Interactive Outdoor Web-based Distance Learning Using Mobile Terminals

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Abstract

Outdoor learning provides an opportunity for direct learning experiences which can enrich the school curriculum in different subject areas, such as natural sciences, architecture visual arts and industrial/civil engineering. This experience-based instruction can be effectively enhanced by computer-based learning environments by providing each student with a mobile device fully connected to the Internet and to its word-wide resources. Such one device can be used by a student to access customized information which may be related to the places that constitute the outdoor environment. In this paper, the general architecture of a mobile Web-based distance learning service for interactive outdoor learning is described, along with the guidelines which have led to its design. In addition, an evaluation exercise has been carried out in order to confirm the adequacy of the approach and to determine the future development of the system.

INTRODUCTION

Recent advances in telecommunication and network technologies are enabling new important real-time applications characterized by the keywords *interactivity* and *multimedia* [1]. One of those emerging real-time applications is represented by interactive distance learning. Traditionally, a distance learning service allows students to attend a lecture that is taking place at a remote location, providing them with the possibility to interact with the remote teacher, for example, by interrupting the lecture for asking some questions. From the communication standpoint, a distance learning service requires a sort of bidirectional transmission of audio and video between the instructor and the students, accompanied with additional educational material, such as still images, messages, appointment schedules, needed to organize and conduct the lecture.

Moreover, the technical advances in the development of new mobile terminals, the increasing request of advanced wireless services and the wide success of the Internet are also making user mobility and ubiquity two key features for the information technology infrastructure of the near future [2]. In particular, the trend of integrating the Internet and the mobile telephony is revealed by the success of the WAP protocol [3] and, at least in Europe, this kind of integration technologies will be soon improved by the introduction of the future European mobile network infrastructure, known as UMTS (Universal Mobile Telecommunications Standard) [4]. Based on the considerations above, we may claim that it is becoming very important to design and develop new interactive Web-based distance learning applications that enable user mobility through the mixed use of mobile terminals and the Internet. Such those modern distance learning applications may offer mobile didactical services to the students thus allowing, for instance, outdoor learning experiences in scientific and technical educational fields. By using mobile technologies and adequate portable devices, the learning process can partially take place outside the classroom. The benefits of such one outdoor learning activity for both teachers and students may be summarized as follows:

1. additional resources are made available to teachers to carry out their teaching activity, and
2. students' traditional experiences in the classroom may be enriched and complemented with real experiential knowledge obtained on-the-field.

In essence, outdoor experiential activities can facilitate the construction of abstract concepts and enhance meaningful learning, providing for long-term awareness of the reality. Through outdoor based programs, students may gain a realization of their relationship to the real environment, which cannot be learned through abstract sources.

Typical specific fields where the educational process may greatly benefit by (a mobile) technology that enables interactive outdoor distance learning are:

1. Industrial engineering: Guided visits to industrial plants may be organized with the help of mobile devices that allow students to directly inspect the production process, along with a prerecorded on-line help provided by mobile terminals. Moreover, Web-based mobile learning environments can also permit to the students to perform supervised laboratory activities in industrial environments.

2. Architecture/civil engineering/visual arts. The guided visit of cities, streets, buildings and museums may be conducted by students with the help of mobile devices, through which information about the architecture, the history and the urban planning may be provided. The mobile training system should operate either by offering a menu-based interface to allow the choice of the information required by the user or by directly providing the correct information on the basis of the student's position during the visit.

3. Zoology, geology and other natural sciences. Moving across open areas may enable students to discover interesting things, while listening to appropriate explanations trough mobile devices. In addition, the mobile device can be also used to record and store the information to be used subsequently.

Within this scenario, we have devised the general architecture of a mobile Web-based application that enables interactive outdoor multimedia learning activities. In this paper we illustrate such one Web-based distance learning service along with an evaluation exercise carried out to confirm the adequacy of the approach. The remainder of this paper is organized as follows. The next section describes the general architecture of our mobile Web-based distance learning service for interactive outdoor learning and its main components. Section 3 reports on different application requirements that have to be met in order to make the service effective. Finally, Section 4 concludes the paper by discussing future development of the proposed system.

SYSTEM ARCHITECTURE

To implement the above mentioned educational service for interactive outdoor learning, we propose an architecture based on the integration between software applications based on Web technology and mobile access network infrastructures. Two relevant problems come out from the attempt of integrating the best effort nature of the Internet with the mobile access infrastructure that is characterized by low bandwidth and unpredictable connection stability.

On the one hand, a typical problem with the use of wireless technology is related to the typical low value of available bandwidth and the high latency that characterize the network access through mobile devices. This problem is typically exacerbated when streams of multimedia data that are usually provided by modern Web-based distance learning tools have to be transported by wireless networks and displayed by means of mobile devices. In essence, the downloading activity of massive amounts of multimedia educational material, which may include text, high definition images, sounds, digital audio and video may pose a very critical transmission problem to the mobile networked technology. On the other hand, Internet-based services may be often unavailable, while, if the mobile terminal can obtain its access to the network, then the wireless telecommunication network usually guarantees services availability with a very high rate. Hence, from this point of view, it is worth noticing that the design and the implementation of Internet-based services that satisfy the important requirements of *reliability* (i.e. capability of an application to correctly work in presence of specified faults) and *responsiveness* (i.e. capability of an application to be correctly work in an acceptable amount of time) are not trivial tasks.

In order to circumvent the former problem mentioned previously (i.e. the difficulty of wireless network technology to transport complex multimedia educational data with a tolerable latency), we have decided to resort to the available technology. In particular, we have decided to adopt an inexpensive video conferencing system which is able to provide low quality video with a telephone-quality transmission of voice for supporting live lectures (such as, for example, the well known CuSeeMe and NetMeeting applications), coupled with the use of third-generation cellular telephone technologies (such as GPRS and UMTS) that are able to provide available bandwidth ranging from 115,000 bps to 2 Mbps. With respect to the latter problem we have mentioned (i.e. the scarce level of availability and responsiveness that traditional Internet-based services may offer) we have decide to design and implement our Web-based distance learning service by introducing and exploiting software redundancy, namely by replicating the service across a certain number of Web servers geographically distributed over the Internet.

In this context, a typical approach to guarantee service responsiveness consists of dynamically binding the service client to the available server replica with the least congested connection. An approach recently proposed to implement such one adaptive downloading strategy at the Internet side amounts to the use of a software mechanism, called the Client-Centered Load Distribution (C2LD) mechanism [5]. With this particular mechanism, each client browser request of a given Web document is fragmented into a number of sub-requests for separate parts of the document. Each of these sub-requests is issued concurrently to a different available replica server. The mechanism periodically monitors the downloading performance of available replica servers and dynamically selects, at run-time, those replicas to which the client sub-requests can be sent, based on both the network congestion status and the replica servers workload.

Summarizing, the general architecture of our proposed system, may be thought as constructed out of the following five components:

1) *a set of replicated Web servers*. The reliable provision of educational services is based on the use of a set of replicated servers that hold the educational material and respond to the requests issued by different users by means of the well-known HTTP protocol (augmented with the C2LD software mechanism). The geographical distribution of those replica servers across the Internet aims: i) at redirecting each client request towards the nearest set of replica servers that are able to guarantee a low latency in their response, and ii) at distributing and balancing the workload among different servers across the Internet. Needless to say, in order for the service to be correctly implemented, all the replicated Web servers must be maintained in a mutually consistent status;

2) *the Internet*. The Internet network, through the use of its application-level HTTP protocol, provides the transport of the educational information from the set of replicated servers and the computer gateways that are located at the interface between the two network communication infrastructures;

3) *the gateway between the Internet and the mobile network*. The interface between the Internet and the cellular network infrastructure is maintained at one or more application gateways where management policies and translation mechanisms are implemented that are able to translate data from one of two different network infrastructures to the other;

4) *the mobile network infrastructure*. It is owned by the telephone network carrier and may be thought of as constructed out of two different parts: a set of *base stations* that represent the access points for the cellular mobile terminals, and the so-called *core network* that is in charge of linking together all the base stations and of transporting the data. Different cellular network infrastructures and technologies may be in principle used and provided by different network carriers;

5) *mobile terminals*. They are owned by the final users that use them to obtain the access to the interactive outdoor Web-based distance learning service. Those mobile devices must be equipped with a special light-weight micro-browser (such as those implemented within the WAP technology). Such one micro-browser needs to have multimedia capabilities to perform the playout of digital audio and video data.

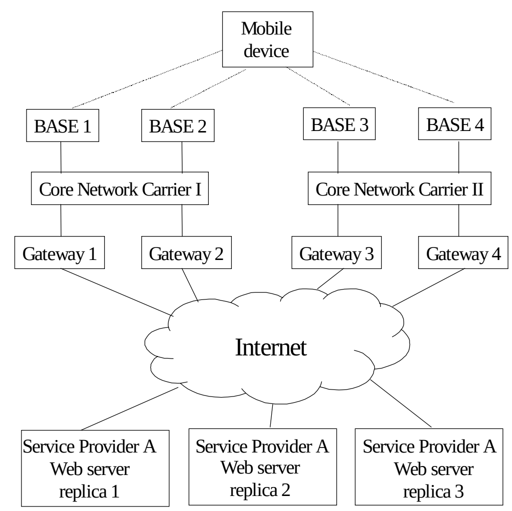

Figure 1: System architecture

All the system components mentioned above are parts of the general architecture depicted in Figure 1. In essence, based on the architecture above, our designed educational service is supplied to potential clients as follows. By means of a mobile device a client can be connected to the mobile network thorough different base stations. Different base stations may, in general, be under the control of different network carriers. Each carrier provides, through the correspondent core network, the connection to a set of gateways which are, in turn, connected to the Internet. On the Internet site, different ISPs (Internet Service Providers) may exist which maintain our designed Web-based educational system, by exploiting the replicated web servers methodology.

In order to make effective the general architecture seen in Figure 1, we need to integrate appropriately two critical software components:

- the multimedia document downloading mechanism (i.e. the C2LD mechanism), and
- a software Information Management Module (IMM) that allows the system users to retrieve the didactical material from the Web-based distance learning service, accessed through mobile terminals, on a personal customized basis [6]. Needless to say, in fact, the didactical contents each client is provided with: i) need to be dynamically downloaded according to the student's needs and profiles, and ii) need to be time- and place- dependent.

The remainder of this Section briefly discusses on how the two above mentioned software modules may be incorporated within the general system architecture illustrated in Figure 1. As far as the C2LD mechanism is concerned, two possible alternative implementation solutions may be devised. In fact, the C2LD mechanism can be located either on the mobile terminal or on the application gateway. Those two possible solutions have to be contrasted on the basis of the two following considerations. If we decide to implement the C2LD downloading mechanism within the micro-browser embedded in the mobile terminal, then a very powerful mobile device is needed (in term of both computational power and memory) to run the C2LD software code. Moreover, it is worth considering the communication scenario depicted in Figure 2. As seen in that Figure, when the educational material downloaded by the client's micro-browser embedded in the mobile terminal downloads from the designed educational service arrives at the application gateway, it is then routed towards the micro-browser through a static network path (i.e. gateway -> core network -> base station -> mobile terminal). This entails the fact that using the C2LD download mechanism implemented within the mobile device is not useful since the C2LD mechanism tries to fragment each client browser request into a number of smaller sub-requests which are then forwarded to different servers trough different network routes. Based on these considerations, we have decided to implement the C2LD mechanism directly on each application gateway. This solution has also the further advantage to permit to integrate the C2LD software mechanism within a standard Internet proxy system.

As far as the Information Management Module is concerned, three possible alternative solutions may exist. In fact, the IMM can either be implemented as a replicated information on each replicated Web server, or be implemented on the application gateway or, finally, be implemented on the mobile terminal. These three different solutions give rise, respectively, to the three following models:

1. *Replicated IMM*: in this scenario a software copy of the IMM is installed on each web server replica to adapt the information content to be downloaded to the personal profile and geographical position of each client. First, this entails the fact that the micro-browser within the mobile terminals provides only the visualization interface for the download application. Second, all the read and write operations needed to keep updated the IMM status located at each replica server, have to be performed in a mutually consistent way.

2. *Centralized IMM*: in this scenario there is a single centralized IMM server that provides the management of the information corresponding to each system user. This approach removes the consistency problems concerning the read and write transactions but, on the other side, creates a communication bottleneck just in the AMM server.

3. *Distributed IMM*: in this scenario it is the mobile device itself that run and maintains the IMM software. Hence, the micro-browser application refers to local data (e.g. student profile, geographical position, access time) in order to compute the material to be downloaded. This approach simplifies the system architecture but, on the other hand, calls for the use of a more powerful mobile device.

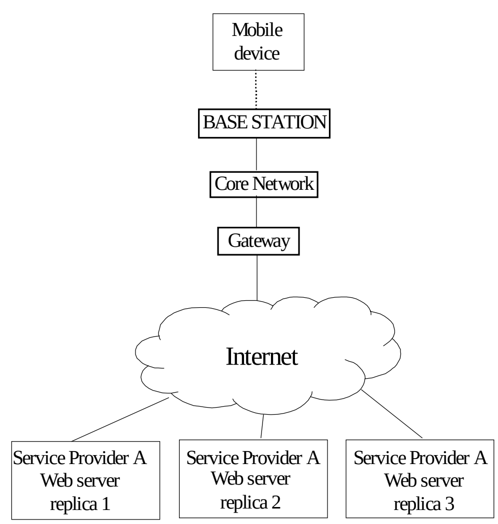

Figure 2: Communication scenario for a single client

In our designed system, we have adopted the following hybrid solution. Based also on the consideration that the C2LD download mechanism has been implemented at the application gateway, we have decided to break down the IMM functions in the two different following parts:

- a set of local data (student profile, geographical position, access time) are recorded locally on the mobile device;
- the rest of the IMM software module is running on the application gateway.

This devised solution minimizes the updating consistency problems and can be implemented also on mobile devices with a scarce computational power.

EVALUATION EXERCISE

Typically, a Web-based distance learning application enabling interactive learning requires to handle the following different media types:

- Text and images: these are classical data types for Web-based multimedia. The communication bandwidth needed for downloading text and images with an acceptable delay usually depends on the document file dimensions. Due to the typical limitations of battery life for handheld devices, they tend to have small displays. Considering this limitation, we can suppose that also the image size will be generally small.
- Digital audio and video (on an on-demand basis): prerecorded audio/video streams can be used both to present digitized lectures and to provide additional non-live multimedia educational materials (such as slides, voice-based comments, etc. …). With this in view, in order to obtain audio and video of a good quality the system can buffer packets and delay their playout time (thus minimizing packet loss rate). This strategy is usually adopted to implement audio and video streaming.
- Audio and video live conferencing: they are used both for student-to-student interactions (two or more students cooperate in the learning process) and for student-to-teacher interactions (including real time lectures and on-line tutoring). Using buffer to compensate for variable network delays, in this case, may augment the network delay, thus resulting in low interactivity. Hence, for live audio and video, a lower quality may be traded off for lower delays.

To summarize the bandwidth requirements needed for audio and video transmissions, we are able to show a simple taxonomy based on the interactivity degree and presentation quality. Hence, Table 1 reports bandwidth requirement values typically needed to transmit digital audio and video with a satisfactory quality in a distance learning environments [1,7]. It is worth noticing that those bandwidth requirements have been estimated on a half-duplex, point-to-point communication basis. If we wish our designed Web-based distance learning service be available for mobile terminals, it is clear that the bandwidth requirements mentioned above need to be met by the mobile network infrastructure. In order to investigate this issue, we report in Table 2 the communication bandwidth provided by different European digital cellular technologies.

	Interactive (low)	**On demand**	
		Low	**High**
Audio	8 kbps	8 kbps	128 kbps
Video	64 kbps	64 Kbps	6 Mbps

Table 1: Bandwidth requirements for audio/video communication in distance learning environments

In particular, from an analysis of Table 2, we can deduce that the actual European technology (GSM, *Global System for Mobile Communications*) is not currently able to support digital audio/video communications, and, in addition, it can be considered also unable to transmit long pieces of text and images. The next cellular technology, instead, which will be available since next year, is termed GPRS (*General Packet Radio System*). Unlike GSM, GPRS will be able to provide different Quality of Service levels and a bandwidth up to 115,000 bps. We can consider the bandwidth provided by GPRS as adequate to successfully transmit text and images. Also low quality prerecorded educational audio (resulting in 8Kbps) can be effectively sent on the GPRS mobile network.

Technology	**Time of availability**	**Bandwidth**
GSM	available	9600 bps
GPRS	available since 2001	up to 115,000 bps
UMTS	Global deployment since 2005	up to 2Mbps

Table 2: European digital cellular technologies

The third generation European cellular technology is UMTS (*Universal Mobile Telephone System*) that will be completely developed since 2005. This technology will be able to provide different Quality of Services levels and a bandwidth up to 2Mbps. The UMTS communication infrastructure may be considered adequate to the transmission of prerecorded multimedia files as well as to the support of live audio/video conferences.

CONCLUSIONS

In this paper we have emphasized the importance of designing and developing new Web-based distance learning applications for interactive outdoor learning. These applications can be developed by integrating the mobile features of future cellular telephone networks with the modern Web-based technology. The most important problems posed by those applications amount to:

1. Satisfaction of bandwidth and delay requirements (for the mobile network infrastructures),
2. Satisfaction of availability and responsiveness requirements (for the Web based services deployed over the Internet).

On the Internet side, our designed system meets the above mentioned requirements by using the replicated Web servers technology coupled with the C2LD software downloading mechanism. On the mobile network side, the currently available technologies (such as GSM) have been demonstrated to be insufficient to support multimedia didactical applications. The next generation cellular phone technologies (e.g. UMTS) will satisfy the performance requirements needed by a didactical application to effectively support an outdoor learning session. Since the UMTS technology will be available in Europe since 2002, the next step of this research is to set up a simulation platform that permits to test the real performances of our system. This simulation environment is considered to be mandatory to experiment a complete version of our mobile Web-based distance learning application for interactive outdoor learning.

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BIOGRAPHIES

Marco Roccetti received an Italian Dott. Ing. Degree in Electronics Engineering from the Faculty of Engineering of the University of Bologna, Italy, in 1989. Since November 2000 he is a Professor of Computer Science at the Department of Computer Science of the University of Bologna. His research interests include: i) design, implementation and evaluation of multimedia computing and communication systems, and ii) performance evaluation and simulation of distributed and parallel computing systems.

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