An open framework for prototyping the delivery of multimedia-rich virtual learning experiences through the Internet

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ABSTRACT

Incorporating interactive multimedia, VRML, and real-time video and audio conferencing into a multi-user, object-oriented framework to create a collaborative virtual learning environment is one scenario for killer applications towards emerging telecommunication infrastructures, such as the Internet 2 or the current Internet enhanced with QoS mechanisms. In this paper such an open framework for enabling rapid prototyping and delivery of virtual learning experiences through the Internet is presented. Towards this end cultural heritage content is exploited. VRML and Java are the key technologies. Based on this framework, the *Enigma* application is presented which enables groups of users to monitor multimedia-rich virtual guided tour sessions inside 3D representations of archaeological sites. A live guide controls these sessions so that all users have the same view of the content. Directions for further research based on the conducted work are presented.

Keywords

Virtual learning environment, guided tour, live guide, VRML, JAVA, virtual monuments, multimedia

1. INTRODUCTION

The effectiveness of systems incorporating interactive multimedia, virtual reality, and real-time video and audio conferencing for education purposes is still under investigation [John01]. However, technically speaking the use of multi-user, object-oriented technologies for creating a collaborative virtual learning environment is one scenario for killer applications towards emerging telecommunication infrastructures, such as the Internet 2 [STAR00], or the current Internet enhanced with Quality of Service and multicast mechanisms. Obviously, the widest benefit and largest aggregate use of a broadband infrastructure will be realized by resource demanding applications, such as those composed of several multimedia streams.

Several scenarios for networked collaborative learning applications can be defined according to the content used. Content based on the preservation of cultural heritage is one category. It can be composed of virtual representations of ancient or modern monuments, images & videos of the actual sites, descriptive texts and aural narrations. In other words, it combines different types of media.

In the last few years there has been a considerable work on the digitization of cultural heritage content [FHW], but there are still more to be done. However, what is missing, is the dissemination of this content through the network, not only in terms of Web page retrieval, but also in terms of interactive, networked learning environments where end users actively participate in the training session, and interact with the content, with professionals that guide them inside the content, and with other participants. This would

Journal of WSCG, Vol.11, No.1., ISSN 1213-6972
WSCG'2003, February 3-7, 2003, Plzen, Czech Republic.

require both the definition of application scenarios based on digitized content, and addressing network requirements of such an application, unless a very fast network is used [Pape01]. This combined knowledge cannot be easily found to the same experts. Besides, addressing network requirements of such complex and highly demanding applications in a consistent way is still an open research issue [Matij99], [Pop02], [Pham01].

In this paper, an open framework for enabling rapid prototyping and delivery of virtual learning experiences through the Internet is presented. Emphasis is given on cultural heritage content and its manipulation within such a learning environment. The Virtual Reality Modeling Language (VRML) [Web3D] and Java [Java] are the key technologies, as being the most popular, open source tools for networked virtual reality applications for the Internet. Java based extensions, such as the External Authoring Interface (EAI) [EAI], and the Java Media Framework (JMF) [JMF] are exploited to integrate all the different media streams.

Based on the above framework, the *Enigma* application is presented which enables groups of users to monitor multimedia-rich virtual guided tour sessions inside 3D representations of archaeological sites. A live guide controls these sessions so that all users have the same view of the content.

The rest of the paper is organized as follows: In Section 2 background work on virtual learning environments based on open or other technologies is presented. In Section 3 an open framework for prototyping multi-user, virtual learning sessions for cultural heritage content, based on VRML and Java is presented. In Section 4 the Enigma application is introduced. Finally, in Section 5 directions for further research based on the conducted work are presented.

2. RELATED WORK

Educative, networked virtual reality applications based on cultural heritage or other content have appeared so far, such as those described in [NICE], [PapeAnst01] [Anst00]. However, these are customized for certain virtual reality display systems, such as CAVE and ImmersaDesk, which are too expensive to be widely applied. Besides, these applications have been demonstrated based on Internet2 infrastructure. In [ARCHEOGUIDE] outdoors augmented reality as well as position and orientation tracking techniques are exploited for accessing information in context with the exploration of a real ancient site.

A great effort has been consumed so far in the development of Internet-based, collaborative virtual environments for training or more general purposes. Despite its weaknesses VRML [Nad99] seems to be the key technology as it is customized for the network. Such examples are presented in [Nigg99], [Geroim99], [Holm02], [Broll97], [Masa00], [hirm98] [Bouras00].

In all these and other relevant works a number of key issues for building collaborative virtual environments are addressed, such as user interface design [Bow01], consistency [Li01], synchronization of different media types [Liao98] resource scheduling [Fais00], streaming geometry [Risc02], user interactions [Stief99], [Braun01], intelligence [Whan98] and assisting agents [Evers00], heterogeneity [Trefftz02], graphics specific matters [Fuchs80] etc. Experience and technologies described in the literature for the development of virtual collaborative environments are also applicable in the case of cultural heritage content.

3. AN OPEN FRAMEWORK FOR PROTOTYPING MULTIUSER, VIRTUAL LEARNING SESSIONS

Accessing virtual representations of cultural heritage content through the Internet in a multi-user environment is technically challenging. Various issues have to be addressed, with the most important being:

- Content structuring and encoding
- Definition of the application scenario and target users
- Implementation framework
- Application architecture & extensibility

Each of these is examined separately in the Subsections that follow.

3.1 Content Structuring and Encoding

Cultural heritage content can be composed of virtual representations of ancient or modern monuments. VRML provides the means to realize such representations, although it has been blamed – because of its simplicity - for inefficiency to reproduce the needed detail to help preserve historical consistency. The 3D content is complemented with photo-realistic images & videos of the actual sites, descriptive texts and aural narrations. In other words, different types of media are usually necessary to give a complete description of the site.

VRML can handle different types of audiovisual objects, organized in a tree hierarchy, where parent nodes describe spatio-temporal relations between audiovisual objects, while leaf nodes correspond to primitive content types (such as 3D shapes, textures, links to sounds and video clips). In this context, several interactions with the content can be defined, however in a “standalone” mode, because everything has to be downloaded at the beginning. This makes VRML insufficient for multi-user distance learning scenarios where client-server interactivity is required. Furthermore, virtual representations of monuments can be huge in terms of size and rendering requirements and thus unsuitable for the network. Therefore, scene-partitioning techniques have to be applied to support progressive downloading or streaming of the 3D scene according to user visibility. Some sophisticated techniques for partitioning 3D scenes have appeared in the literature [Guez99]. An example of small-scale segmentation is shown below. Figure 1 (left part) illustrates three ancient buildings, which are normally attached to each other. A room-based segmentation is applied enabling the inner buildings to be loaded only as soon as the user approaches the entrance (right part). Large scale scene partitioning concerns segmentation of the 3D content to smaller cells, based on the configuration of the 3D space and some visibility preprocessing. The implementation of such mechanisms with VRML is possible through “hyper linking” (e.g. by exploiting the anchor node and the proximity sensor) of the different segments and with special scripting.

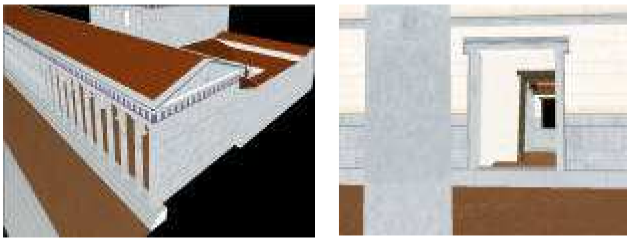

Figure 1. Small scale scene partitioning

3.2 Definition of the application scenario and target users

In an educative application several levels of interactivity with the content can be defined.

1. The user may download all the content and interact with it locally (this is referred to as *local or client-side interactivity*). Prerecorded guiding tours or avatars can provide hints for navigation inside the content (e.g. clickable areas, links to Web pages etc).

2. The user may partially retrieve content in a client-server mode and interact both locally and remotely (the second case stands for *remote or client-server interactivity*). In this scenario scene partitioning algorithms can be applied so that the user can progressively download the content.

3. The user may belong to a group of users and monitor a common training session, which is controlled by a live guide. The guide navigates inside the 3D content and either indicates hints for interaction, or presents the relevant information about the points of interest. In both cases, a means to communicate with the group of users is necessary. This can be achieved through written text (e.g. chat) or live voice combined optionally with a pointing cursor controlled by the guide and focusing at certain areas of interest inside the 3D scene. The guide may also send images, grabbed video frames or video clips relevant to the 3D content. (The interactions of the guide with the users are referred to as *one-way*). Limited interactions of the users are, also, allowed with the guide and with other users of the group, according to the application scenario (e.g. chat communication).

4. The 3D world representing the site or monument can be shared equally to a group of users who are able to interact with each other. Every user is represented through an avatar. The ability of every user to interact with every other user is referred to as *two-way* interactions.

Work presented in this paper is mainly based on the 3rd scenario, which is illustrated in Figure 2.

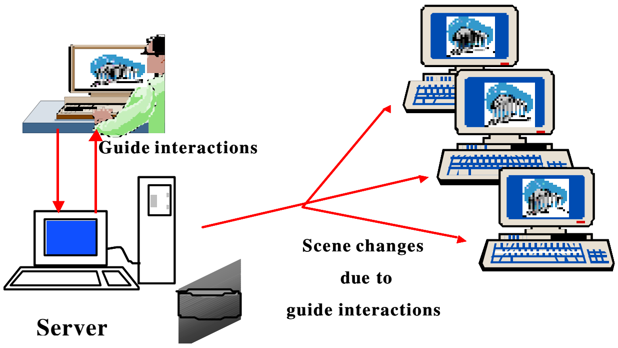

Figure 2. Architecture of the 3rd scenario

3.3 Implementation framework

VRML provides ways of making content interactive (e.g. through sensors and scripting), but supports only local interactivity. Nevertheless, in order for a group of physically remote users to have the same view of the content, multicast techniques should be applied. Therefore, for scenarios 3 and 4 advanced scripting and/or programmatic extensions for network interfacing are required.

The EAI provides the means to VRML to communicate with Java by defining a series of functions that act upon the VRML browser. The EAI allows controlling the contents of a VRML browser component embedded in a web page from a Java applet on the same page. In theory, interconnection with Java allows a VRML application to use all Java APIs available. In the case of our application scenario (scenario 3 in Subsection 3.2), the JMF API can be exploited to enhance the training session with streaming media, such as the live voice of the guide or videos from the actual site. The next paragraphs describe how these tools can be used to provide such an implementation framework.

3.3.1 Using EAI to control the VRML scene

The EAI allows 4 types of access into the VRML scene:

- Getting control of the VRML browser.
- Sending events to eventIns of nodes inside the scene.
- Reading the last value sent from eventOuts of nodes inside the scene.
- Getting notified when events are sent from eventOuts of nodes inside the scene.

In this way, EAI enables to control the position and orientation of the camera or certain objects in the scene. Thus, the interactions of the guide can be handled by Java code and the VRML application can be extended by exploiting the capabilities of Java.

3.3.2 Live audiovisual communication with the end users

One way for the guide to explain in detail the visible objects while navigating is through live voice. The JMF API implements streaming media over the RTP/RTCP protocols and therefore can be exploited in this case. Furthermore, an object inside the VRML scene can be used as a pointer indicating the objects of interest that the guide presents while speaking. The pointer must be synchronized with the voice otherwise it will be misleading.

In general, synchronization of different media flows is a quite critical issue in networked applications, because of the unpredictable behavior of the underlying network in terms of delays and losses [Liao98]. Different levels of synchronization can be defined:

- **Intra-stream** – Handles the smooth playback of different chunks of data, such as audio/video frames. In networked applications it is usually handled with buffering at the receiver.
- **Inter-stream** – Maintains temporal relations/dependencies between different data flows (e.g. lip synchronization between audio and video). In the case of applications with multiple flows, other inter-stream synchronization requirements may appear, as well, according to the application scenario. For example, in the case of the live guide the pointer must be synchronized with the voice of the guide and also with the chat messages, otherwise, the users will not be able to understand where the guide refers. This kind of synchronization is usually achieved by assigning the same timestamps to the flows to be synchronized and with appropriate buffering schemes at the receiver.
- **Inter-user** – In applications with shared content two-way interactions with the content must be reproduced in a synchronized way to maintain consistency. Apart from network delays/losses, this type of synchronization is also affected by heterogeneity in user terminal processing capabilities and access networks.

JMF handles intra-stream and inter-stream synchronization of continuous flows (audio, video) based on the RTP protocol (through timestamps) and by implementing buffering schemes at the receiver. Therefore, inter-stream synchronization between continuous and discrete media flows, as well as inter-user synchronization is achieved through application specific implementations, as illustrated in Figure 3.

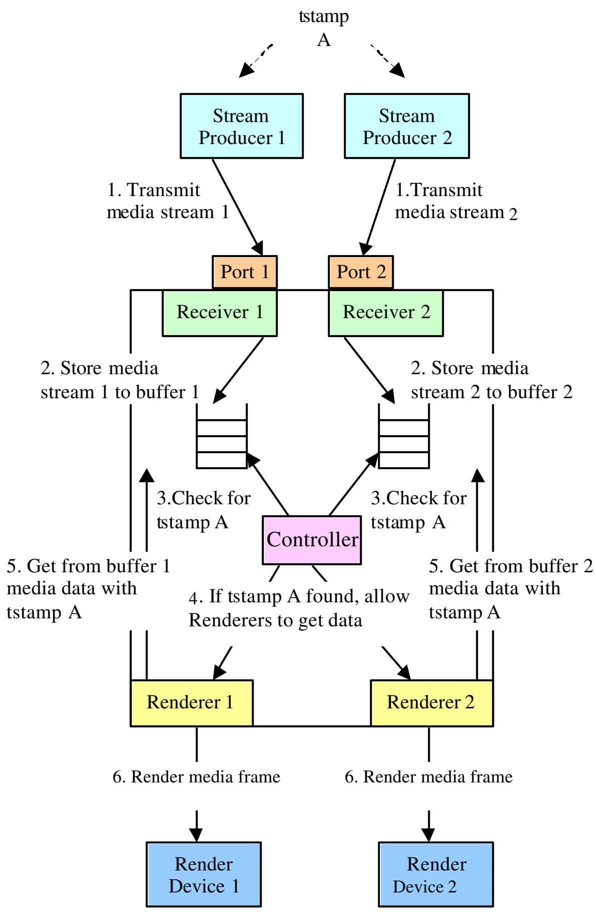

Figure 3. Inter-stream synchronization

3.4 Application architecture and extensibility

Table 1 and Figure 4 illustrate a generic architecture, and how different data types flow from the guide to each of the end users.

1.	Get control of the VRML browser.
2.	Get control of selected nodes in the VRML scene.
3.	EventOut: Send changes in fields of the selected nodes(VRML data) to the Java process
4.	Establish TCP/IP connection
5.	Send VRML data
6.	Get media stream from source.
7.	Send media stream over RTP, using JMF
8.	Store the media stream in a buffer
9.	Synchronize the two buffers using timestamps
10.	Send synchronized data
11.	EventIn: Send changed field values to the selected nodes in the VRML scene (rendering)
12.	Render the media stream

Table 1. Data flows from the guide to the users

The part of the figure enclosed in the lower frame illustrates the component responsible for data streams synchronization, described in Figure 3, of the previous subsection. The components enclosed in the upper frame implement the main application logic, which includes:

- o Generation of the different data flows
- o Establishment of connections for their transmission
- o Reception of these flows
- o Synchronization management
- o Reproduction of the flows to the end user terminal

What is of importance in the implementation of such a training environment is the adoption of an extensible architecture, enabling to easily add/remove media object components and parameterize the 3D content. This concept is illustrated in Figure 5 (next page).

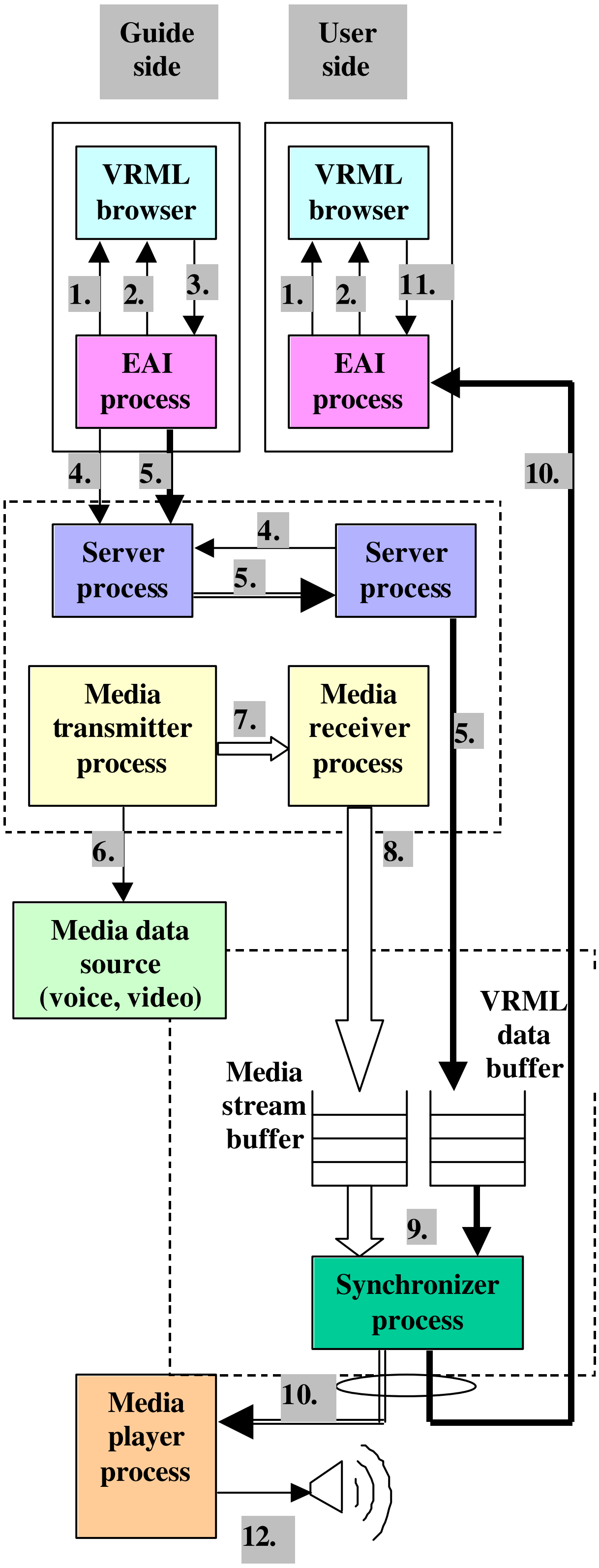

Figure 4. Generic architecture of guide-users communication

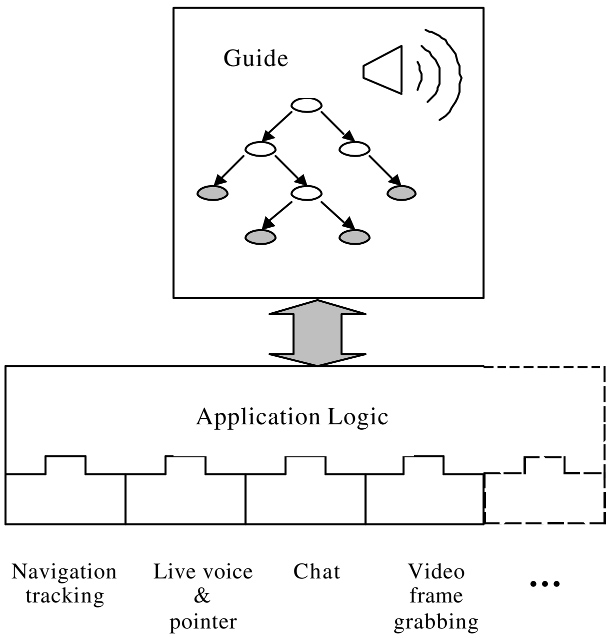

Figure 5. Extensible Architecture

The "plug in" architecture of JMF is compatible with the one of Figure 5, enabling the support of various RTP formats and payloads included so far in the API, or implemented by any application developer. Handling non-RTP streams (e.g. VRML parameters) through Java can be thought of as an extension to the JMF API.

4. THE ENIGMA APPLICATION

Based on the concepts described in the previous sections, a prototype application (*Enigma*) has been developed and tested based on 3D content developed by the Foundation of the Hellenic World [FHW]. This content represents the ancient theatre of Epidaurus (Figure 6), as well as a part of the ancient city of Priene (Figure 1).

Figure 6. The Epidaurus theatre

Small-scale partitioning techniques have been applied, especially in the case of Priene, where the VRML files are huge.

The application scenario, which was implemented is the third one described in Subsection 3.2. The streams produced by the guide and transmitted to the users are:

- o VRML position & orientation parameters
- o Live voice of the guide
- o Pointer coordinates in synchronization with the live voice
- o Chat communication of all users including the guide

The implementation of the Enigma application was based on VRML and Java, by exploiting the EAI and JMF APIs, as described in the previous sections. The most popular VRML viewers are currently implemented as Web browser plugins. This limits communication with Java to be realized through applets. On the other hand, applets have certain restrictions, especially as far as JMF is concerned:

- o They don't support media capturing, unless all security restrictions are abolished, e.g. by signing the applet.
- o They don't support multicast sockets. This restricts the transmission of continuous media to point-to-point connections.
- o They can't reproduce custom JMF payloads.

Within this context, a Java application was implemented for capturing and transmitting the live voice. On the other hand, a Java applet is responsible for tracking the movements of the guide inside the 3D scene, and the pointer position, and for multicasting these to the group of users. A proximity sensor defined to cover all the 3D space of the monument generates *position_changed* and *orientation_changed* events, as the guide moves inside it. Similarly a plane sensor maps the position of the mouse cursor into the XY plane through the *translation_changed* event and moves the pointer object to the same position through the *set_translation* event. The guide applet gets control of the two sensor nodes through EAI and sends the variables representing navigation and pointer position to the user applet. The user applet re-generates the movement using the corresponding eventIns that allow a Java applet to affect the VRML world. It is very easy to replace the VRML content in order to apply any other 3D world. The only change required is to define the proximity and plane sensors, to track the navigation and pointer movements, correspondingly.

A basic application requirement is to ensure synchronization of different data streams. The data to be synchronized is of the following types:

- o A voice stream, over RTP, linear, 44100 Hz, captured from microphone, using software from JMF.
- o Two data streams, over TCP: The position and orientation of the camera (3 floats for the position,

4 floats for the orientation, 1 integer used as timestamp with precision to the second), as well as the position of the pointer (3 floats for the position, and 1 integer used as timestamp with precision to the second).

Both data and voice streams are stored in buffers and are accessed by the Synchronizer class as shown in the generic synchronization scheme of Figure 3. Another way to achieve synchronization between voice and data streams was examined. Based on on-line examples found in the JMF website [JMF Solutions], a custom voice packetizer was developed at the guide side incorporating the VRML parameters to the audio packets. In this way, the synchronized data were sent to the end user to the corresponding depacketizer. Although this synchronization technique is functional, it is based on a custom stream, and therefore is not very generic. The only case when two-way interactions are allowed is through the chat communication. The intra-user synchronization is not specially handled, for the time being, but it is achieved through synchronization messages sent by the guide to the users to indicate synchronization points within the training session.

The Enigma application has been tested within a laboratory environment and has been demonstrated in the training session of the *Amman Cultural Heritage 20*02 conference [Amman2002], with 20 users.

5. OPEN ISSUES AND FURTHER WORK

There are several directions for further research, building on the work presented. Several application extensions will be realized and plugged into the existing architecture. A video frame grabbing component has been implemented based on JMF and is about to be incorporated to the Enigma application. In this way, users will be able to also experience live video of the actual site, together with the 3D data. Users with low processing capabilities will see key video frames related to the places of navigation, while users with high processing capabilities see the whole video. It is desirable that 3D navigation is synchronized with the illustration of the relevant video. In this way sophisticated synchronization algorithms will be explored.

The video frame grabber component is a building block for implementing content filtering mechanisms, so that different user devices and access technologies are served without the need to re-author the content. Towards this end, scalable content authoring based on technologies, such as XML and X3D based browsers [XJ3D], will be considered.

Other algorithms for scene partitioning will be applied to the 3D content and tested in a networked environment. In this way, QoS requirements of complex applications with streaming geometry and other continuous media will be explored.

To overcome the problems with applets (e.g. multicast sockets, JMF custom payloads) restrictions the Enigma application will be transferred to an application-based implementation. Also, based on the availability of relevant software the transformation of the application to an MPEG-4 environment will be considered. Extending the application scenario to a fully shared world (according to scenario 4 defined in Subsection 3.2) will be studied, as well. Peer-to-peer architectures [Peer-to-peer] and multicast techniques will be studied in this case.

6. ACKNOWLEDGEMENT

This work has been partially funded by the E.C.

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