# Towards a Wireless Architecture for Mobile Ubiquitous E-Learning*

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**Abstract**

New wireless technologies can be used to boost interactivity, thus helping create community, as people remain online even while going about their business. The use of wireless technology paves the way for a literal interpretation of *mobile ubiquitous computing*. People can get online, be reached, and interact *anywhere* and *anytime*. In this paper, we propose an original platform based on wireless technologies to support learning communities in university campuses and discuss how it could be used to improve ubiquitous interactivity and cooperation among teachers and students.
**Keywords:** learning community; wireless technologies; mobile and ubiquitous computing.

## 1 Introduction

Students taking notes on laptops or tablet PCs, rather than on paper, are an increasingly frequent sight on campus. The devices they use are often equipped with wireless network interface cards (WNICs), based on either Bluetooth or Wi-Fi technology [5, 13]. *Thin devices* are even more widespread: almost all students own a mobile phone and often a PDA, in addition, both of which may also have a wireless interface. Smartphones with wireless connection technology such as GPRS, UMTS or EDGE [12] are becoming available and the quality of data transmission is nearing that of home desktop computers connected to the internet via ADSL over a wired line, thus enabling the exchange of multimedia content with the devices carried by students.

New wireless technologies can be used to boost interactivity, thus helping create community, as people remain online even while moving around. The use of wireless connectivity means that the technology is now here for us to lend literal meaning to the expression *mobile ubiquitous computing*. People can get online, be reached, and interact *anywhere* and *anytime*, not only when they are at a desktop in their office, a terminal in a department laboratory or their home PC but also while they are traveling from one place to another, while on a train or bus. A person can be online during a break in the cafeteria or while resting in the park after lunch. The user's environment no longer needs to be re-created whenever s/he shifts from one platform to another in carrying out cooperative work or participating in the community; rather, the environment constantly follows each user.

In this paper, we propose a *wireless e-learning platform* that enables students and teachers to interact, cooperate, and be involved in a university learning community, anywhere and anytime. In section 2, we describe the cooperative environment we envision and the value-added services that

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this platform can make available; related works in the literature are briefly surveyed in section 2.1. In section 3, we outline the functional modules that make up the platform architecture and discuss the technological issues and requirements to be considered in deploying the platform. Section 4 lays out our plans for continuing this work.

## 2 Application Scenario

Our platform is designed to provide four main functionalities that support learning on a university campus. The functionalities integrate with one another so as to build a "cocoon" that wraps a student in a university community offering learning activities anywhere and anytime. The functionalities are:

1. fostering cooperation and interactivity among students and with teachers during lessons, both inside the classroom and out;
2. supporting students in their training process, favoring the creation of study groups;
3. providing students with an enhanced information-distribution system for items of interest;
4. allowing students access to campus facilities.

As far as point one is concerned, the PCs held by students and teachers and equipped with WNICs can be used to deploy a *mobile ad hoc network* (MANET) [14], i.e. a network infrastructure that provides wireless interconnection among mobile devices. A MANET is deployed on-demand – e.g. when a lesson starts – and enables the use of unequipped classrooms for laboratory activities, thus optimizing the use of campus resources. If the area covered by a MANET includes an access point (AP), i.e. a device equipped with both wired and wireless network cards, a *hybrid* wired/wireless network can be built. This might, for example, allow students to download documents from the internet related to topics under discussion in class that have been pointed out by the teacher. Building a *virtual classroom* equipped with students' own devices has the additional advantage that all the work performed is stored on the student hosts and thus accessible without subsequent access to the campus network.

The availability of a communication network and of thin devices enhances interactivity among students and teachers, thus supporting the creation and management of a learning community. Students can use multicast and broadcast network services to publish their questions to the class, see the questions asked by others, and perhaps indicate priority for such questions. The instructor can thus continuously monitor the list of pending questions, sorted by priority, and decide what questions to answer when. Students may also be allowed to reply to classmates' questions, with their responses checked by the teacher. Thin devices can be exploited either to ask the teacher short questions or to reply to the teacher's questions – multiple-answer or fill-in-the-blanks, for instance – posed in class. A teacher can incorporate content created on the fly during class into his/her lessons, by distributing a slide, a drawing or other content from disk to students, who can save it and add notes, instead of having students who either copy (part of) the lesson by hand or download it from the teacher's website afterwards. Because of the wireless nature of the interconnection network, the deployment of a virtual classroom is equally easy when the lesson takes place off campus. The same can be true of browsing the internet from locations where a wired network is unavailable, once an access point has been included in the MANET. Imagine, for example, veterinary students visiting a farm, geology students visiting the Dolomites or groups that tour museums or industrial installations.

Obviously, MANETs can be similarly exploited to allow students to form study groups, to exchange their documents and class notes, as well as to do collaborative exercises, regardless of where they are, be it a cafeteria, a library, a study hall, a dorm or a train. This is not simply a case of finding an educational use for a technology because the technology is here. It is true that ubiquitous communication is inevitably a growing factor in group dynamics but, moreover, mobile devices, properly deployed, are valuable tools in leading a group to "consciously examine its processes" so as to "improve its ability to operate as a group" [15] (p.104), an essential aspect of teaching adults and part of the raison d'être for group learning and training. The interaction such devices afford has become one to the internal factors that traditional education has so famously overlooked [15] (p.89). The transition from educating groups of individuals to fostering the growth of a culture among groups as a whole [15] (p.117) has been underway since the mid-twentieth century, well before the changes brought about by the information revolution began to make themselves felt in the classroom, but these more recent advances have changed the nature of the very space we live, learn, and teach in. It is imperative for educational institutions to turn this "feature of the epochal transition into a resource for teaching" [6].

Furthermore, there is valuable promise in the potential for an activity such as distributed note-taking to embody a convergence of developments on the social (or even cognitive) and on the technological planes. The shift of focus away from the individual to "socially shared cognition" looms large in [9]'s *mots de l'éscalier* apropos of the artifacts of culture that bespeak the process of growing contextualization. The *bon mots* about "distributed intelligence" in an introduction whose admitted hindsight covers the decade from 1983 to 1993 thus somewhat antedate the widespread adoption of distributed technologies in social interaction. This convergence can be no accident and is itself an example of contextualization. With this borne in mind, it is not hard to see how simply sitting together in a room does not represent an actual complete context for a generation of college students who, in Italy at least, have been living a "continuously shared life" through texting (i.e. sending short cellphone messages) since they were teenagers. This "shared space" has created a parallel reality [24] (pp. 16-17) alongside the extra-virtual space occupied by so many silent individuals in a classroom (using "extra-virtual" to identify the physical environment we might refer to as "real-world," were it not for the bias of an earlier era reflected in this view of what is real). The presence of this other world of existence with its great potential for collaborative endeavor has implications too great for the educator to ignore.

Wireless devices not only allow their owners to participate in cooperative applications; they can be used to obtain information relevant to a user from the environment. Everyone has felt the frustration of navigating through a university website for a long time before finding the notice s/he was looking for, of overlooking an urgent notice that was published just before the event it referred to or of struggling to find information amid a boardful of notices. By contrast, a *virtual bulletin board* can be designed to *push* urgent notices (e.g. a class or exam moved to a different classroom at the last minute or canceled), either on people's thin devices or by sending an *instant message* [25] to be read from any location via wireless device. Unlike desktop-based email, pushed messaging on ubiquitous devices need not be treated as wholly asynchronous communication. Rather, its virtue is precisely that it is atopical, i.e. it belongs to a spatial context that may overlap, run parallel to or coincide with the physical context that the recipient happens to inhabit at the moment of being texted. Nevertheless, this type of communication shares with email the quality of deferred retrieval, so that a room-change announcement, for example, may be noted by a recipient who makes no effort to allow the details of the change to register; for s/he is well aware that the pushed message can be pulled anew as its extra-virtual relevance draws toward the threshold of critical information. Such a *virtual bulletin board* is built by means of multicast communication mechanisms that support both classifying the group of users interested in a certain news item and routing the news to them. Wireless technology also allows implementation of an *intelligent environment* where people can interact so as to obtain useful information, for instance by exploiting RFID [1] through RFID tags affixed on doors of faculty and student-service offices. People can download information that affects them to their wireless devices from RFID tags. This could prove useful for office hours, class schedules, and reading lists, for example, as well as, announcements of grants or Ph.D. positions. Updates of this information might well then also be pushed to those who had signed up during an earlier visit. A navigation service can be provided, enabling students and visitors to find out where they are on campus and how they can reach their destination by downloading a campus map from the MANET to a PDA or smartphone that 'knows' their current location. Active RFID could be used to enable people to leave "notes" in the environment, letting others know a textbook has arrived at the bookshop or commenting on the day's lunch menu. Such wireless graffiti would not only make the information available without entering the facility (reducing repeated questions) but also put interactive life, "the shared urban living space" [24], into the physical campus. This would serve to prevent the parallel context from consisting of dead air.

The technologies mentioned above can be integrated into the environment in order to offer other, marginal functions such as identifying people. Many universities need to control access to facilities such as cafeterias, parking lots, libraries, and copy machines. Currently, students at the Università di Milano have a magnetic card they use to log in to ATM-like machines to sign up for exams or print out certificates summarizing their academic career to date, i.e. the list of credits they have acquired. The drawback of magnetic cards is that they cannot interact with the surrounding environment. Here, again, RFID technology might offer better support for such services. The point is not just to provide access-control functions in a fancier way but to integrate subsidiary, administrative tasks with the actual activities that are the cognitive tokens of the same community membership whose physical tokens consist of access functions. Information lies at the interface between these two spheres of existence and therefore presents a natural opportunity for integration.

### 2.1 Related works

We have considered various works in the literature that propose solutions to support ubiquitous e-learning through wireless technology. *ActiveCampus* [2] is the platform that most closely resembles our proposal. It has two parts, *ActiveClass* and *ActiveCampus Explorer*, both web-based. The former module is a query/answer system that uses a central server to gather students' questions in the classroom and publish them on both teacher and students hosts. The centralized server may prove to be a bottleneck, while a distributed solution would probably scale better. Furthermore, a distributed solution could also be deployed in environments where no server is available (e.g., in activities outside the classroom where only the participants' devices can be exploited). Moreover, *ActiveClass* does not take into account the need to distribute multimedia or access the internet during lessons. The latter module allows a user to discover people, places or information of interest in the neighborhood, to communicate with people, and to leave annotations in the environments for other interested users. *ActiveCampus Explorer* was designed for point-to-point interaction between a user and another entity. It could be extended so as to publish notices for certain subgroups of users. Neither of the two components provides a function to support interaction and cooperation inside study groups formed on the fly by students.

Systems that assess students in class over thin devices have already been deployed. In [19], cellular phones are used to identify students in the classroom and locate them as they ask or answer questions. This system is heavily based on the peculiar characteristics of the I-MODE service, which for instance identifies thin devices through a unique identifier rather than via the phone number, thus guaranteeing student privacy. In universities in the United States, textbooks accompanied by a personal response system ("clicker") are increasingly popular [11]. Clickers are thin devices with an infrared wireless interface that allow students to reply to multiple-choice questions a teacher poses to the class. A clicker is sold along with each copy of the textbook. It is distinguished by a unique code that enables teachers to identify students and see how each of them replied to a certain question. A drawback of these systems is that the wireless technology they adopt has a limited communication range (around 25 meters), cannot support a large number of students, and is highly sensitive to external interference, such as sunlight coming in classroom windows. Moreover, clickers are inexpensive but support only very simple interaction because their reduced keyboard offers only a few input functions.

Several proposals support interaction with the environment on behalf of users visiting a site. *MUSEX* [31] supports children learning and interacting in a museum employing PDAs. Masterpieces are tagged with RFID tags that can be queried to download content related to the work being observed. *PAST* [3] allows visitors to an archaeological site to download content onto their PDAs, explaining major attractions in the neighborhood, based on the current user location. Tourists using the Lancaster *GUIDE* system [16] can use wireless APs to download information about monuments to visit or ongoing events, which are selected by the system according to a tourist's interests, as provided to the system through a form filled out by tourists themselves. These are only some examples. Such platforms focus on point-to-point interaction between a user and the environment, but are not tailored to the needs of learning inside a campus. Nor they are able to support cooperation among users.

## 3 Functional Architecture and Technological Issues

The services described in the previous section can be provided by a distributed platform customized to exploit different wireless technologies on different kinds of devices. We assume that each person is equipped with one or more wireless devices, counting laptops, PDAs, smartphones and cellular phones. Moreover, students, and perhaps university staff and faculty, are assigned an RFID card. Main offices in the campus have wired internet access, but APs are also placed around campus to support internet connectivity even where no wired network is available. Which services a given user is offered depend on the devices s/he wears or carries. The functional modules that make up the proposed wireless e-learning platform are represented in fig.1, according to the ISO/OSI reference network architecture [29]. A device may carry only a subset of modules, depending on what type it is and on the services it can convey.

The MAC layer involves protocols for MANET characterization, which is needed to deploy virtual classrooms or to establish study groups. The ad hoc module might implement a modified version of protocols proposed in the literature [21], because, in wireless e-learning, a given MANET must involve only devices related via the application they are cooperating with, which does not necessarily mean all the devices in a given area. A module capable of establishing a *hybrid* network is needed. This is useful, for instance, where an AP is available, to extend MANETs so as to allow people internet access or when an instant message has to be sent through the hybrid campus network. *Quality-of-Service* (QoS) functionalities are needed to exchange multimedia content among participants either in a lesson in a virtual classroom or in a study group. The QoS service at the MAC level usually consists of channel access policies (e.g. [27]) and queuing-management policies (e.g. [4]) that guarantee a certain minimum bandwidth as required by applications. The *RFID* module is needed to deploy an intelligent environment. It allows wireless devices to interface with RFID tags that label office doors or display cases so as to provide users with information about the office's

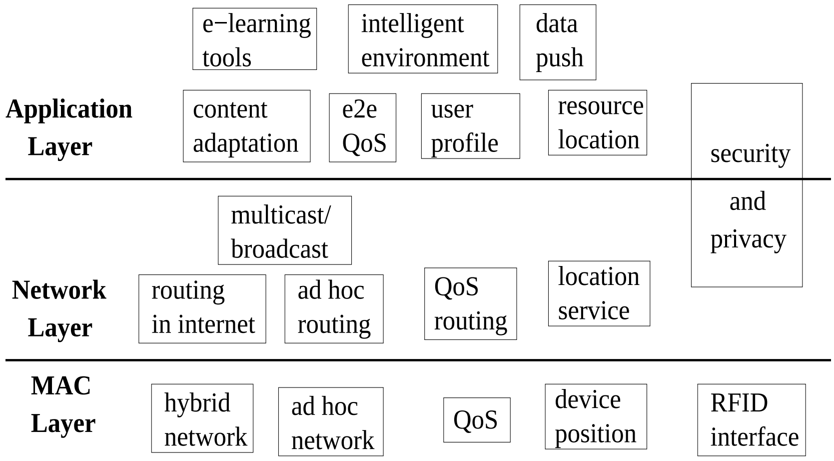


Figure 1: Functional architecture of the wireless e-learning platform.

staff or faculty or the exhibit's content. It is also needed to recognize a user when s/he wants to access a campus facility. The *device position* module at the MAC layer implements triangulation algorithms (e.g. [18]) that determine the position of a certain device in the environment. This service is useful for navigating, i.e. showing a visitor his/her current position on campus.

At the network layer, *routing protocols* are needed either to exchange data within a virtual classroom or study group or to deliver urgent notices to the right users. Routing must be accomplished on either a MANET or a hybrid network. In addition to unicast, *multicast* and *broadcast* services (e.g. [20]) are also needed, in either case, to support group communication in cooperative activities or to send data to multiple recipients - up to and including all the recipients in a given MANET. The *location service* module is needed to push urgent notices to users roaming around the campus. This module provides distributed service to determine the current location of a given device (a PC, PDA or whatever). This information is useful, for example, to position-based routing protocols [10], which find a path toward one or multiple destinations, on demand, in a highly mobile environment. Our wireless e-learning platform exploits the location service to route urgent notices to the subset of users interested in the notice topic according to their profiles and to maintain a routing infrastructure among the users who are cooperating in a study group despite their peregrinations around campus.

QoS support may also be needed at this level to exchange audiovisual content or to guarantee low latencies both to real-time interactive applications and to high priority traffic. At the network layer, QoS is guaranteed through routing protocols that find a suitable path for transmitting data as a function of QoS requirements. These may reserve bandwidth and buffer resources along the established path (e.g. [17]). Certain cooperative applications could, on the other hand, require high reliability in data delivery, as a QoS guarantee. Reliable multicast protocols such as [20] are fully accommodated by this module.

At the application layer, the *user-profile* module is in charge of recording information about each user that allows the system to supply him/her with customized services. The module registers the topics of interest, i.e.: the courses a teacher is in charge of or a student is enrolled in, the kind of device s/he prefers (chosen from those listed at the beginning of this section), the device's address (the unique MAC address in the case of either a laptop or a PDA, the phone number otherwise), and the application chosen for the virtual bulletin board. Possibly, several devices and applications may be listed in order of decreasing priority, for use in case one of them is not available. The *content-adaptation* module is in charge of translating content into different formats suitable for different devices. As an example: users can be notified of the time and classroom for an exam according to a registered preference for notification on their PC screens via an image that shows a screenshot of the classroom reservation the teacher made on the departmental website. Due to the bandwidth and memory constraints of thin devices, this notice would be converted into an SMS text message (short-message service) for users who would rather receive notices on their mobile phones. The *resource-location* module has a twofold purpose: it aims at determining whether a person is currently connected to the campus network through either a wired or wireless device, whenever an urgent notice must be delivered to him/her according to the topics of interest in his/her profile and the preferred device is either a PC or a PDA. In the former case, the location information is exploited together with the output of the location service (from network layer) to build an appropriate routing structure to push the urgent message through the network (*data-push* module). If the person is not connected to the network or the preferred device is a cellular phone, the notice is translated into the appropriate format – by the content adaptation module – so as to be sent via the wireless phone network. Moreover, the *resource-location* module identifies shared services and content supplied by other users or devices in the framework of distributed cooperative applications [22]. In this case, the module also provides information about the protocols needed to access those resources and about how their parameters are customized.

Application-level protocols for end-to-end QoS are also implemented, such as the Real-Time Protocol [26]. The *intelligent environment* module provides a user interface between the wireless device and an RFID tag that the device's owner can interrogate for information about the surrounding environment. The *e-learning* module groups a collection of tools that support teaching and learning inside the classroom and out, for participating in study groups and sharing content, for student assessment. Peer-to-peer tools [7] might also be included in this module.

*Security and privacy* policies are implemented at both the network and application layers. Specifically, the policies must guarantee that only interested devices are connected to a MANET and associated with a certain workgroup or cooperative application. They have to ensure that user-profile information is accessible only to authorized parties, as is information about a user's current location. They need to prevent the data being exchanged by users in a workgroup from being overheard by third – unauthorized – parties, and so on.

## 4 Concluding remarks and open issues

In this paper, we propose an original platform based on wireless technologies to support learning communities in university campuses and discuss how it could be used to improve ubiquitous interactivity and cooperation among teachers and students. The value of rooting community in parallel but twinned realities, whose existence is both online (albeit wired) and extra-virtual, is long established [8], as are the value of diamesic discourse variety in communities of practice [30] and the efficacy of multimodal intelligibility [28]. In other words, communities become more effective at joint tasks as messages are conveyed over an increasing range of communication means and perceived through concurrent representational schemas. Moreover, as messages specialize for conveyance over various media, audience diversity requires multiple transmission channels and different synchronizations for the same message *the more so the more general the message*, it turns out [23]. Applied to the classroom, this implies that pressure will only increase to convey the same didactic message in written, drawn, and spoken form, at both real-time and deferred instants, and toward both extra-virtual and (spatially or communicatively) distanced learners. Because no single instructor could possibly teach at such bandwidth, only a wireless learning community will be able to cascade out information at the clip demanded.

Possible implementations of some of the functional modules have already been proposed in the literature; however, their suitability with respect to the peculiar characteristics of this environment needs to be analyzed. Adaptation may be required. Original, alternative algorithms, better suited to a wireless e-learning platform, may have to be designed. Other modules must be completely designed from scratch. Interfacing among both existing and original modules must be accomplished.

As a first step toward developing such a platform, we are modifying the ActiveCampus system [2] so as to decentralize it and base it on a MANET. Implementation is underway and experiments will involve laptops, PDAs, and mobile phones equipped with either Wi-Fi or Bluetooth interfaces. Our laboratory's Wi-Fi network and a cellular phone network will be used for connectivity. At the same time, we are developing a complete specification for the wireless e-learning-platform architecture, including module interfaces and data flows among them, to serve as a reference for module design and interoperability.

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