Specification of a Functional Architecture for E-Learning Supported by Wireless Technologies

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Abstract

This paper proposes a distributed platform designed to support pervasive learning and interactivity on a university campus and to ease tasks related to learning and teaching. The platform exploits wireless technologies in order to provide service access anywhere and anytime. The platform architecture is described, and the functionalities of the modules composing it are discussed, together with the relationships among modules.

1. Introduction

The availability and use of small-size devices (*thin devices*) equipped with wireless network interface cards (WNICs) is increasing, thanks to the standardization of wireless technologies and the low cost of devices. Almost all young people own a cellular phone – now with support for value-added services such as the ability to transfer images and browse the Internet – while PDAs (Personal Digital Assistants), *smartphones* and laptops are increasingly widespread. This work proposes the functional architecture for a system to exploit such devices in support of pervasive teaching and learning on a university campus, so as to boost interactivity among students and with teachers, as well as to make services and functionalities available *where* and *when* the user wants. Thin devices help achieve this goal because of their portability: a user may carry his/her own device – storing all his/her personal data such as agenda, phone numbers and so on – *wherever* s/he is, and use it to gather information about the surrounding environment. Thanks to wireless technologies, devices are *potentially* able to interact with one another and with the environment without the need for networking infrastructures. Users could thus access data and services *anytime* and *anywhere*, even while moving. The infrastructure described in this work is designed to support interactivity and content exchange, both inside and outside class, as well as within workgroups, to enhance distribution of relevant notices and to support *ambient intelligence*. The innovative aspect of our project is twofold. From a pedagogic point of view, the proposed infrastructure aims at integrating a variety of learning and teaching tasks, while making course contents available outside class *on devices owned by users*, thus boosting continuous involvement. As we have pointed out elsewhere [1], owning the devices encourages learners to consider the content 'theirs', too. This principle has been borne out in recent experience with student's readiness to review lessons on iPods or iPod-like devices when instructors provide materials in .mp3 format, easing the melding of study time into time spent commuting, for example. From a technological point of view, it highlights the main functional requirements to be satisfied, through the design and deployment of a whole stack of novel protocols and services. Various projects to support learning through wireless technologies (*W-Learning*) have been proposed in the literature (e.g., [2, 3, 4, 5]). These systems usually involve point-to-point interactions only. The ActiveCampus [6] proposal comes closest to the system envisioned in this work. However, ActiveCampus does not support group interaction among multiple wireless devices organized in a *Mobile Ad Hoc Network* (MANET), nor does it supply the large variety of services that are integrated into the proposed infrastructure. The social impact the proposed platform could have is analyzed in [7], which also contains more thorough discussion of related work.

2. System Overview

The environment envisioned supports services that fall into four main classes (fig.1):

1. **In-class activities:** A *virtual* class can be formed either in an unequipped classroom on campus or in a site students are visiting. A communication network is deployed on an ad hoc basis using students' and teach-

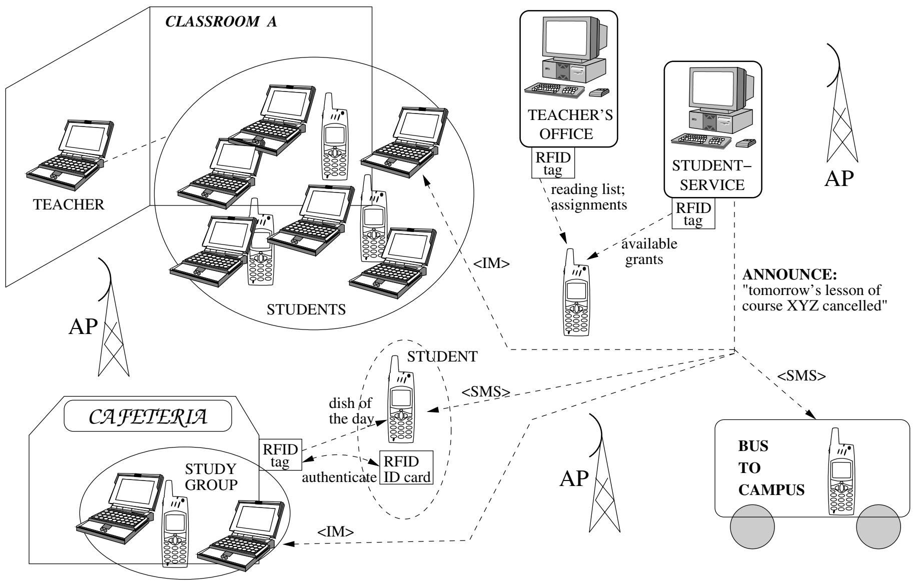

Figure 1. Layout of the environment envisioned

ers' devices. This group of services includes tools for sharing content among the participants in a lesson, for student assessment, for a *query & answer* system. Internet browsing is possible if an access point (AP) to the fixed network is within range.

2. **Group training:** The same services used to support interactivity during a lesson can be applied during training within groups of students. Wireless networking allows a group to be set up *anywhere*. If enough network coverage can be achieved – for instance through APs or gateways with WNICs – by connecting different wireless LANs, then users outside of reciprocal communication range or on the move can participate in a group.

3. **Announcement system:** This service aims to promptly deliver urgent notices to interested users only, wherever they may be, in the most appropriate format, as per their preferences (e.g. an SMS on their cellphones rather than an Instant Message on their laptops).

4. **Ambient intelligence:** The infrastructure involves tools that allow users to locate resources (e.g. offices) on the campus map, and to obtain information from the environment through their portable devices.

3. Proposed infrastructure

In order to provide the classes of service mentioned above, functionalities must be deployed at all architectural layers (fig.2). An incremental specification of the platform is provided below, analyzing what functional modules are needed for each class. In sec.3.2, interactions among modules are described. On a given device only a subset of modules may be implemented, depending on the device's characteristics.

3.1. Functional modules

In-class activities. When students form a virtual class, the platform runs mechanisms to build a MANET from their devices. Each WNIC on each device has an appropriate wireless MAC module associated with it (not shown in the figure) that implements the first two levels of the OSI stack for a given wireless technology. If APs are available, connections to a fixed network are possible. Because students and teachers may own devices equipped with different technologies, a heterogeneous network must be deployed. As an example, communication between two Bluetooth devices that are in the same classroom but are members of different piconets could take place via Wi-Fi/Bluetooth gateways and an intermediate Wi-Fi 'cloud.' The *ad hoc gateway* module at the network layer is responsible for translating packets routed among heterogeneous networks into the proper format depending on the nature of the next-hop link. This module is found only on devices equipped with multiple WNICs and on APs, as it can also take care of interoperation with the internet. Devices with gateway functionalities could be spread out around the physical space or obtained by supplying some students with extra WNICs in order to guarantee all participants network connectivity. Packet forwarding is performed along the paths through the heteroge-

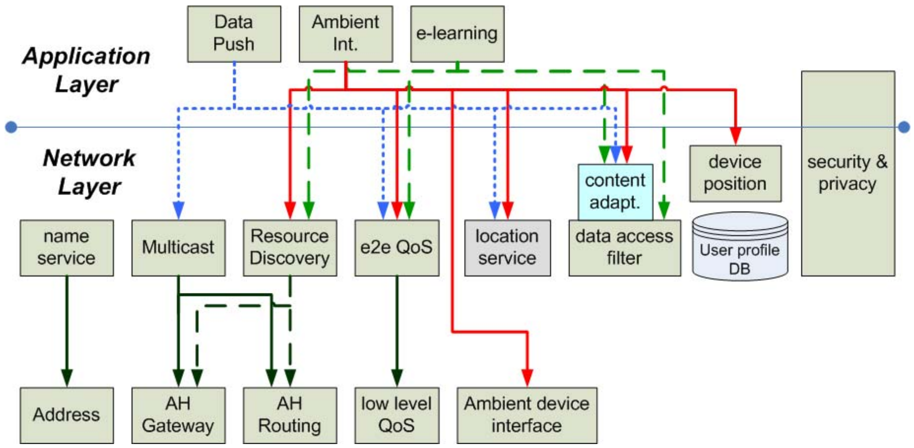

Figure 2. Functional architecture

neous network found by the *ad hoc routing* module. The topology considered for routing involves all existing wireless links, independently of their technology. Because a virtual class might be deployed not only in a classroom but also off campus, routing modules must be able to deal with *mobility* when students dynamically change their positions with respect to one another. Inside a classroom, communications may be either point-to-point from a student to the teacher – e.g. when a student replies to a question – or multicast, when a student's question is shown to everyone in the class or when a teacher wants to distribute contents from his/her device to all the students. In the latter case, group membership may change dynamically as students arrive late or leave early. Membership monitoring and multicast routing rely on the *multicast* module. If multimedia content is shared, appropriate policies must be implemented at both the MAC and the network layer in order to guarantee *quality-of-service* (QoS). At the MAC layer, channel-access policies are needed to decrease the probability of collision on wireless links; at the network layer, routing decisions are taken so as to forward packets along highly reliable links, with enough bandwidth available or with low latency. At the application layer, the *e2e-QoS* module involves mechanisms to guarantee QoS, end-to-end, and acts as an interface that supplies lower-layer QoS mechanisms with the QoS application requirements in a suitable format. At a higher layer, an *e-learning platform* provides tools for content sharing, distributed note-taking, student assessment, and so on. Tools may need QoS guarantees when transferring data over the network. The *content adaptation* module is used to supply given content in several formats – text only, images, multimedia – to suit different devices. Finally, the *resource discovery* module enables applications to discover devices that can offer a certain kind of resource. Devices are represented via symbolic names, whose resolution into network addresses is handled by a *name service*. Appropriate mechanisms must be deployed to retrieve the location of a resource residing on a wireless device [8]. Indeed, an address associated with a mobile device may change over time because of movement and changes in the WLAN it belongs to. Resources are supplied mainly by the teacher during lessons; his/her device quite naturally is used to record what students are taking a lesson, as a repository of contents produced and exchanged in a lesson, and possibly to coordinate communications.

Support for cooperative work. The functionalities needed to support cooperative training are much the same as used for in-class activities. The main difference lies in their architectural organization. In workgroups, all students may assume the role of resource provider. In both cases, a *peer-to-peer* approach seems the most appropriate, possibly hybrid so as to allow users (e.g. a teacher) to choose whether they are willing to serve as super-peers. Internetworking can support cooperative work among participants in different locations. For example, students can set up a study group using a local ad hoc network. If another group is studying the same subject, the two may then connect. To this end, the *resource discovery* module detects the existence of similar interest groups. If they exist, the *location service* module discovers their position inside the network and this information is used along with the network and MAC layer modules to build a communication infrastructure that connects the groups.

Announcement system. When a user – e.g. teacher or university staff – wants an announcement to be published, the announcement is posted to the campus website and is also *pushed* to interested people (*data push* module) in the format they prefer. A *user profile* database is maintained with an entry for each user. An entry records the topics the user is interested in, the device s/he prefers for delivery of urgent notices, user contact information, and the format s/he prefers for notification, such as SMS text messages, email with "URGENT" as subject or instant messages. The last three fields may also include several alternatives in order of preference. Access to the database occurs only through the *data access filter* module, which produces the appropriate database views according to the given user's authorization, as per the *security & privacy* module. The list of users interested in the announcement is extracted from the *user profile* database. For each user who prefers to receive instant messages, the *location service* module looks for his/her device connected to the hybrid campus network somewhere. The *multicast* module builds a forwarding structure rooted at the office that generates the announcement and involving all connected users. An email or SMS message is sent to users who either are not currently connected or prefer those formats. The *content adaptation module* is responsible for converting the announcement into an instant message, an SMS or the body of an email message with the appropriate subject, so as to make it suitable for different kinds of devices. The QoS modules can be used to assure low latency in announcement delivery or reliability.

Ambient intelligence. Ambient intelligence consists of equipping the environment with devices (e.g., RFID tags, sensors, wireless APs) and allowing a user roaming around to retrieve information about the surroundings, perhaps leaving notes for others. The following examples show how ambient intelligence can be used in such an environment and the functionalities required of the platform.
A first year student, Alice, arrives on campus and does not know where to find the student-services office. She "asks the campus" and, as a result, the APs around her triangulate her position via the *device position* module. A map is then sent to Alice's PDA with a red dot at her current position and a green dot for the sought-after office. When Alice arrives at the office, a long line of students is waiting their turn. But using her Wi-Fi-enabled PDA, Alice can query an ambient device (*ambient device interface* module) near the office door for information about the forms needed to switch major or about grants available and their deadlines. Ambient devices might include sensors or active RFID tags. Such devices on teachers' offices allow retrieval of information about available thesis projects or downloads of the list of assignments due next week onto students' devices. The *bakery algorithm* could be implemented: a user is assigned a number and s/he can avoid waiting in queue; a notification is sent to his/her device when his/her turn is approaching. Bob is going to a cafeteria for lunch. He passes a bookshop and – through his PDA – asks the bookshop RFID tag whether a copy of the textbook for the computer networking course is available. Since the reply is "no," Bob posts an order for the book, requesting notification via SMS on his cellphone number when it arrives. Each evening, the bookshop manager downloads the orders people have placed. When Bob arrives at the cafeteria, his RFID card authenticates him and he is allowed to enter. On his smartphone Bob, receives the day's menu and information about discounts. After lunch, Bob is going to meet two colleagues to prepare an exam. They "ask the campus" for a study room in their neighborhood with enough available seats for all of them and make reservations. When they enter the study room, sensors at the entrance update the number of places available. If they connect their PCs, the wireless network in the room records their current position (*location service*), so as to have them connected in case they are sought by other students or an announcement needs to be sent them.

Security and privacy This module merits separate discussion. Its functionalities cut across all architectural layers and service classes and are exploited by several modules. The main purposes of this module are: (i) authenticating users who want to access certain services provided by the platform, in order to determine whether they are authorized to perform the requested action; (ii) customizing the behavior of other modules in order to provide a proper *view* of data maintained by the platform according to the user's *role*. Point (i) also involves checking the identities of users who want to participate in workgroups and guaranteeing that the data exchanged inside a certain group cannot be overheard by third parties. Point (ii) involves masking the names of students who submit questions in class, to guarantee that the name is visible only to the teacher but not to other students. This encourages shy students, while allowing teachers to single out students who need ad hoc tutoring. On the other hand, a teacher should not have access to information about students not enrolled in his/her course, nor to the marks students achieved in other courses, nor to the training activities performed by students for his/her course. Some of the issues involved in security are analyzed in [9].

3.2. Module relationships

This section describes inter-operation among modules. The transport layer is not considered: it involves both transport protocols characteristic of the specific wireless technologies available on a certain device and the TCP/IP stack, which is now supported by all major wireless standards. The *e2e-QoS* module takes QoS requirements specified by users through high-level applications (i.e., those included in the *e-learning platform*, in *data push* or in *content adaptation*) and transforms them into a format suitable for QoS modules at lower layers, such as a `TSpec` [10]. Information contained in the *user-profile* database is used by the *data push*, the *content adaptation*, the *e-learning*, and the *security* modules. For its part, the *data-access filter* module uses only the services offered by the *security* module. The *resource-discovery* service is used by the *e-learning* platform. This module also takes care of customizing the protocol stack to set up a connection with a remote server. This is needed because wireless standards involve peculiar protocols, whose parameters must be appropriately configured. For instance, it could instruct *gateways* to modify addresses when passing from a Bluetooth to a Wi-Fi MANET or to act as a proxy. Hence, *resource discovery* affects almost all lower-layer modules, except for *location service*, *device position* and *ambient-device interface*. *Content adaptation* may be requested by *e-learning* tools, *ambient intelligence* and *data push* modules. This module uses only the services of the *e2e-QoS*. The *ambient intelligence* module uses *content adaptation* to translate data into a format suitable for the specific device querying the environment. The services provided by *resource discovery* and *e2e-QoS* may be used to retrieve the information a user is looking for and to guarantee that data are appropriately delivered to destination, respectively. All routing modules may come into play, as well as *location service* and the modules at the MAC layer. The *data push* module also uses *location service*, *multicast* and all routing modules at the network layer. All functional modules at the MAC layer except for the *ambient-device interface* could be used to push data. The *location service* module may use data gathered by the *device position* module. *Multicasting* also takes advantage of topology information available from the other routing modules. Similarly, QoS routing may guarantee quality requirements, perhaps requesting policies offered by the *QoS* module at the MAC layer. Routing modules use channels built by the *ad hoc gateway* module at the MAC layer.

4. Conclusions and future work

This paper proposes a distributed infrastructure that uses wireless technologies and their ability to support user mobility to provide services for learning and teaching tasks in universities on an *"anywhere and anytime"* basis. Functionalities integrate gracefully, thus avoiding data duplication and inconsistencies, while providing a uniform interface to the platform's services. The system takes advantage of the devices owned by users, thus allowing them to carry their personal data and work environment around. It can adapt to the characteristics of heterogeneous devices and use any existing infrastructure to provide services as appropriate. We are currently implementing functionalities for in-class activities. The implementation was based on ActiveClass. Databases were redesigned and reliance on any existing fixed infrastructure was removed while MANETs support is under deployment, so as to be able to support activities everywhere. Preliminary experiments with PDAs and Wi-Fi are being conducted in our laboratory. We plan to be able to test the main in-class modules in a small course – by providing groups of students with devices running the modules - within a few months.

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