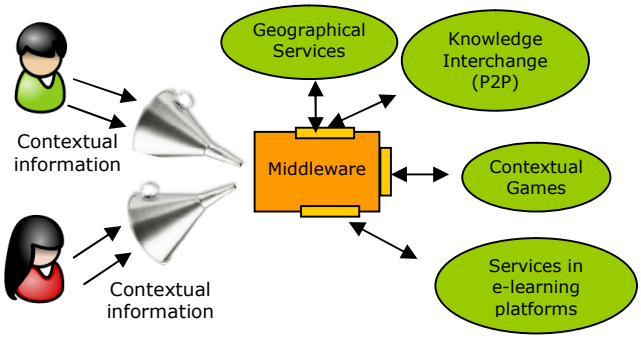

Figure 1. Offering personalized services and information depending on user's contextual information..

- Communication tools (e.g., forum, chats) from e-learning platforms (e.g., dotLRN or Moodle). Lately much effort has been undertaken to develop useful e-learning tools but most of the new mobile applications leave them aside, with almost no interoperability with other systems. For that reason, authors have developed interfaces between many e-learning services and the M2Learn framework. These interfaces let students access the e-learning contents and services not only anytime, but also anywhere, and with any kind of device. These interfaces also give the opportunity of integrating information from the mobile applications to the e-learning platforms.
- Collaboration. The framework supports the incorporation of Web-based tools for collaborative work such as Google Docs. This feature let the developer create mobile learning applications that include for example a text document that will be created collaboratively among the students.
- Knowledge. M2Learn framework manages different formats of knowledge representation, e.g., PDF, and DOC. But the framework also gives support to the integration of knowledge from search engines, web sites (e.g., Wikipedia) or Learning Management System's (LMS) FAQ.

In the development of this middleware, some issues have been considered, such as which is the best model of m-learning application: learning on the move or learning with mobile devices?; which is the kind of mobile applications that provides an added-value in the educational experience?; how the new features can be implemented inside these new kind of applications?; and why is better to include the existing e-learning resources into the mobile-learning paradigm instead of doing everything again from scratch?.

III. IS M-LEARNING LEARNING WITH MOBILE DEVICES OR LEARNING ON THE MOVE?

When we talk about mobile-learning, it is possible to assume that m-Learning is all kind of activity carried out in an educational environment with a mobile device. This trend basically moves the traditional learning, with a teacher giving a master class in a classroom, towards the mobile world. Many examples can be found, for example in [2] where an application on a mobile device reads a chapter of a book in a karaoke-style; or the MPSS project [3], where students must follow some courses and are evaluated through some test exercises using the mobile device.

On the other hand there are other m-learning projects oriented towards outdoor learning. This is a totally different point of view, due to the fact that in these projects the idea is not to try to apply the old methodology into the new technologies, but they try to develop new environments where mobile devices offer an added value to students' education. These environments do not try to supplant the master class. They just complement the traditional and more formal education, opening a new range of possibilities to

students. For example, Bouvin [4] worked in a prototype where learners should explore and document parts of a city for later presentation in plenum. Other project more oriented to the context-awareness is a prototype developed by Bomsdorf [5] allowing learning materials to be selected depending on a given situation – this takes into account learner profiles such as their location, time available for learning, concentration level and frequency of disruptions. Similarly, a context-aware mechanism has been developed by Bouzeghoub et al. [6], which takes into account time, place, user' knowledge, activity, and environment together with the device capacity for adaptation to the user.

After many years of researching in this field our point of view is that m-Learning must complement both e-learning and traditional learning, because in our opinion each methodology has its own place.

Thus, from our study [7], the most spread m-Learning applications can be classified into several kinds of applications depending on its functionality:

- Learning on the move: Intended to education out of class, not replacing the face-to-face class, but complementing it, and providing different ways of learning on the field. There, m-learning seems to cater for certain specialties more than others such as agronomy, biology, geology, archaeology, tourism, etc.
- Location-sensitive. Location-based systems provide a very interesting added-value to mobile learning applications. They allow the creation of context-aware applications that lets students interact with the environment in a totally new way. This kind of applications react specifically to their current location, time and other environment attributes and adapt their behavior according to the changing circumstances as context data may change rapidly.
- Mobile review: Mobile devices offer very good results for quick reviews of aspects that the students have previously learnt in class. This is typically useful for example in the train. This model is often presented for both review of contents with documents or notes; and auto-evaluation with quiz tests.
- Collaboration: Development of collaborative exercises together with other students, giving rise to applications such as mash-up systems (based on geographical information services), Wikis, or games.
- Services from e-learning tools. For instance, quick accesses to services of a LMS, for example, check the messages in the LMS forum of a course; or access a Virtual Lab.
- Podcast allows ubiquitous learning whereby students can access a variety of educational material anywhere, anytime on iPods, MP3 and MP4 players or mobile phones. Podcasts allow anywhere, anytime learning. They permit students to access educational materials at home, while travelling to university or work, or doing any activity they choose. They can play the recordings at any time, which is convenient to them rather than be confined to set class times. Podcasts in the educational setting allow students on-demand access to audio or video-recordings of lectures or other learning materials at their convenience. But although Podcast is a very in-fashion methodology, does not really suppose a revolution in education. It only applies the same methodology (a master class given by a lecturer) to a new format. It presents an important disadvantage that avoids its generalized use in education: it is one-way.
- Augmented Reality is a technology that basically merges information or images with video-streaming from a Web-cam. The result is similar to virtual reality but using real-world images in real-time. Some of the many potential revolutionary applications in education are related for example with the study of architecture, art, anatomy, decoration, or in general anything that a graphic, a simulation or a 3D model could improve the comprehension of the concepts.
- Games can be one of the most powerful tools for learning. Students are easily engaged with them, especially with those that use natural interaction, such as motion recognition (e.g., puzzles; or question-based contests using the mobile device as a pointer).
- Other useful m-learning applications are for example reminders or schedulers of the learning process. This applications helps students to remind some events at certain moments and places, e.g., "Remember take the Math's book from the Library" when the student is walking nearby.

The proposed framework has had in consideration the different possible applications that a mobile learning project includes, so it can offer useful information and services to them, simplifying considerably its development.

IV. LEARNING METHODOLOGIES AND THEORIES APPLIED TO MOBILE LEARNING

From the educational point of view, the different learning methodologies and theories have also been taken into account in the design of the M2Learn framework. The objective was to design a framework to give support to different kinds of applications, not only from the functionality point of view, but also from the educational.

According with the literacy, there is no academic theory or methodology specifically developed for mobile learning, addressing assessment, pedagogy and instructional design issues. In its place, the traditional learning theories are being applied with more or less success depending on the kind of application and environment. The following points describe the main theories, methodologies and paradigms.

A. Behaviorism

Learning theory mainly developed by Skinner. It is based upon the idea that all behaviors are acquired through conditioning [8]. The other important exponent of this theory

is Pavlov. According with Pavlov, behavior becomes a reflex of a given stimulus [9], as in the case of Pavlov's dogs. In this theory, learning is based on a stimulus (problem), its response (solution) and the reinforcement given (feedback). This reinforcement can be presented as a comment, an award or a punishment.

Mobile learning examples can be found in applications devoted to deliver content, get the learners' response and provide constant feedback:

- Classroom response systems [10].
- Mobile Performance Support System for Vocational Education and Training (MPSS Project) [11].
- Content delivery by SMS.

Roschelle describes as a benefit of the implantation of this theory in mobile learning the anonymity in the students' responses [12]. Thanks to technology students do not feel worried about consequences of bad answers. It helps the teacher in understanding the classroom's knowledge level [13].

Although this approach is widely used in e-learning and has some advantage in m-learning, it finds several disadvantages such as the use of limited displays and restricted input methods when it is used as a way to deliver content.

B. Constructivism

Constructivism views learning as a process in which the learner actively constructs or builds new ideas or concepts. It is often associated with pedagogic approaches that promote active learning, or learning by doing. In this theory, learning is viewed as a process where learners actively construct new concepts from their experiences (previous and current knowledge) [14] through two processes:

- **Accommodation**. The process of reframing the mental representation of the external world to fit new experiences. It also promotes that failure leads to learning. Along these lines, when we act on the expectation that the world operates in one way but it does not happen, we accommodate this new experience and reframe our model of the way the world works. So learning comes from the experience of failure, or others' failure.
- **Assimilation**. It is the incorporation of new experience into an already existing framework without changing that framework. This may occur when individuals' experiences are aligned with their internal representations of the world, but may also occur as a failure to change a faulty understanding. For example, they may not notice events, may misunderstand input from others, or may decide that an event is not important as information about the world. In contrast, when individuals' experiences contradict their internal representations, they may change their perceptions of the experiences to fit their internal representations.

In this theory, such as Bruner points out, instructors encourage students to discover principles by themselves, helping them to move from passive listeners to active constructors of knowledge by working to solve realistic problems [15].

Constructivism itself has many variations, such as Active learning, discovery learning, and knowledge building. Other branch is social constructivism that defends that knowledge is built when learners interact with others through talks and activities about shared problems or tasks. Here, learning is supported by more skilled members.

Regarding mobile learning, one of the most relevant applications within this learning theory is any kind of application based on role-games. To that effect, some educational games fit perfectly with this theory. Educational games provide an immersive experience that helps learners to act in the educational environment (virtual world) as an active. It provides a better knowledge acquisition, because they can manipulate the virtual world without the fear of a failure. Games also allow interacting with other learners collaborating to achieve a particular task.

Other kind of application that matches with this theory is the location-based systems aimed to facilitate learning out of the classroom, for example in an art or archaeological museum.

Finally, participatory simulations are also related to this theory [16]. This kind of applications proposes immersive recreation of real situations to become part of the process. Here learners do not watch a simulation, but they are part of it [13].

C. Situated learning

This paradigm promotes learning within an authentic context with social interaction [17] [18]. In this case, teachers propose problems to be solved (Problem and case-based learning) to students in real environments, where they feel immersed in an authentic environment that helps a better acquisition of knowledge. It fixes perfectly with mobile learning through the context aware and location-based systems [19] [20].

D. Observational Learning or Social learning theory

This kind of learning occurs when an observer's behavior changes after viewing the behavior of a model [21]. Thus, this paradigm is based on imitation of a model that the observer finds interesting, attractive or desirable in some way.

Although this approach does not necessarily imply interactivity, it is widely used in mobile learning through the use of Video-based systems (e.g., web-based video systems, mobile TV or Podcast), that transmit knowledge to learners through the use of videos. Other mobile applications that make use of this paradigm are those where authentic situations are described to show how to react in certain situations.

E. Collaborative learning

This paradigm promotes learning based on social interactions [22]. In this environment, there must be a

dynamic interaction among instructor, learners and the proposed activities to help them creating their own truth thanks to the interaction with the others.

This approach also fits perfectly with mobile learning, because handheld devices can offer synchronous and asynchronous communication methods. In addition, the Web 2.0 concept is arriving also to the mobile environment, supporting collaborative work such as edition of on-line documents, creation of wikis, blogs, virtual boards, etc.

V. NEW LEARNING NEEDS NEW TECHNOLOGIES

Once we determine the way to go inside m-Learning, other aspects must also be considered. Mobile devices are getting better everyday, incorporating new functionalities, such as GPS receivers, motion sensors, Wi-Fi connectivity, etc. These new features must be included inside the educational environment; especially those related with geo-location, due to the fact, knowing where students are in each moment can be used for offering them personalized services [23].

It is a fact that the main and most widely used location method in mobile devices is the Global Positioning System (GPS). This technology offers a quite reasonable accuracy at outdoor environments. Each GPS satellite transmits data that indicates its location and the current time. Signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are farther away than others. The distance to the GPS satellites can be determined by estimating the amount of time it takes for their signals to reach the receiver. When the receiver estimates the distance to at least four GPS satellites, it can calculate its position in three dimensions.

However, the use of this technology inside buildings is not possible (without the use of GPS repeaters, which are not very spread) because the receiver needs to have direct contact with the satellites. For that reason, technologies such as Wi-Fi, Cell towers or RFID are appearing in location systems for indoor environments.

In the Wi-Fi based location the mobile device recollects different levels of noise and power that the access points spread in an environment (at least 3 access points are required) every few milliseconds. This information is processed to obtain the user's coordinates [24].

This same philosophy is being applied with Cell Towers instead of using Wi-Fi. This is the case of the new iPod that is revolutionizing the mobile market thanks to its great interface features and location capabilities [25] [26].

On the other hand, Radio-frequency identification (RFID) is a technology that is being used in more environments, and is one of the pillars of the called "Internet of Things". It is an automatic identification method, consisting in storing and remotely retrieving data using devices called RFID tags or transponders [27]. This identification is usually used for identification [28], as the substitute of bar codes, tracking any kind of products or even animals or people. Some tags can be read from several meters away and beyond the line of sight of the reader. In addition this identification method can also be used to locate people in an area, but it only locates people when the RFID reader identifies the tag that the user carries.

VI. LEARNING AS A SERVICE (LAAS)

But innovation in mobile learning, besides hardware, also requires new methodologies and paradigms that guide the development of new projects.

In our case, during the last years we have been developing the Learning as a Service (LaaS) paradigm, which is an extension of the widely extended Software as a Service (SaaS). SaaS is based on the idea of having different services available on the Internet (on the Cloud) that can be used and integrated regardless of physical location. In the case of LaaS, these services will come mainly from e-learning applications, as we work in the education environment. As examples of services provided by e-learning applications and used in our middleware we can find: forum rooms and chat from LMS, Wikis, Blogs, collaboration tools, etc.

LaaS is based on the concept of modelling the educative services with the objective of providing better interoperability capabilities in different levels: service-service, platform-platform, and service-platform. Equally it is based on the encapsulation of learning objects services. The aim is to develop autonomous and self-contained services that can be easily integrated in different environments such as Learning Management Systems and mobile learning environments.

The main objective of this paradigm is the reuse of existing services, providing interoperability of services among platforms and applications. This methodology has been coined as a consequence of the important efforts already done in the e-learning field, and the fact that new mobile learning applications usually leave them aside.

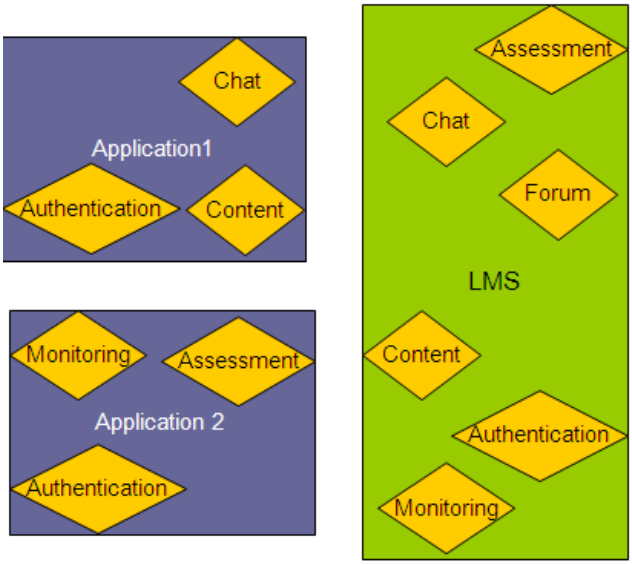

Figure 2. Different applications and LMS in an educational environment with replicated services.

New mobile developments tend to create everything from scratch, giving rise in one hand to a very spread student's e-portfolio. On the other hand, both economic and time project efforts are considerably higher than if services were designed for service reutilization and interoperability among platforms and applications (Figures 2 and 3).

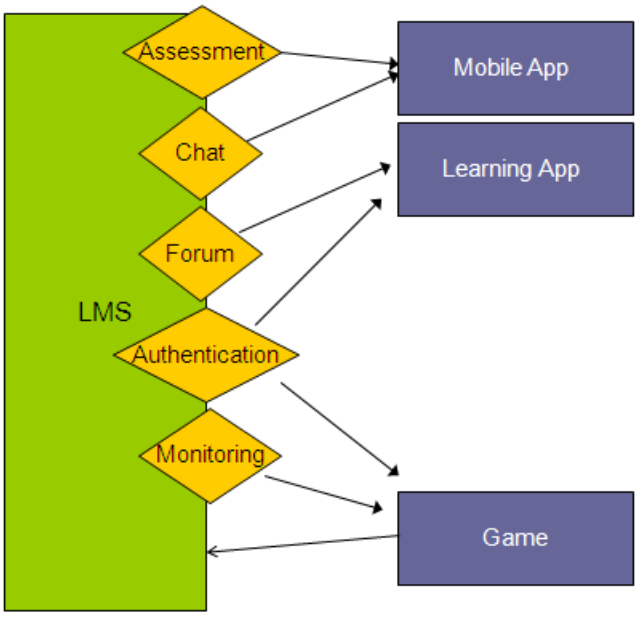

Figure 3. Reuse of service. Utilization of LMS's services in external applications, including games and mobile learning applications. Other applications such as games could include also services in the LMS.

As a consequence, LaaS methodology promulgates the creation of learning services that could be integrated in other applications and services. Thus, M2Learn framework includes interfaces to externalize many LMS's services, such as forum rooms, and FAQs to be easily integrated in mobile learning applications; games; or any other kind of applications. LaaS also remarks the importance of integration of external services into the LMSs, extending its functionality.

As a consequence, other result of the application of LaaS in our project is that the monitoring activities of mobile learning applications can be integrated into the LMS. Thus, teachers will have the opportunity to check the whole e-portfolio of the student, no matter if the information comes from the LMS, from a mobile application, or other service.

In addition, there is another surrounding concept to this methodology within educative services: Digital Educative Ecosystems [29]. This concept is based on the idea of creating environments made of different integrated systems (mobile clients, applications, services and other tools) devoted to improve the learning experience by supporting communication and collaboration. One of the bases of this concept is the use of SOA (Service-oriented architecture) technologies such as SOAP [30], Web Services [31], ESB (Enterprise Service Bus) [32] or REST [33]. Actually, most of the developed services in the project follow the REST methodology.

VII. Connecting with the Learning Repositories: Services in LMS

Reading the m-Learning bibliography, most of applications do not have any relation with the already existing LMS. Some examples are in [34], where a prototype was developed in order to use Moodle through Smartphones. Basically they changed the three-frame template of Moodle for a one-frame template to allow users to visualize better the content. Finally it did not offer the whole functionality of Moodle because many features did not work properly in a smartphone.

Other example can be found in [35] where a web service-based architecture is proposed to move some of the Moodle functionalities into a mobile device. This also allow to re-use some of the existing services in LMS, such as authentication, monitoring, etc., so it is not necessary to create them again.

Thus, excepting some prototypes, most of m-Learning systems are isolated and autonomous applications that do not make any use of the knowledge stored in them. These platforms are in fact the real support of the e-learning methodology, but it seems like we wanted to let them out of the m-Learning paradigm.

That is why we also try to interconnect these e-learning platforms with the mobile devices, in order to take advantage of all the services and knowledge already existing in them.

Our middleware interacts with the university LMS also through a set of RESTful Web Services, providing an interface to implement some functionalities in a mobile device, such as, access to forum rooms, content or FAQs. In addition, as we have cited before, there are other advantages related to the re-use of services instead of creating them again: authentication, tracking activities, evaluation, content, etc.

In addition, the LMSs can provide very useful contextual information. For example, for many context-aware applications knowing the courses where a student is signed in can be very useful in order to personalize the offered services. For example, by using the credentials (login and password) it is possible to retrieve information about his/her educational environment, e.g., accessing to the university's e-learning platform. In this case the system can know the student's degree or subjects, and provide this information to higher level applications that will use it to personalize the services provided to the student.

VIII. Middleware Design

Once we have achieved all these conclusions we are prepared to design the middleware that will make easier the creation of context-aware m-learning applications, interconnecting them with the already existing LMS services.

Firstly, the architecture of the system must ensure it is possible to use several sensor networks to provide contextual information about the user [36] [37]. For that reason several sensors controllers have been developed in order to understand the information provided by physical sensors (level 1 at figure 4). At this stage we are working

with GPS, RFID and Wi-Fi, but the system is designed using open interfaces so that it is easy to add new location methods, such as cell towers, Bluetooth, infrared, etc.

The proposed architecture can be studied as a stack of services, protocols and applications. At the top level is the context-aware application (level 6 at figure 4) that uses the contextual information provided by sensors to access to particular services such as information in a LMS, e-mail, etc (level 5 at figure 4).

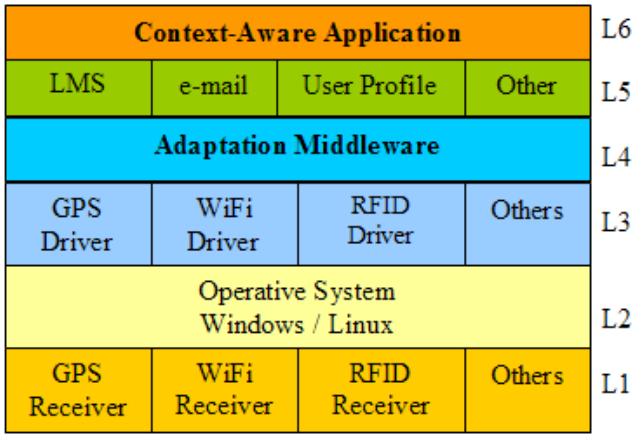

Figure 4. Architecture scheme

The most important level in the stack is the adaptation middleware (level 4 at figure 4) that is a homogenizer layer that offers an interface to the applications. The context-aware application will not have to interact with the sensors, and even it will not know from which sensor the information comes from at this time. This interface provides all the contextual information in a transparent way, ensuring the applications will not have to worry about the implementation of the lower layers. This is the same philosophy than the TCP/IP levels.

It is based on a set of wrappers (or controllers) that interact with the physical devices and offer homogeneous information about not only geo-location, but also about the user's context (Figure 5).

The main goal of this interface is to use the information retrieved from the location technologies to obtain more information about the user. For example, from a particular user is possible to know basic information like the geo-coordinates and the name. It is also possible to know information about the device and the operating system.

On the other hand, the framework uses a communication manager that is in charge of the management of the external communication services and tools. For example, one of the developed wrappers is an interface to a forum room in dotLRN, so the developer can easily create applications that read or write messages in a forum, so the teacher will be able to see the activity in the mobile application through the LMS. This particular interface has been developed creating a REST-like Web Service that wrap the complexity of the dotLRN forum management. The M2Learn framework connects with this service to offer this functionality to the mobile application developer.

Other example of service integrated in the framework is an intelligent question-answer system that retrieves information from different sources to answer students' questions. This service can be configured to access to Web Sites such as Wikipedia or the university site; institutional databases; or search engines to look up for answers.

Finally, the top level applications use all this information provided by the interface, but without knowing from which source it comes. The fact is that there is a lot of contextual information about the user and services that can be used to improve the learning experience.

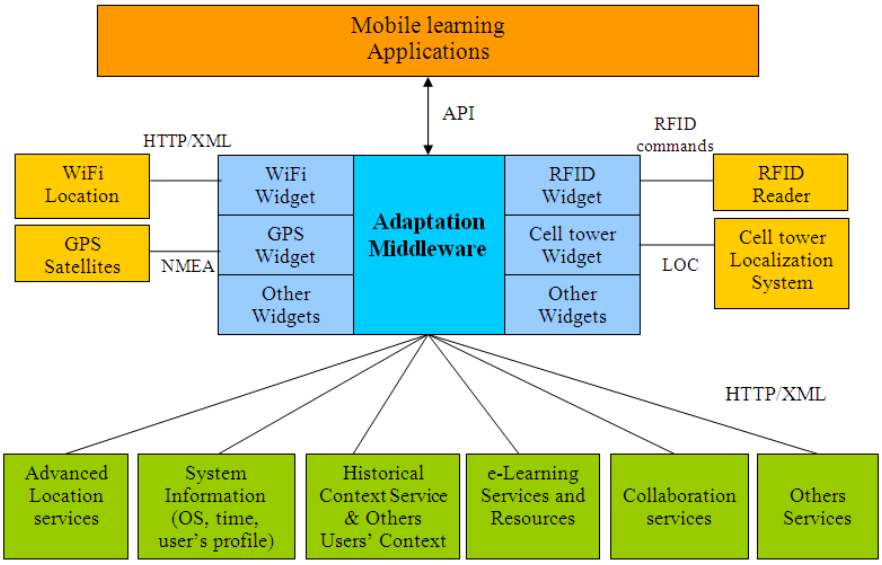

Figure 5. Architecture to provide interoperability between different location technologies and retrieve contextual information for M-Learning applications.

All these modules make up the M2Learn Unit (Figure 5). It is the API that higher level applications use to access the contextual information and personalized services.

This interaction is achieved through a set of Web Services. They provide an interface to implement mobile device functionality, such as for example, access to forum rooms, content, or FAQs. In addition, there are other advantages related to the re-use of services instead of creating them again: authentication, tracking activities, evaluation, content, etc. The LMS can also provide very useful contextual information.

However, a mobile learning environment is not made up of a single user, but is complex digital ecosystem with different kind of users (students, teachers, and staff), services, applications and platforms. That is why our scenario envisages the coexistence of several M2Learn Units communicating and collaborating simultaneously.

From a general overview, the mobile digital ecosystem built around the M2Learn framework contemplates the co-existence of (Figure 6): M2Learn units, e-learning applications, and LMS.

From a development point of view, there are two possible ways of building applications using the M2Learn framework:

- A mobile client built over the M2Learn framework, using its API to access the information and services available in the mobile digital ecosystem.
- A Mash-up system that retrieves the information of the mobile clients in the environment through the Context-Hub.

The interaction in this mobile digital ecosystem is possible thanks to two important modules:

- Context Hub. This module receives the user's contextual information and allows its distribution (Figure 7). Using the Context-Hub module users can discover information about other surrounding users. In addition, this module is also fundamental to support the development of mash-up systems. It provides contextual information of all the mash-up system users, which can merge location, preferences, history and other services.

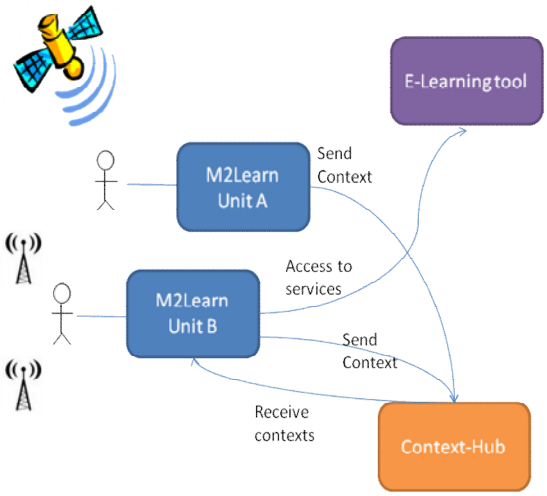

Figure 7. Several M2Learn Units sending their context to the Context-Hub. The Unit B retrieves all the context to allow high-level applications its use.

- Context Directory Service (CDS). This service is a central directory where all the external services must be registered in order to be available for the M2Learn Units. Later, applications built over the M2Learn framework access the CDS requesting the available services in this environment (Figure 8).

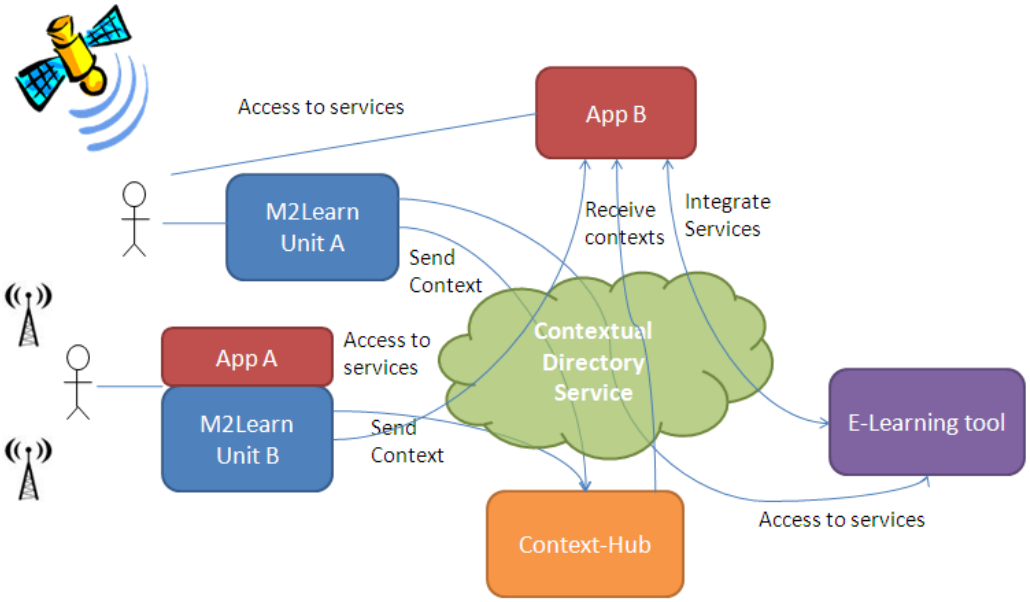

Figure 6. Interconnection of modules through the Contextual Directory Service. Some applications make use of the Context-Hub to get other users' contextual information. Application A is built in a mobile device over a M2Learn Unit, while the applications B in a Web-based Mash-up system that retrieves information of the mobile digital ecosystem and matches with a service from an e-learning tool.

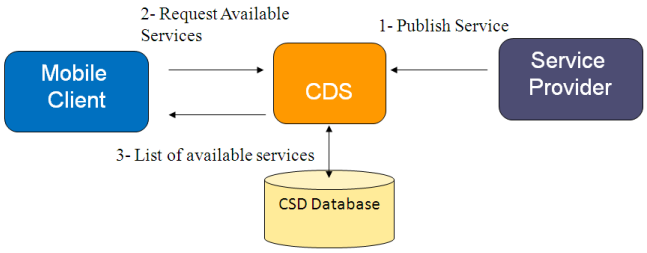

Figure 8. A service provider register a service in the CDS. Later a mobile application request the CDS the list of available services.

IX. EVALUATION

Evaluation has been conducted using students of a "Professional Expert Course on Mobile Programming". They have developed several applications using the framework. Later, students completed a questionnaire on user satisfaction and the simplification degree obtained through the framework's use.

Within this experience, students easily developed a mobile context-aware application that loaded different LOM-based resources depending on their location and profile. One of these resources was a simulation of a virtual laboratory of thermodynamics. The development of this application was effortless, and required very few lines of code thanks to the use of M2Learn.

X. RELATED WORK

In the following section other context-aware frameworks are described intended to create not only m-learning applications, but any kind of context-aware system. But any of them offer the same set of features than our framework, due to the fact that it offers information and services not only from the mobile device (contextual information) but also from the university LMS and from other external services.

A. *HyCon Framework*

The HyCon framework [38] was developed to provide a general platform suitable for experiments with hypermedia mechanisms in a context-aware and mobile environment. HyCon encompasses an infrastructure for implementing context-aware services and applications and a framework, which can be used by applications programmers to build such services and applications.

B. *Stick-e Note Architecture*

The Stick-e note software [39] infrastructure developed at the University of Kent and provides one of the first approaches to support the development of context-aware applications.

The aim of the infrastructure is to simplify the creation of context-aware applications using the electronic equivalent of a Post-it note and, as such, it focuses on information presentation and in particular discrete context-aware applications, i.e., those in which the information presented to the user does not change continuously.

In such applications, separate pieces of information are attached to specific contexts (location, states, temporal ranges, and adjacency) and are presented to the user when the appropriate context is entered.

The infrastructure is aimed at mobile users carrying small computing devices, such as PDAs, enhanced with environmental sensors, but is essentially an on-line system and does not explicitly address mobility issues.

C. The Context Toolkit

The Context Toolkit [40] is an architecture developed at the Georgia Institute of Technology that aims to provide reusable solutions to the problems of developing context-aware applications. The main aim of the toolkit is to free developers from having to deal with the low-level details of context acquisition and allow them to concentrate on the specification of higher-level application behaviours.

The toolkit is inspired by the success of toolkits for Graphical User Interface (GUI) development and is based on the GUI concept of a widget as a reusable component for abstracting away from and hiding the specifics of a physical device. Through the widget abstraction, the Context Toolkit aims to enable context data to be handled in the same way user input is currently handled.

The Context Toolkit provides useful domain-specific abstractions for the incorporation of context data garnered from sensors into applications, through the use of the widget abstraction, and this is its major strength. In addition, the interpreter abstraction of the toolkit provides a means to convert sensor data to higher-level context.

D. *MiLK: The Mobile Informal Learning Kit*

MiLK [41] is a support tool that allows teachers and students to develop event paths that consist of a series SMS question and answer messages that lead players through a series of checkpoints between point A and point B. These event paths can be designed to suit desired learning scenarios and can be used to explore a particular place or subject. They can also be designed to facilitate formal or informal learning experiences.

E. *The Context Fabric*

The Context Fabric project being carried out by the Group for User Interface Research at the University of California at Berkeley [42] proposes a novel approach to providing support for context-awareness in the form of a service infrastructure model. This model attempts to shift as much of the task of context-aware computing as possible to a network-accessible middleware.

This approach aims to aid the development of applications based on a diverse and constantly changing set of sensors and devices by providing uniform abstractions and reliable services for common operations. The Context

Fabric provides sensor abstraction and is one of the few projects providing an explicit treatment of proximity as a useful concept in context-aware computing. Sensor fusion as an approach to managing the uncertainty of sensor data is not dealt with in the project.

XI. CONCLUSSION

M2Learn project gives a solution to the development problems within the mobile learning field. At the same time, this project promotes the creation of innovative applications and provides the guide for the development of new applications based on the new key factors of mobility in learning: context-awareness, social interaction and integration of e-learning resources.

Mobile devices are a very familiar tool for learners. Their experiences are closer to the use of videogames; watch videos; communication via mobile devices; and use of collaborative technologies (e.g., blogs, wikis, mash-ups and social networks) than to be a mere listener in a master class given by a teacher. Therefore, thanks to the use of these devices, students will take an active role in the learning process in a more interactive and according way to what they are accustomed to use. Learners will feel more motivated and engagement with learning. This idea was remarked by Elliot Soloway, an expert in mobile learning from the University of Michigan: "*The kids these days are not digital kids. The digital kids were in the '90s. The kids today are mobile, and there's a difference. Digital is the old way of thinking, mobile is the new way*."

M2Learn project is intended to give a step further in the state of the art of design of mobile learning applications. It supports the development of innovative mobile learning applications that really complement and enrich the learning experience. This is a learner-centred paradigm that really encourage the "anywhere, anytime", improving the social interactions, providing a personalized educative experience to each learner, and reaching to places where traditional or on-line learning cannot reach. M2Learn Middleware is devoted to help mobile learning to find its place in education, as a complement to traditional and on-line learning instead of replacing them and promoting blended approaches.

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