Security, Interoperability, and Quality of Service Aspects in Designing a Telecommunications Platform for Virtual Laboratories

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Abstract—**The distributed processing and access requirements in implementing distributed virtual laboratories imply a number of challenges related to security, interoperability, and quality of service. This paper explores these aspects, then accounts for them in a distribution model comprised of five schemes: one for each of these aspects as well as processing and data storage distribution.**

Keywords—**Virtual Laboratory, Telecommunications Platform, Interoperability, Quality of Service, Security.**

I. Introduction

Thanks to the strong and sustained development of computer networking in recent years, coupled with constraints of traditional learning, tele-learning is becoming an increasingly popular idea [1]. Although much attention has been paid to adapting learning material delivery [2] and the classroom setting [3] to a networked world, the same cannot be said of the laboratory setting.

Distributed virtual laboratories are learning environments. As such, they inherit some of the human and material characteristics of their traditional real-world (physical) counterparts. This includes some characteristics that can be taken for granted, but are no longer obvious in a computerized and distributed setting, such as the possibility to observe learners and monitor their behavior and progress.

Traditional laboratories have more differences with virtual ones than just being non distributed. Some of the interactions and manipulations that take place there may not be computer mediated. Yet, their existence and their being freely observable may play an important role in the learning and evaluation processes. Once they are moved to a computerized interface, however, these properties may be lost, but they should not be. This is also of particular interest to the learning and cognitive sciences community whose current focus is to provide insight and palpable measures of the benefits of the learning environments they propose. From the engineering side, this translates into providing tools that make this easier and possible.

Activities performed in laboratories, whether traditional or virtual, include

- distribution and consumption of laboratory session information;
- live explanation and instructions from the teacher to a group of learners;
- team formation;
- exchange with colleagues (team members);
- personal exchange between teacher and learners (questions and answers);
- setting up montages;
- manipulation of montages and instruments;
- observations making;
- measurement (data acquisition);
- data analysis;
- monitoring, evaluation, and intervention by the teacher;
- report writing;
- report submission;
- report annotation and grading by the teacher.

In implementing virtual laboratories, care should be exercised to preserve the ability to support these activities and their characteristics.

Their being distributed also adds new challenges and possibilities specific to that setting.

From the users perspective (be they the learners, teachers, or designers), distribution aspects may be categorized as being fully visible, translated from simpler configuration choices, or fully transparent. This is where the concept of a *telecommunications platform*, layered under a given virtual laboratory implementation, becomes useful [4]. The platform abstracts the implementation-related distribution and telecommunications details from anyone who is not necessarily a specialist in those fields. The telecommunications platform itself is composed of three layers:

- the tools and functionalities adaptation layer;
- the base tools and functionalities layer;
- the network adaptation layer.

Implementing this platform in the specific context of distributed virtual laboratories poses a number of challenges related to security, interoperability, and quality of service (QoS). This article first explores those aspects, then accounts for them in a distribution model. This model is part of the development of a virtual laboratory design methodology (which is not covered in details here).

II. Security Aspects

Traditional learning environments are already concerned with some form of security. Indeed, the evaluation process, for instance, is usually performed on a per-learner or per-team basis. Learners are identified (authenticated) with their id. cards and plagiarism is of concern.

In addition to a virtual-form equivalent of traditional functionalities, a distributed laboratory may provide access to networked equipment or data stores. Distribution may involve going through public network infrastructures.

The jurisdiction under which private authentication information is located for all users (e.g., an university) may not wish to delegate the authentication task to the jurisdiction where a learning environment is implemented (e.g., a department of a faculty of the same university) as this would effectively delegate to this latter jurisdiction universal access to an user's resources located under any jurisdiction. Cryptography-based authentication tools must be provided to address this issue, but delegation of trust or responsibility should also be supported by explicit declaration.

In an open environment, users should not only benefit from the possibility to exchange information between one another, but also have the possibility to transfer and download content which is subject to a controlled usage. In such a context, securing those transfers is of a primordial importance and this should be reflected in the very process used to design virtual laboratories.

Learners teamwork is common in laboratories. The authorization (or permission) facilities made available in a virtual laboratory must be sophisticated enough to allow the easy definition of new teams (group of users) and exclusive sharing of information between team members. These facilities should also allow teachers to access learners' data, sometimes with no possibility for the learners to subtract their data from this (and without forcing teachers to use a dangerous full permission access for what is their regular work).

III. Interoperability Aspects

Likewise, there is a matter of interoperability between heterogeneous networks and communication supports that can be used to access the laboratory environment. This should be taken into account as well in a virtual laboratories design process and methodology.

When networked laboratory equipment (such as measurement equipment) is used, telecommunications protocols other than the general usage ones (such as Ethernet, IP, etc.) come in use. One such protocol is the General Purpose Interface Bus (GPIB, IEEE 488.2) and it can either be supported natively or through bridges to other protocols.

Aside from the telecommunications side, computer software is also of concern for interoperability.

In our prototypes, we have investigated the use of CORBA and its capacity to support interoperability between Internet protocols and xDSL technology. We conclude that, in order to address this specific problem, a proposed design methodology should include one step dedicated to networks and supports adaptation at the level of the telecommunications platform.

IV. Quality of Service Aspects

As for quality of service, the main concern is the delay to access, transmit, and display the (possibly multimedia) information that is exchanged in this type of environment. This aspect deserves particular attention in the context of virtual laboratories where interactive simulation, tele-measurement, and tele-experimentation are among the considered approaches and methods.

Among other concerns, there are the quality of images and the precision of measures. These are directly related to the available bandwidth. In non-real-time situations, they can be traded against the transmission delay.

Quality of service is something that can be negotiated and configured. When dealing with an human user, we must be careful to use a level of language that can be understood given that most people involved are not and cannot be expected to be experts in networking. This is where the idea of QoS translation must be properly applied.

V. Informational Aspects

From measured data to learning support material, information needs to be collected, transmitted, stocked, processed (translated, filtered), and disposed of.

In order to determine what should be done with a piece of information, it first needs to be categorized. Information can be

- essential or superfluous (optional);
- precious or redundant (sometimes called *soft state*);
- perennial or ephemeral (and then valid or no longer valid);
- private, public, or subject to any diffusion policy in between;
- constant or variable;
- correct or incorrect.

This categorization can in fact depend on the point of view. For instance, information which is precious to a data store becomes redundant once copied to be delivered through an user interface; extra precision on numerical data might be considered essential for computational purposes but superfluous for visualization.

The way superfluous information is treated is of particular interest. The cost of including that information for treatment may depend on parameters such as processing power and transmission systems bandwidth.

Experimentation protocols used (and taught) in traditional laboratories usually dictate that measures which are at some latter point in time deemed to be incorrect then be crossed out in such a manner that they are still readable. The alternative, just erasing them, is viewed as a bad practice since judgment is itself subject to errors and keeping a trail of what has been done can help rectify these errors. This practice needs to be supported as well in virtual laboratories.

VI. Distribution Model

We account for the challenges we just exposed with a distribution model. Its implementation constitutes one of the latter steps in a design methodology for distributed virtual laboratories. This methodology, as well as its associated models, are supported by software tools which reduce the design and implementation effort asked of the discipline or domain specialists. Some of these tools have already been developed as part of the LVEST project [5]. Other such tools are now in development and will contribute to further enrich our telecommunications platform.

The distribution model includes

- a processing distribution scheme,
- a distributed data storage scheme,
- a QoS scheme,
- an interoperability mechanisms scheme, and
- a security mechanisms scheme.

These interrelated schemes act as an expression of user requirements in terms of provisioned resources and their chosen configuration. An algorithmic engine is required to select proper schemes from these input specifications.

Let us review each of these schemes in more details. For each scheme, we will explore its role, its structure, its relationship to other schemes, and implementation options.

A. Processing Distribution Scheme

This scheme's role is to provide a picture of how processing is distributed among all the computing resources provisioned to implement a virtual laboratory.

This scheme comprises a list of functional processes with their network location and access point, as well as their connectivity. Each of these processes can act as

- a data source,
- a data sink,
- a data filter,
- a data duplicator,
- a data multiplexor, or
- a data demultiplexor.

The idea of a data flow is central to this modeling.

This scheme is related to the QoS one since processing such as data filtering can be implemented to shed superfluous information in the presence of low-level QoS. Thus, it is also related to data representation, which is part of the distributed data storage scheme. It is furthermore related to the security and interoperability mechanisms schemes since those require processing.

Technological choices for implementation include

- directly programming sockets;
- using Remote Procedure Calls (RPC);
- using web technologies, HTTP and
  - XML-RPC;
  - server-side solutions such as CGI, `mod_perl`, or Java servlets;
  - client-side solutions such as Java applets or Javascript applications;
- using the Common Object Request Broker Architecture (CORBA);
- using Java Remote Method Invocation (RMI).

The processing itself can be done in hardware or software; its design can be open or closed. In the case of an open software design, there is obviously the usual choice of platform and programming language.

B. Distributed Data Storage Scheme

The role of this scheme is to describe where data is stored, how it is categorized, and how it can be accessed and moved around.

Network-wise, a data store needs to be well connected to its data producers. Indeed, if laboratory experiments that are based on real data are to be inspected for evaluation or the subject of further analysis, the produced data has to be stored. That data may be produced in real time, at a fast rate, with good precision (more bits per sample), and the producer may have limited temporary local storage for it. On the other hand, any human being who wishes to monitor or control the data acquisition process need not be as well connected to the data source since the data can be filtered to reduce its demand on the network.

This scheme is related to the QoS one in that data may be tagged for the purpose of adapting to the available QoS. It is related to the security mechanisms scheme in that some data is subject to a controlled usage. In practice, for performance reasons, some functional processes of the processing distribution scheme will need to be tightly coupled with the implementation of this scheme.

Technological choices for implementation include

- relational databases (with SQL interface);
- object-oriented databases;
- directories (with LDAP interface);
- file systems.

For the data itself, choices include

- direct custom binary storage;
- direct custom textual storage;
- structured documentation storage (using, e.g., an XML schema);
- existing open formats.

C. Quality of Service Scheme

The role of this scheme is to describe the QoS that has been associated with the provisioned networking facilities for a virtual laboratory.

This scheme is composed of a list of links with appropriately stated QoS parameters for each (usually including some indication of bit rate and delay guarantees, if any). From this list, methods are defined to deduce total costs and expected end-user perceived performance.

This scheme is related to the interoperability mechanisms scheme since the latter may offer support for varying levels of QoS.

D. Interoperability Mechanisms Scheme

The role of this scheme is to identify the points within the virtual laboratory infrastructure where different technologies have to be combined.

This scheme is made of a list of interworking functions (IWF) used a the junction between heterogeneous systems, be they telecommunications or computing systems.

This scheme is related to the QoS one in that the capacities of different infrastructures allow for different levels of QoS. It is related to the processing distribution scheme in that some forms of processing may only be available for some of the communications and computing platforms.

Technical choices for implementation include

- hardware solutions such as GPIB-Ethernet bridges;
- software based protocol interworking;
- encapsulating software functionalities within a single common interface technology such as CORBA.

E. Security Mechanisms Scheme

The role of this scheme is to identify the security mechanisms which are needed by a virtual laboratory, their location, and also the way they rely and delegate on one another.

This scheme is composed of a list of security mechanisms with their location and configuration. From this list of mechanisms, a method is defined to produce a list of actual algorithms which are needed for implementation. This can be cross-referenced with a list of available algorithms in the countries that the laboratory will actually span to determine if the laboratory as designed can legally be implemented. Delegation of trust and responsibility are also represented in the scheme.

This scheme is related to the distributed data storage and processing distribution schemes in that distribution implies communications, which need to be secured. It is also related to the QoS scheme since security related computations such as encryption can be time consuming and thus affect the offered QoS level.

Technical choices for implementation include

- various cryptography-based software and hardware solutions for data encryption and authentication;
- hardware solutions such as magnetic card readers for authentication;
- filesystem-based permissions for authorization;
- access control list (ACL) for authorization.

VII. Conclusion

A distribution model which covers relevant telecommunications aspects is only part of the what is needed to elaborate a complete virtual laboratory design methodology. Other models are needed to cover the domain of a scientific discipline which is to be studied, the laboratory sessions, etc. Software tools which implement algorithms to manipulate these models and offer required functionalities are also required. The methodology itself is comprised of several steps grouped in stages of a complete life cycle [6].

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