An Integrated e-Learning Solution for Control Systems Education and Future Perspectives

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***Abstract* - Technical characteristics of an innovative prototype e-learning platform using satellite communications for control theory courses are exposed. A detailed account of all necessary tools and mechanisms is presented enabling real time text, and audio/video based communication between tutors and learners. The provided end-user driven services include: a virtual classroom, offline operation, sharing of applications, private/public chatting, audio/video streaming. In addition a concise description of the pilot network architecture depending on the DVB-RCS standard is presented justifying further the choice of the communications platform. Simulation results concerning the teaching of fundamental issues in Networked Control Theory within the proposed architecture are provided. Connections with hybrid configurations such as wireless terrestrial broadband technologies (DVB-RCS/ WiMAX, DVB-RCS/Wi-Fi) are further analyzed and justified. Finally some conclusive anticipated directions related to the future of modern control courses education in connection with state of art technological advances are explored.**

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I. INTRODUCTION

Over the last few decades, in many educational institutions around the world, *e-learning* techniques and collaborative methods have emerged as key sources of expansion and competition within the stages of the education process. With the advent and proper use of new multi-media tools and facilities, such as the internet and html-platforms, there is a constant and increasing contribution to the educational and learning processes, since information now becomes highly distributed as well as more comprehensive and integrated.

Inevitably, under some performance limiting technology constraints, teaching and learning can now happen anytime and anywhere. The technological innovations provide to both teachers and learners a variety of new interactional situations in which all have their own particular characteristics. Some courses are using e-learning which are predominantly face-to-face with some online interaction; some are blended with online interaction supplemented by face-to-face interaction in a more balanced fashion, while other courses take place primarily online, see for further details [20].

In this work, we provide the technical specifications for the conceptual design of an integrated e-learning solution using satellite communications for control systems courses. In the sequel a detailed account of all the necessary tools and mechanisms is provided while simulation results and concepts for an end-to-end distant teaching solution of a basic Networked Control Systems course are introduced. Furthermore new hybrid architectures integrating advanced communication concepts with terrestrial networks towards a wireless e-learning Classroom for control education purposes are proposed. However, in order to describe the pilot platform, it is appropriate to briefly review and identify the basic ***concepts*** of control theory such as: *dynamical system, stability, feedback* and *dynamic compensation.* These concepts should be understood by all mathematics and engineering tutors forming the common foundation of any control curriculum; see also [16], [24] and [25].

Practically speaking, the e-learning platform should provide to both tutors and learners with several realistic and integrated applications coming from different fields of science and engineering (circuit networks, robotics, financial/actuarial problems, biological systems etc), where mathematical equations have specific physical meaning and merit.

For practical and pedagogical reasons, the e-learning platform may contain all the necessary tools and state of the art infrastructure so that educators and learners are provided with the appropriate computational environment for in depth qualitative and computational investigations of the abovementioned techniques aided with figures, schematics and colourful diagrams. In addition, since in control and system theory there exists a variety of theorems, propositions, criteria and methods, it would be highly pedagogical and desirable that the e-learning platform provides the needed equipment to communicate seamlessly and reliably with each other as well as with other institutions' laptops and control labs. For instance, several examples of instability (note that stability is the 2nd concept of control) can be derived and more techniques can simultaneously be applied and compared, and perhaps new ideas related to stabilization criteria and techniques could further be developed. Additionally, the very interesting mathematical tools used for the stabilization of different types of systems are varied in different fields of mathematics (from algebraic differential geometry to functional analysis) that can be easily taught and attended.

Finally, in the sequel, some further details of the most common applications of control theory into realistic situations are given; following the motivations and lines of the interesting article written by Murray et al. [18], published into the IEEE Control Systems Magazine.

Over the last four or five decades, the advent of analog and digital electronics allowed control systems technology to spread far beyond its initial applications and foreseen expectations and has made it an enabling technology in a plethora of applied scientific areas. Visible successes from past investment in the control sector include:

- Guidance and control systems for aerospace vehicles, including commercial aircraft, guided missiles, advanced fighter aircraft, launch vehicles, and satellites; these control systems provide stability and tracking in the presence of large environmental and system uncertainties.
- Control systems in the manufacturing industries, from automotive to integrated circuits; computer-controlled machines provide the precise positioning and assembly required for high-quality, high-yield fabrication of components and products.
- Industrial process control systems, particularly in the hydrocarbon and chemical processing industries; these systems maintain high product quality by monitoring thousands of sensor signals and making corresponding adjustments to hundreds of valves, heaters, pumps, and other actuators.
- Control of communication systems, including the telephone system, stability of delayed optical networks, cell phones, and the Internet; control systems tools regulate the signal power levels in transmitters and repeaters, manage packet buffers in network routing equipment, and provide adaptive noise cancellation to respond to varying transmission line characteristics.
- Special mention should be given to the recent developments of the emerging field of Networked Control Systems (NCS's). That is the integration of communication and control sub-systems into a coherent well coordinated process were control is achieved over a real time wired or wireless data network.

These applications have had and are continuously generating an enormous impact on the overall productivity of modern society. Even more, quite recently, in [23] a prototype telemedicine centre that can be initiated by private-public health sector partnerships (PPP) is constructed. The approach has been introduced considering systems and control science conceptualisation and formalism, since several constructive formal methods and powerful tools of these two fields of engineering and mathematics have been widely applied. The whole project is based primarily on satellite facilities; see Galileo/ESA initiatives; see ESA [11-13].

Thus, an intelligent, integrated engineering-systemic model structure is described that can be easily adapted to serve multiple and diverse user needs. The proposed model demonstrates the promise of IC technologies in the delivery of patient-centred healthcare. Moreover, it provides a stepping-stone for distant continuing *education* between academic health sciences' centres, i.e. the Nursing Departments of Universities, the Medical Centres, the Hospitals, the Health Care Laboratories etc.

II. An Organized Approach for the Teaching Procedure

Let alone all these practical applications and all the innovative technological trends that should be considered, we must also find and to a certain extend re-invent an appropriate pedagogical way to teach courses in control theory and practice. Indeed teaching control courses involves more than just transferring to students certain mathematical concepts and sophisticated techniques. It is a way to provide deeper insight and to develop mental habits for the understanding of control concepts and practices. It is common true; see also [14] that students learn more willingly by processing from the specific to the general and by working simple problems before approaching more difficult and challenging ones. Hence, it is most advantageous to organize e-learning teaching procedures by arranging a sequence of computational and theoretical laboratory short projects which gradually proceed from simple to more advanced tasks. In the next few lines, we try to design the educational e-learning platform considering several didactic and pedagogical aspects:

- At first, the proposed platform must be user *friendly* and easily *adaptable* on the basis of student-to-student needs and class-to-class didactic requirements. Moreover, the platform should be fully scalable and continuously updated with new software and hardware tools and facilities.
- Secondly, the students should be able to *interact*, to *plan* and to *propose* specific engineering problems from different disciplines such as Power, Aerospace, or Robotics. Afterwards, with the tutors' assistance, they should gain a deeper understanding of the problem, investigating the basic mathematical tools and designing constructively the necessary steps in solving it. Very often incomplete understanding and unwillingness for participation is due to lack of concentration. Therefore, the tutor should enhance students' curiosity and motivation in solving the engineering problem.

- Thirdly, the platform should be able to *collect* easily *questions, inquires* and *ideas* proposed by the students. In fact, to conceive new ideas and thoughts is one of the main achievements of the educational interactive process. Some students are more capable in stating questions, while others might be more interested in answering them or working with them.
- Fourth, the platform should provide the *theoretical* as well as the *practical aspects* of control problems. Students learn easily through hands on experience. The platform should further develop the abilities of the students for engineering problem solving and design rather than just teaching specific tailor made techniques of the cookbook type. An easily accessible theoretical background enriches students' motivation especially in the engineering departments. On the other hand, laboratory experiments and PC spots, figures and graphics attract the students of the mathematics departments.
- Fifth, students should be able to *present* their results, thoughts and plans orally as well as in writing. The platform should provide all necessary tools in this direction. Communication among students of the same University or with other Universities is of primary importance. Writing a good and useful report or preparing a successful oral (or interactive) presentation requires skills and effort. A problem in mathematical science is solved, if the students can convince others that they have actually solved it. Definitely, communication standards should be emphasized in the learning and education process.
- Finally, students should be able to *re-examine* and *re-assess* their own results. Some of the best effects may be lost if the students fail to re-visit the finished projects and designs, in order to obtain more well ordered knowledge, and perhaps more general conclusions.

III. Overall Pilot Description of Our Model

The proposed platform consists of the necessary H/W and S/W infrastructure and the respective educational content and it realizes teleconference sessions between a central office (tutor) and at least two (2) remote sites (learners). Communication between these sites is realized using the *Hellas Sat bi-directional satellite* platform.

Moreover it enables all participants to communicate with each other and exchange messages and ideas through text, audio and video. More specifically, all users will view a live video stream (coming from the tutor's site). This stream can be either the instructor himself or any other video source (e.g. video tape) and can display content that is essential for a deeper understanding of the subject being covered.

In addition, all participants can work collectively on the same applications and share their own content. Apart from a suite of standard tools, such as *slide show*, *whiteboard* and *html browsing*, the participants can actually share a PC or a Laptop with all relevant applications.

Furthermore, at any instance during a session a student can request permission to use the system resources, by "*raising his/her hand*" and as soon as the instructor passes the token to the requesting student, the latter can work on the applications or even speak through a microphone. This conversation will be either private, i.e. between the instructor and the learner, or can be heard by all session participants. When the student is done, he/she passes the token back to the tutor.

Finally, through the platform a video on demand procedure will allow all remotely located students to share post-processed previous online lessons with the accompanied documentation available for downloading. This "*Video-on-Demand*" is transmitted in a specific time schedule published to the relevant sites, thus enabling trainees to further study the training material at their own pace or getting prepared for later sessions.

It is emphasized that the performance expectations created out of any type of e-learning platforms should be certainly high, at all levels of the education process. However, it is questioned how much of it is going to be truly feasible, and up to what point it can help particularly in the case of mathematically oriented courses. The reasons behind the high expectations on distant-learning stem from well-known characteristics of e-learning systems; see for more details [5]:

- In principle, access is possible from anywhere - any time, thus making possible flexible (even just-for-me) and just-in-time courses of learning.
- The tutor can be anywhere and do most of his teaching job at any time (preparing materials or following-up and coaching his students-learners).
- Synchronous activities of a tutor (or tutors) and a learners' group (at an agreed time) is allowed, but again without restrictions on the location of the people involved, and, even more, with the possibility of addressing a much larger audience than a conventional class.
- Assessment, to a large extend, can be automated and final grading can be seamlessly integrated into the institution's information system.
- The learning material and experiences can be enriched in many ways, and can be easily maintained and updated (as compared to preparing, a new edition of a text book).
- There are also indications that motivations for deeper understanding and stronger retention may be induced.

Consequently, some of the fundamental questions that anyone could raise involved in the e-learning educational procedure relate to proper adaptation issues. In particular how someone can attach all these innovative concepts of new technologies to improve the quantity and the quality of the learning process in mathematics, since there are many levels that need to be considered, and many variations within each level, that cannot be expected to be considered as a universal recipe. Thus, reviewing the next lines, for the proposed scheme, we are making the assumption that

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mathematical control courses are provided for freshman/sophomore level of the mathematics and engineering departments.

IV. INEGRATED E- SERVICES AND APPLICATIONS

The proposed educational platform provides the tools and mechanisms that enable real-time text, audio/video based communication between the tutor and the learner. The services that will be offered include:

- ***Virtual classroom***, i.e. the transmission of live content among the pilot sites.
- ***Offline operation***, i.e. the review of previously saved material, thus enabling learners to further study the training material at their own pace or to get prepared for later sessions.

The applications and tools included in the e-learning platform cover the needs for an interactive collaboration environment that can efficiently support distant-learning sessions. These applications include:

- ***Sharing of applications***: All participants can actually "share" a PC, along with all relevant applications, without the need of actually installing these applications on all participants' machines. More specifically they can share:

(i) A *whiteboard application* for the creation and editing of diagrams and drawings, using standard tools (lines, boxes, circles, ellipses and arrows), freehand drawing, imported images and text. The attributes of the drawing elements (color, fill, width, etc.) can be specified/modified at any time, while certain help features (grid, snap to grid, pointers, bring to front, send to back, etc.) allow users to interact and jointly create easily complicated shapes and diagrams.

(ii) An *html browser application* for navigation through locally stored content or the Internet thus ensuring that all users are viewing the same page at all times. The application provides the standard browsing functionality (Stop, Refresh, Back, Forward), while it allows users to edit a bookmark, list and add or delete entries according to their preferences. The bookmark list can also be used as a table of contents for locally/remotely stored training material and facilitate the instructor or students to browse their "electronic notes".

(iii) A *MATLAB web application*, see also [3], can be used since several aspects in control courses (see also [1]) can be demonstrated using creatively the MATLAB/Simulink environment. During the e-learning process tutors and students can use PC with MATLAB where several of the basic concepts of control theory can be appeared, refer also to the first section. To enable tutors and learners to use the same or a common working environment individually on their home computers, or even using an Internet connection, we use the ***M****ATLAB* ***W****eb* ***S****erver* (**MWS**). MWS is a cgi-bin application that is used to launch MATLAB script files (m-files) remotely. The user can give parameters that are used during the m-file execution. With MWS, almost all built-in and self-written MATLAB functions and routines can be called from the m-file, including functions that produce graphics to be shown to the user. The following set of automatic control related problems can be solved and demonstrated with the existence of m-files of MWS:

- polynomial mathematical operations,
- polynomial roots finding,
- solution of a matrix equation $\boldsymbol{Ax} = \boldsymbol{b}$,
- pole-zero map of LTI models,
- step response of LTI models,
- process model simulations (storage tanks and heat exchangers),
- closed-loop simulations, and networked control with delays
- optimization tools,
- pricing tools etc.

(iv) A *slide show application* for PowerPoint presentation ensuring that all users are viewing the very same slide at all times. The application provides typical browsing capabilities (moving to next/previous/first/last slide or to a specific one), while it allows the active user to draw annotations on the slides (lines, pointers, etc.), in order to present his/her ideas more clearly, while on the other hand, viewers may easily follow-up and better understand the content presented.

- ***Private and public chatting***: any participant is able to send a text message to his/her classmates (*public chat*). The messages of all users are displayed in the order they arrived, while the name of the sender is added at the beginning of every message. This functionality is available to trainees at all times, unless the instructor has specifically disallowed chatting during a session. In addition, there is the ability for a private discussion between the instructor and a learner (*private chat*). Both parties may initiate this conversation while all messages exchanged during such a session are not broadcasted, unless the instructor decides to do so with a simple click of a button.
- ***Audio/video streaming***: all users are able to view a live video stream (coming from the tutor's site). This stream can be the instructor himself or any other video source (e.g. a video tape) and can display content that is essential the subject being taught. At any time-slot during a session, a student can request permission to use the system resources, by "raising his/her hand" and as soon as the instructor passes the token to the requesting student, the latter can work on the applications or even speak to all participants through a microphone. When the student is done, s/he can pass the token back to the tutor, or the tutor can obtain it any time, should s/he decides to do so. There is a "Participants List" which displays the participants of the current session, as well as the status of each participant (e.g. raised, active etc.).

V. SERVICE REQUIREMENTS

A. An overview of the service

A typical online learning program includes the text and graphics of the course, exercises, testing, and record keeping, such as test scores and bookmarks. Extending the basic concept, e-learning introduces real-time interaction among participants. Organizations planning to contact interactive computer-based sessions, need a number of collaboration and content presentation tools that will enable all registered users to participate in a lecture and access the training material or create their own "notes". Furthermore, the system should support offline operation enabling the students to review the material at their own pace, any time they feel they need to do so for their own better understanding.

Such a tele-education set-up can be utilized only via broadband connections that allow content (i.e. audio and video streams) and data streaming to be transmitted towards the student group. At the same time students need be able to interact with their instructor using an appropriate return channel.

B. *Equipment Use*

The proposed pilot system enables the interconnection of the tutor (trainer) unit (central site) with the students units (remote sites). All users will work over a standard PC with the "client" part of the educational application and they will be connected to a Local Area Network in order to have access to the Internet and browse web pages.

In the central site (trainer's studio) there will be specialized equipment installed, such as microphones, digital cameras, video projectors and VCRs, as well as the respective audio and video consoles. This audiovisual infrastructure will stream content from the instructors' site towards the students. In addition, there will be appropriate equipment and applications for image processing and video postproduction, which will be used either for educational purposes, i.e. as part of the courses to be delivered, or as tools for preparing the training material for offline operation.

In the remote sites (students' workstations), all students will be able to respond to questions or submit comments to the instructor through their microphones connected to their PCs or by using their standard keyboards.

The communication between the central and remote sites will always go through the Head End where there is the "server" part of the tele-education system. In both the instructor's and the students' sites there is the "client" part of the tele-education system. The communication will be realized with the DVB-RCS satellite backbone infrastructure, guarantying proper and reliable bi-directional communication among users.

C. *Personnel and premises description*

The facilities both centralized (in main site) and distributed (in the other sites) network structures can be based on conventional switches. A Leased line (at least 256kbps) is complementary available in the main site. For live video broadcasting a Panasonic digital video console with a Mackie digital audio console can be used to produce video streaming. For offline content postproduction two AVID DV Suites can be used. Finally the streaming content can be published through a windows media encoder installed on a Windows Server machine. For the image processing applications Adobe Photoshop and Corel Photopaint is used while for video editing Adobe Premiere or AVID DV-Xpress is used.

In every site, an IT team is proposed which will be responsible for proper system operation while sessions will be prepared and delivered by highly specialized professors of the educational institute.

VI. TYPICAL EVALUATION PROCEDURE AND SIMULATION PERFORMANCE OF NETWORKED CONTROL SYSTEMS (NCS)

A. *Typical Evaluation Procedures*

During the pilot operation the tele-education service will be evaluated in terms of the educational process as well as of the required infrastructure. More specifically, the quality of the service (QoS) will be assessed using the following criteria:

1. quality and usability of available tools,
2. effectiveness of the response time of the bi-directional communication upon the overall educational procedure,
3. users' acceptance and friendliness, both for the instructors and the students (questionnaires are going to be filled by the end users).

Furthermore, the infrastructure needed for the utilization of the service will be assessed using the following criteria:

1. installation and customization time,
2. reliability of the network, and
3. user friendly administration of the platform.

The above parameters will be valued against the cost of installation and operation of the service. The cost benefit of the tele-education pilot will provide useful information for fine-tuning the commercial offering of the service.

Interviews, self-reporting and observational methods will be used on the basis of their feasibility and appropriateness for each user group. Suitable tools, e.g. questionnaires, will be developed prior to the operation phase and they will be fine-tuned during the pilot operation according to the special needs of each user group.

B. *Simulation Results of a Networked Control System (NCS)*

An interesting use of the proposed platform is the teaching of fundamental issues in the rapidly emerging field of Networked Control Systems (NCS) see [2], and [11] for analytical and detailed overview. A basic issue is the inevitable presence of networked induced delays introduced either by the shared Internet infrastructure or/and the satellite link. A typical simple setup is presented in Figure 1.

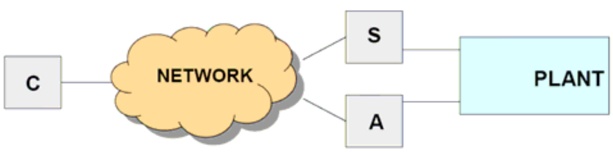

Figure 1: Typical Networked Control Loop (S=Sensor, A=Actuator, C=Controller)

For educational purposes the remote control of a DC motor via a simulated network with delay is presented see also [10]. Indeed the proposed platform is ideally suited for introducing students into the fundamentals of NCS technologies within a control systems curriculum, since the induced delays are unavoidable by the very nature of the platform's infrastructure. In the sequel we present simulation results of a simple experiment controlling a DC motor with transfer function:

$$G_M(s) = \frac{2029}{(s+26.3)(s+2.3)},$$

while the employed PI speed controller is of type:

$$G_{PI}(s) = \beta\left[\frac{K_p\left(s + K_i / K_p\right)}{s}\right].$$

The parameter β was used in [4] as a scheduling variable taking care of the network delays.

The PI controller was tuned neglecting the network delays. The chosen parameters are β=1.0, K_p=0.1701, K_i = 0.378 were selected based on overshoot and settling time specifications. The total round-trip delay was taken to be a constant total delay of 0.0965s. Assuming that the total delay is equally divided between the uplink path (controller to actuator; see Figure 1) and the downlink path (sensor to controller) the tracking performance degradation is drastic as can easily be seen in the provided Figure 2 below where a comparison is made between the NCS (= delayed) version of the control and the delay-free case. In the summary report see related reference (TCP/IP Performance) a detailed account of the TCP/IP performance over satellite links with corresponding delays is provided for an error free non-congested channel. Relevant tables are given for terrestrial, hybrid and satellite links.

VII. TELE-EDUCATION PILOT ARCHITECTURE

A. User Needs and anticipated results

One of the objectives is to set up an integrated training solution that enables any organization and corporation (end-users) to continuously educate their personnel. The proposed solution is best fitted in asymmetric, broadband environments (such as the satellite) where the geographic dispersion as well as the number of the concurrent participants practically prohibits the adoption of any other, typical web-based training systems. Such a competitive advantage is also highlighted in case the training material includes multimedia or bandwidth hungry content (such as video and audio).

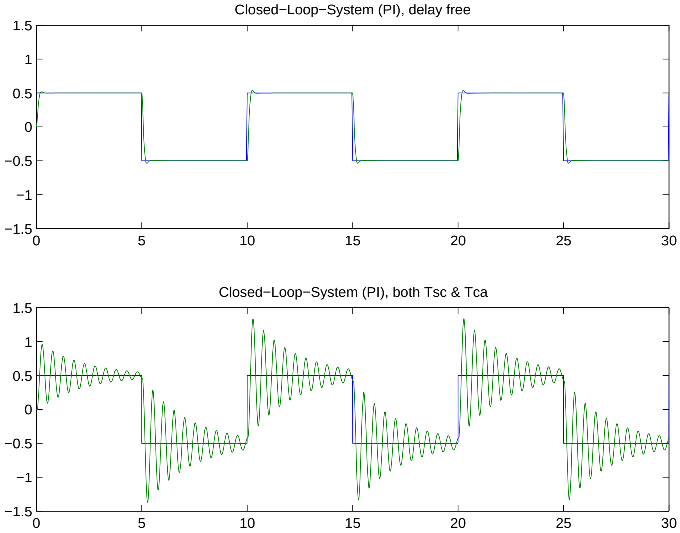

Figure 2: PI control of a DC motor with constant total delay 0.0965 s

The tele-education service is expected to benefit the user in terms of:

1. *Fast and easy deployment* of the system, especially in remote geographical areas.
2. *Interactive tutor- student communication*
3. *Low operational costs* as user-friendly graphical interfaces hide all communication and presentation complexities eliminating the need for trained personnel.
4. *Low training costs* due to enhanced multicasting techniques.

B. System Description

The tele-education platform includes two major components:

a) Transport and communication module

It is responsible for handling all data exchanges between the users of the system. It is also responsible for receiving messages from the user in control and broadcast them to all other participants. In addition, this module handles the delivery of the required assets (images, videos, training material etc) from the teacher's site to the registered students. Finally, the communication module handles the broadcasting of the live video stream, as well as the audio stream that is generated when a student in control speaks to the microphone. The required sub-components for the communication module can be found in the Uplink and Downlink Server and have no interaction with the operation logic of the training application, in order to provide a well-defined layered architecture for the entire system.

b) Training logic module

This module contains the logic of the training system and hosts the applications (whiteboard, text editor, html browser etc) that provide its functionality. It is responsible for generating all necessary messages, depending on user or system

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actions and passing them to the communication module for broadcasting. It also receives the messages sent by other system users and acts accordingly. Due to the fact that this module is unaware of the communication infrastructure, the same application can operate in stand-alone mode, as well as LAN mode. This feature makes the whole system scalable and allows for various configurations to be supported from the same application environment, without the user knowing anything about network connectivity complexities. It is not a complete ***C**ontent **M**anagement **S**ystem* (**CMS**) but if needed it can be integrated with one.

The *Head End* which consists of two parts:

(1) A group of servers utilizing advance multicasting transmission techniques enabling the reliable transmission of information over the satellite and its distribution to the ***L**ocal **A**rea **N**etworks* (**LAN**s). More specifically, there are four (4) unicast servers, two (2) multicast servers (***C**ontent **P**rovider **M**anagement **S**ystem* – **CPMS**) in a "hot standby" mode 1+1, one (1) server for the SOCKS protocol, two (2) IP traffic managers for the local network in "hot standby" mode 1+1, one (1) server for storing the web pages, two (2) IP encaptulators in "hot standby" mode 1+1 and all the required communication infrastructure such as switches, firewalls etc.

(2) A group of servers for the pilot application, i.e. an application server, a media server and the REFLECTOR which contains the central database and the tools required for the authentication of the users and administration of the application.

The communication-related infrastructure can support several simultaneous users while the application-specific infrastructure is preferred to be dedicated to one active user for bandwidth constraints and to simplify platform management issues during the pilot operation.

The ***Network infrastructure*** is a satellite network that utilizes the DVB-RCS standard infrastructure, guarantying proper and reliable bi-directional communication between the users.

The ***Tutor's studio*** includes a video/audio encoder and the instructor's workstation with the ***G**raphical **U**ser **I**nterface* (**GUI**), which allows the instructor to manage the applications and coordinate the synchronous training sessions. The video/audio source may be from any source considering the technical specifications of the encoder.

The ***Learners' workstations*** include similar GUI to the one included in the trainer's workstation (with some slightly modified functionalities), while they are all interconnected to a **LAN** having a single downlink server to administrate the communication between all training parties (tutors and learners). Furthermore, they are equipped with a microphone in order for the trainee to submit comments and questions to the instructor.

C. System Architecture

Communication between the central and remote sites is always going through the Head End where there is the "server" part of the tele-education system. Due to the nature of the service, the bandwidth requirements of the instructors side are 2048 Kbps both for uplink and downlink, while at the students' sites 2048 Kbps for downlink (receive) and 512 Kbps for uplink (transmit) is needed. The proposed architecture can be seen in **Figure 3**, see [25]. A communication link in the form of a leased line (SDH) is also required to provide a steady and reliable link between the Satellite Hub and the Head End. In that way, a double hop is avoided on the satellite between the instructor's site and the students' sites. The latter is consuming excessive satellite bandwidth and at the same time is adding delay to the link. The architecture diagram depicts a satellite connection at the Head End only for redundancy purposes.

At this point it is constructive to briefly point out that the **RCS** (***R**eturn **C**hannel via **S**atellite*) platform is capable of supporting independent networks providing different kinds of applications within the HellasSAT coverage. DVB-RCS provides bi-directional broadband connectivity via satellite with bit rates comparable or exceeding terrestrial systems, enabling services such as fast Internet access, intranet/VPN for secure connections, multicast and real time applications; see [6-9].

The configuration of the DVB-RCS system is in the form of a star network architecture consisting of a ground station Hub and a number of Satellite Interactive Terminals (SITs). The proposed system is able to support up to 100 simultaneously active SITs and it can be upgraded to support up to 10.000 terminals.

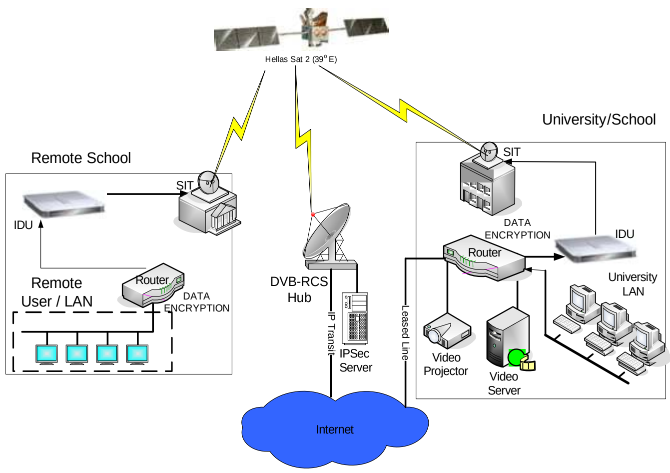

Figure 3: Integrated Educational System Architecture

The forward link, from the central Hub, is based on the DVB-S/MPEG-2 data format and is capable of carrying information with bit rates up to 45Mbps. In the receiving site, each SIT connected to the network is able to upload up to 2Mbps per carrier in the return direction using the so-called ***M**ulti **F**requency-**T**ime **D**ivision **M**ultiple **A**ccess* (**MF-TDMA**) scheme.

The basic reasons that make this technology attractive are its flexibility, the low cost of its Satellite Interactive Terminals (compared to VSATs) and finally the fact that it is developed to be an open standard. The reasons mentioned are briefly explained below:

- Proprietary very small aperture terminal (VSAT) equipment has been available for a number of years, but has addressed only a very limited market. The key reason for this limited uptake is the high cost of VSAT terminal equipment since each provider uses its own proprietary solution.
- The European Space Agency has created a group named Satlabs aiming at pushing the key terminal and hub manufacturers to make their own DVB-RCS solutions interoperable, hence opening new opportunities for adoption of satellite solutions.
- The DVB-RCS technology has a very effective network management system with simple functionality that has also the capability of giving levels of priority to the demand and reserve the appropriate space capacity for each case.

VIII. THE HYBRID E-LEARNING CLASSROOM PLATFORM

A. Hybrid Architectures

As it is demonstrated in [19] the adoption of wireless access point (AP's) is already gaining a sustained popularity in almost every aspect of our everyday activities. For example the IEEE 802.11b wireless LAN has found a plethora of applications including university campuses were students and teaching personnel are experimenting with the capabilities of the network. In that respect the convergence towards a wireless E-learning classroom were all mobile users have access "anytime – anywhere" is becoming a reality. Within the context of our paper various control theory concepts and paradigms can be taught over wireless distant learning networks; see [17], [21], and [22]. We further extend the capabilities of integrating the DVB-RCS communications standard with a class of terrestrial broadband last-mile access technologies such as WiMAX and Wi-Fi for the provision of advanced Broadband services. In that way we provide an integrated informative view of the available technologies for the construction of a highly innovative and realistic E-learning classroom using state of the art communication and terrestrial infrastructures. We do not mention since it is beyond our objective, two more scenarios that can form hybrid networks which involve Power Lines and DSL.

Indeed a typical model for a hybrid network using DVB-RCS and Wi MAX (World Wide Interoperability of Microwace Access-IEEE 802.16) is depicted in the figure below.

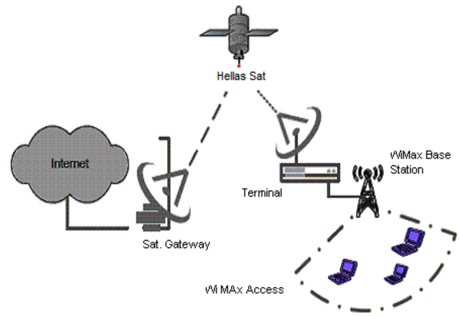

Figure 4: Hybrid DVB-RCS / WiMAX network

In this type of configuration distributed point –to-multipoint connectivity is accomplished on a local level to mobile users using terrestrial access technology. In parallel time the satellite provides traffic aggregation and backhauling using a sat hub/gateway and high capacity Internet point. It is interesting to note that the above schematic reveals a low cost realistic solution deploying a DVB-RCS terminal to be shared by many end – users or groups of users located at different University campuses. It is noted that the Wi-MAX *Base Station* (BS) can be connected using fibber, point to point RF or satellite links to the Internet cloud / backbone. Then Internet connectivity is distributed to the end-users who are using the *subscriber stations (SS)* to interface with the Base Station. The allowable bandwidth is up to 40 Mbps / channel for fixed connections and up to 15Mbps / channel for wireless links. The WiMAX standard includes various and extensive support for Quality of Services (QoS) such as multimedia and other interactive applications. The MAC layer includes services such as Real-time data streams (VoIP traffic), Real-time Polling Services (video traffic), Non-real time Polling Services (delay tolerant streaming) and Best Effort (no specific requirements for delay or rate). Moreover additional applications are supported such as VoIP and Video-Conferencing, Streaming media (video clips), Information Technology (instant messaging, Web browsing, e-mail) and Media content download (Store and Forward bulk data, e.t.c.).

The Wi-Fi (IEEE 802.11) standard for the hybrid scenario is well more industry mature enjoying a higher penetration of AP's (Access Points) but which is primarily of LAN type technology. The maximum physical layer data rate is up to 11Mbps for 802.11b and the interfacing between Access Points and end-user equipment is realized primarily with Ethernet while end-user AP's are managed only via HTTP Web interface. The interoperability issues arising with the DVB-RCS standard are of similar nature with the previously mentioned WiMAX standard. All IEEE standards which are applicable to Wi-Fi are contained within the IEEE 802.11 (a, b and g) group. Moreover it supports most IP-based applications. At this point it is noted that for an urban and remote location WiMAX is probably the most suitable choice to follow when there is no available or existing wired infrastructure.

In the following Tables 1 and 2 a brief catalogue of Network Operating QoS requirements and the corresponding

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applications is presented that are supported by the hybrid architectures DVB-RCS with WiMAX and WiFi technologies.

Table 1. (QoS)-Quality of Service requirements for different broadband advanced applications

Broadband Internet application	Bandwidth (kbps)	Delay (ms)	Packet Loss (%)	Jitter(ms)
Streaming Audio	≥10 (voice)	≤5,000	≤3% (non-concealed) ≤8% (concealed)	N/A
Streaming Video	Varies by format (5-15,000,000)	≤5,000	≤3% (non-concealed) ≤8% (concealed)	N/A
VoIP	Varies by codec(5-80)	≤400 (adequate)	≤1-2% (nonconcealed) ≤6% (concealed)	≤75 (adequate)
Videoconferencing	Varies by codec (5-20,0000)	≤400 (adequate)	≤1-2% (nonconcealed) ≤6% (concealed)	≤75 (adequate)
VPN	High (varies)	low	low	low

Table 2. Applications supported by the 2 hybrid network schemes

Broadband Internet application	DVB-RCS/ WiMAX	DVB-RCS/WiFi
Email	Yes	Yes
Interactive Text	Partial	Partial
Web Browsing	Yes	Yes
File Tasnfer	Yes	Yes
Streaming Audio	Yes	Yes
Streaming Video	Partial	Partial
VoIP	Yes	Partial
Videoconferencing	Yes	Partial
VPN	Yes	Yes

In all of the above scenarios advanced broadband services can be delivered including remote Power lines and DSL. In that case different interoperability issues need to be addressed. The only potential source of performance degradation could be the satellite network segment caused by higher latencies and BER (bit error rates) when compared to terrestrial solutions. Nevertheless technologies such as Performance Enhancement Proxy (PEP) and advanced Web pushing and caching in conjunction with the very good quality of service provision of the DVB-RCS standard allow the support of very satisfactory broadband applications within the proposed hybrid integrated network.

IX. Conclusions

An initial attempt has been made to place on the control curriculum (with sample programs relying from past experiences in the Engineering Department of NTUA, in the Department of Mathematics and the Department of Statistics of the University of Athens and Athens University of Economics and Business, respectively, in Greece, and in the School of Engineering and Mathematical Sciences, City University, U.K.), the significance of laboratory hands-on experience, and the increasingly important role of different software applications in conjunction with communication network architectures in teaching and e- learning.

The ways in which educational experience shapes control courses is discussed with views from highlighting the desirable skills and knowledge of a well educated control engineer and systems analyst in the 21st century. Special attention has been given not to the historical origins of control systems, but to the future. It is expected that stronger emphasis on integrated control laboratories and use of sophisticated software will perhaps have the highest impact on the quality and level of graduates' training. In that direction a NCS educational paradigm with simulation results for the control of a DC motor over a network and the performance degradation due to the induced network delays were introduced. In conclusion, the future of control systems education will undoubtedly experience [16]:

- more real-world laboratory experiments with novel applications,
- increased reliance on computer-aided control software,
- broader education of control courses and more emphasis on interdisciplinary teamwork activities,
- closer ties between real applications and problems, and academia, particularly those related to continuing education,
- continued novelty in the ways control textbooks blend theory and applications for a computer-based instructional environment,
- pedagogical discussions among educators on aspects of control courses teaching,
- continuous updating and sophistication in the laboratory (computer visualization, interactive and virtual) environment as technology keeps advancing rapidly,
- more programs are expected to present newly developed control concepts in the form of highly specialized courses.

In conjunction with the above special attention was given to hybrid communication infrastructures. A successful distant learning technical course depends strongly on the available technological assets it exploits. In that direction specific guidelines and technical standards are given for the implementation of hybrid networks using satellite and terrestrial configurations. In the near future it is expected that low cost and easily implementable architectures of the hybrid type will gain even greater popularity among academia and will be systematically deployed for distant learning control courses enriching the educational experience of the end user.

It is evident that much further work needs to be accomplished, towards fully scalable, end-to-end and integrated e-learning solutions capable of fulfilling the academic needs of educators and. students.

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