An Application of Petri Nets to e/m-Learning Environments

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1. Introduction

Thanks to new technologies and devices, e/m-Learning scenarios are quickly evolving and are becoming more and more difficult to control. Besides educational factors and learning contents, a modern e/m-Learning system must also take into account services, kinds of devices and aspects related to the network. As a matter of fact, both learning conditions and activities at disposal depend on many factors, such as the network load of the location from where the user has logged on. Furthermore, not only has the nature of e-learning material changed deeply over time, but so have devices and connection technologies for their fruition, especially in context of mobile learning based on multimedia broadband services.
Learning paths themselves are developing: teaching is not an univocal process anymore, with fixed steps and tasks, since modern technologies make many alternative choices possible. Moreover, such tasks can be fulfilled or not on the basis of personal and environmental conditions. For instance, a lesson in videoconference can be followed or not depending on the kind of device and network load.
In more detail, as far as didactic motivations are concerned, methodologies are changing. The old “linear” teaching paths are evolving into more complex shapes, where parallel and cooperative activities come abreast of conventional ones. In addition, traditional tasks can turn into many kinds of activities that can be fulfilled using different digital formats and devices.
In the same way, modern communication technologies affect learning deeply from many points of view. One of the most important aspects is that they increase interaction and cooperation and reduce – if not cancel - problems related to distance. This allows to make use of many learning contents, remote lectures, cooperative work and remote use of instruments.
As far as m-Learning is concerned, it was born from the evolution of both mobile devices and network access technologies and made e-Learning independent from location and device. This leads to great advantages but also to many new problems. For instance, not every kind of content can be used with any kind of device. In order to make a content available in an m-learning context, it is necessary to design information properly, adapt it and scale it with respect to different devices.
Moreover, this scenario requires a constant monitoring of the user’s conditions: as a matter of fact, some tasks can be feasible or not depending on network load conditions and devices

as well. This means that such factors become an integrant part of teaching modalities and offers.

On the one hand, this variety can turn out to be a positive issue in many situations: for instance, if network overload makes a videoconference impossible, the student can be suggested to make exercises on his own, etc. In the same way, broadband services allow to cooperate or use didactic structures and instruments otherwise inaccessible.

On the other hand, controlling the evolution of educative paths is complicated by this multiplicity of factors.

In this work, which proceeds from (De Castro & Toppan, 2008a; De Castro & Toppan, 2008b, De Castro, 2009), these features and their relationships are analysed and an integrated layered architecture is consequently proposed which aims at reaching a good compromise between quality of learning and studying conditions.

The proposed architecture consists of a user interface, a module for providing services, a decision engine for evaluating students' improvements and consequently deciding learning paths and a database storing learning and assessment contents. Due to the use of different devices and to the presence of different network conditions, the database stores contents in scaled formats, or ready to be scaled on the fly.

The whole system is controlled by a Petri Net defined on the basis of the above factors. The definition of the Petri Net by means of such dissimilar kinds of constraints is one the main novelties of the proposed approach.

The research activity described in this chapter originates from the experiences of the Teledoc2 project and Cooperative Telemeasurements (www.teledoc2.cnit.it/Teledoc2/home.htm), which are briefly summed up in Section 2.

Section 3 is devoted to the main architecture, its components and the data flow among them.

In Section 4 constraints are discussed about the user's activities, cooperation and network, in order to understand which factors affect the Petri Net.

2. The Teledoc2 Project and Cooperative Telemeasurements

The Teledoc2 project was financed by the Italian Ministry of Education, Universities and Research (MIUR) and carried out by CNIT (National Inter-University Consortium for Telecommunications). The project was active during 2003-2005 and aimed at building a complete, multimedia, interactive and fully-featured online learning service for ICT researchers and PhD students of Italian Research Centres, provided they were branches of CNIT.

As in many e-Learning systems, the main components were a web-based user interface, the network infrastructure, the e-Learning software and the courses.

Teledoc2 was planned for the diffusion of scientific and technological culture in the ICT field, and meant to allow students to attend specialist courses in the forefront of research. Such courses were at disposal broadcast from different Italian Research Centres.

The project aimed at building an efficient service of distance learning of third generation: the courses could be attended in real-time, just connecting to the CNIT proprietary packet communication network and using simple Personal Computers running a custom multimedia application.

The learning strategy, therefore, aimed at recreating a live virtual classroom environment, with a real-time face-to-face relationship and high levels of interactivity among users.

Furthermore, the concept of virtual classroom had to be extended to "ubiquitous distributed service", with no kind of limitation to the user's position.
The whole learning system was designed to be complete, efficient, user-friendly and characterized by fixed and suitable QoS levels.
In order to guarantee reliability, CNIT used all its experience in the ICT field both in the backbone connections and in the local ones.
One of the key network requirements was the support of multicast, a strong element of innovation and originality if compared with most of the other distance learning systems. CNIT decided to build multicast-enabled networks because this way of transmission seemed particularly appropriate for online learning services like Teledoc2.
These applications, in fact, required two basic network requirements: on the one hand, they needed one-to-many and many-to-many communications to reach all participants and to promote interaction; on the other hand, they needed high bitrates, since they had to transmit audio and video of fixed quality.
In context of this project, the WiLab (Wireless Communication Laboratories) research unit of CNIT and IEIIT/CNR (Institute of Information, Electronics and Telecommunications - Italian National Research Council) at the University of Bologna carried on further activities.
In particular, the definition, planning and development of the paradigm of "distributed cooperative telemeasure". The "Telemeasurement" concept (meant as remote control of instrumentation belonging to one single workbench) was described in (Roversi et al., 2004), where this methodology was applied to characterize communication systems based on instruments and programmable platforms with Digital Signal Processors (DSP).
The concept of telemeasurement was enhanced with the introduction of "cooperative telemeasurement" (Roversi et al., 2005), in which various resources are distributed in a network of different laboratories and can cooperate to set up augmented experiments. This extension of the telemeasurement concept wanted to increase measurement capabilities, since the user could access different remote laboratories and use remote devices without having all the needed instrumentation locally. The definition and implementation of this platform involved signal processing, management of distributed resources, development of aggregated user interfaces, transport of signals for measure, innovative remote controls, protocols for gaining access and control of specific laboratory instrumentation, prototypes for testing the schemes designed on the field and a proper communication network.
As it will be explained in the following, after the completion of such activities, research themes evolved into the definition and management of contents, access methodologies and network optimisation.

3. Main Architecture and Petri Net-Based Approach

The e-Learning model used in Teledoc is represented in Fig. 1, where users access learning material and services, such as slides and videoconference.
This model evolves into the Cooperative Telemeasurement paradigm (Fig. 2), where many laboratories put their instruments at disposal, and augmented experiments can consequently be performed.

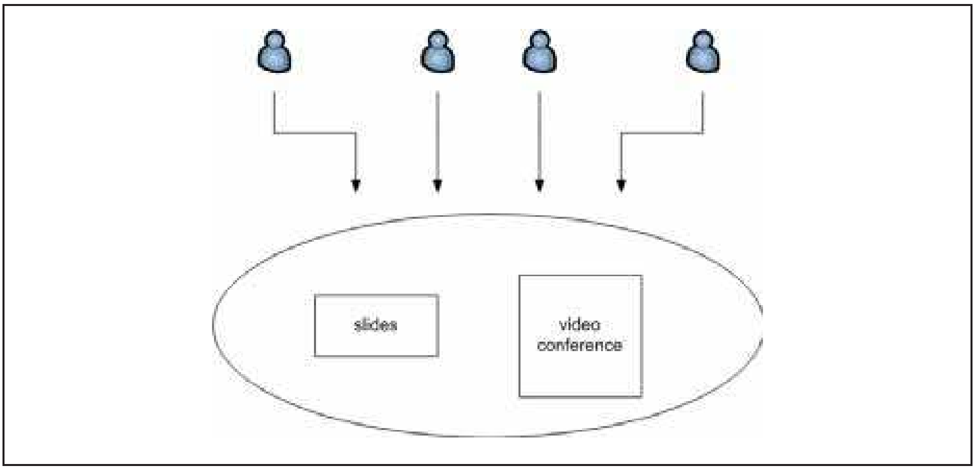

Fig. 1. The Teledoc2 e-Learning model

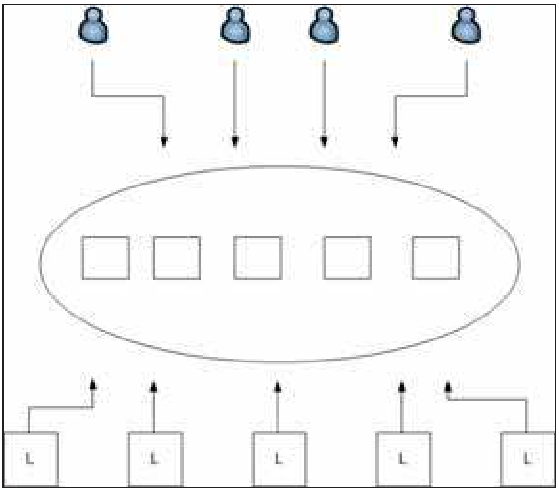

Fig. 2. The Cooperative Telemeasurements e-Learning model

The current viewpoint is to represent the evolution of the whole system, taking further factors into consideration: network conditions (network load and kind of device), didactic prerequisites and cooperative activities. Such a system and the learning paths can be controlled by means of a Petri Net.

In such a complex environment, technologies and feasibility factors play a fundamental role. For instance, videoconference can be feasible or not depending on the device and network load, so that the videoconference material may need to be scaled to audio-only format and adapted to present conditions.

In the same way, a user can be ready or not to take part to a given activity, considering at least two factors. First, he must have fulfilled all the necessary prerequisites; if not so, he must be stopped and proposed other activities. Second, the user must be ready, and so must his companions.
This approach can be depicted as in Fig. 3: the effective fruition of a content depends on many factors, which influence resources scheduling and data format as well. In more detail, if content n is requested, device and network load will indicate whether the request is feasible or not and thus influence scheduling. If the user requests to access content 1 with a PDA, the system will scale such content and adapt it to the device, provided the device is supported for such content. As a matter of fact, not every content can be adapted to any type of device.
The same applies to network load: if, between device and network, the bottleneck is the latter, contents will be adapted in consequence. As a matter of fact, accessing multimedia contents requires a high bandwidth; in case this is not available, contents will have to be scaled, for instance on the fly (De Castro & Toppan, 2008b; Donzelli et al., 2006).

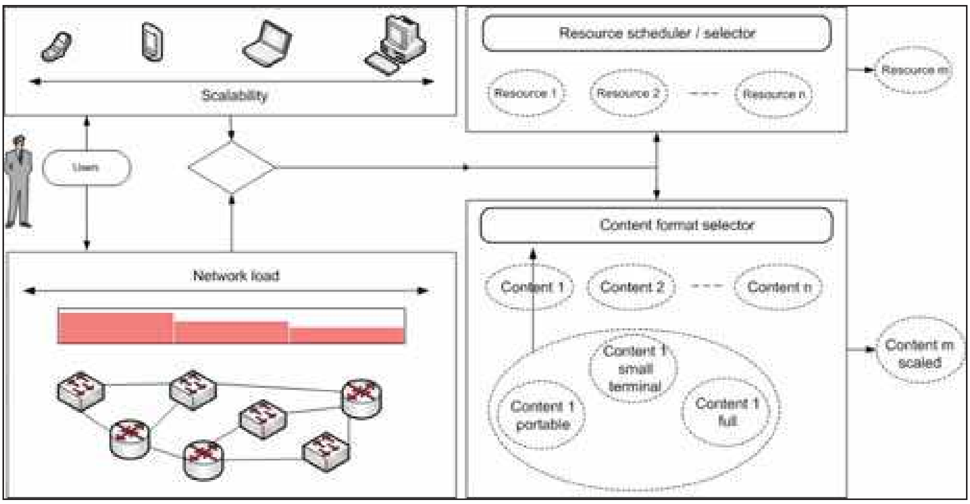

Fig. 3. Scheduling, scaling and data adaptation

In Fig. 4 all the discussed variables are represented: factors related to technology, didactic prerequisites, readiness to cooperate. Given such issues, the system will return the feasibility to use a given content in an appropriate format.
Let us now see how the system and its components can be represented from a single user's viewpoint (De Castro & Toppan, 2008b).
First of all, the overall architecture and didactic prerequisites are discussed. The proposed architecture is presented and its components discussed separately.

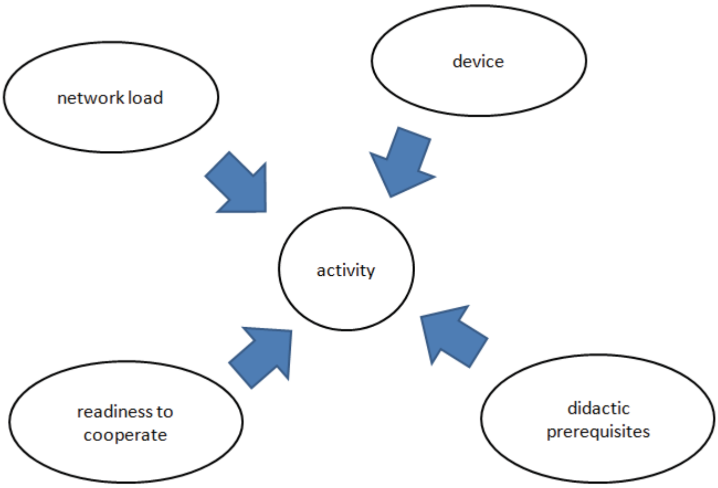

Fig. 4. Factors affecting the feasibility of an activity

The system can be described by means of the 5-layered architecture in Fig. 5, which is increasingly enriched from the left to the right.
It consists of five main blocks: the Query Layer, the Data Adaptation module, the Testing and Path Decision block, the Services and the Database.
The Query Layer allows the user to interact with the system, accessing services and contents scaled on the basis of the user's technology.
The Data Adaptation layer allows to adapt the data format and consequently optimise response time.
Given a knowledge level, the Testing and Path Decision module returns learning steps. In this module the first approach to the use of Petri Nets is defined. In this context, variables are didactic prerequisites, whereas in Section 4 the architecture of such module will be augmented taking into account network factors, as well as cooperative work ones.
The Services level indicates which multimedia broadband services are at disposal, such as booking of experiments, etc.
The Database level highlights the presence of three groups of information: testing and assessment material; learning material; user's data, bookings and access to services.
In Fig. 5, the vertical axis is a first classification; on the right, all the components are expanded and represented with respect to their interaction and to the data flow which takes place among them.
The main purpose and features of each block and its sub-modules are described in the following.
The User-System Communication Interface must carry out the following tasks:
1. receive the user's requests (initial target and successive ones) and forward them to the Testing Module. All such requests are meant to be events that must be notified to the system;
2. receive the suggested assessment tests from the Testing Module and send back the results;

3. receive the suggested learning steps from the Path Decision Module and allow the user to access the studying material;
4. manage access to auxiliary services;
5. transform all such requests and answers on the basis of the user's devices (mobile, PDA, laptop, etc.); more generally, make the user and the system communicate on the basis of the user's device *("Device Interpretation")*;
6. adapt learning data to the user's device and access technology, so as to meet the learner's requirements and optimise the overall process *("On the Fly Data Conversion")*.

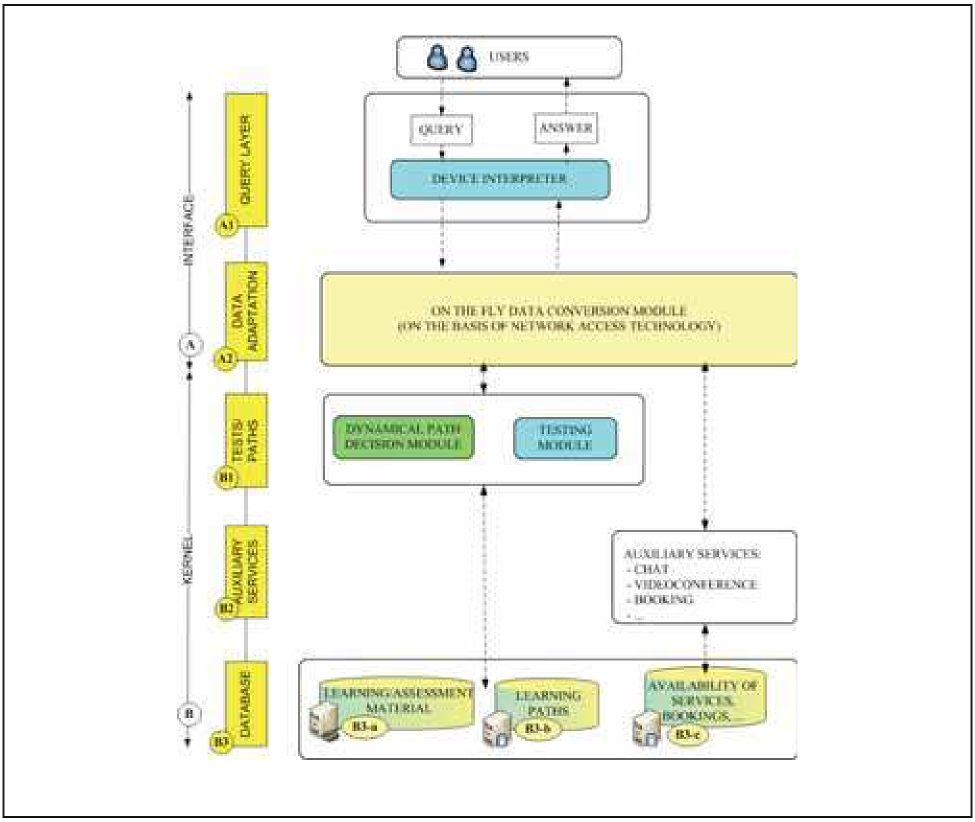

Fig. 5. Main components of each layer

Note that task 5 concerns the management of queries and data with respect to the user's *device*, and is accomplished by the Query Layer. Task 6 concerns data optimisation on the basis of *network access technology* and is fulfilled by the Data Adaptation module.

When talking of data format, two different - even not independent - operations must be distinguished. First, data transformation due to the type of device (*Data Interpretation* on the basis of device). Second, data format optimisation due to the type of network connection (*Data Adaptation*).

As for Data Interpretation, the system must communicate on the basis of the user's device, so the user's data must be converted in a format that both the front-end to the system and the database can understand. This process will last the whole lifespan of the learning process and can easily be done by means of XML conversions.
As a matter of fact, this is a straightforward, general and effective way for exchanging data between heterogeneous environments.
As far as the Data Adaptation module is concerned, in order to optimise response time in each scenario and in perspective of m-Learning extensions, the following guidelines must be taken into account: first, it is essential to reach the best trade-off among the user's actual needs, quality/quantity of data and response time; second, information must be adapted to available technologies (PDAs versus laptops, etc.) (Bronson et al., 1993; Yuang et al., 1994; Caouras et al., 2003).
Developing such a system involves at least two aspects: first, information must be represented at different levels using different formats. Second, an access methodology must be designed for filtering data on the basis of the above criteria. This is accomplished by the On the Fly Data Conversion Module, which retrieves data in its original format and scales it so as to adapt it to the kind of network access technology and device.
The main role of the Path Decision and Assessment Module is to be aware of the user's aims, check his learning levels, and consequently define a tailored studying path.
The main idea is the strict interaction between the Path Decision/Assessment Layer and the database. As a matter of fact, the database stores both assessment and studying material which is selected from the database on the basis of the user's goals and actual achievements.
The database schema can be represented by means of a network of *issues*, *levels* and *prerequisites*. Consider issues I_l and I_m and suppose they are related (such as derivatives and integrals) and meant to be faced at a given level (such as a course of Mathematics at a high school).
For the sake of simplicity, suppose I_l and I_m can be considered steps of the learning process.
Suppose that facing step I_m after step I_l requires prerequisites p_1, p_2, ..p_k.
This kind of algorithm can be represented by means of a Petri Net (Chen et al, 2001; Li et al, 2005) which acts as a traffic light between a learning step and the successive one.
In this approach, the Petri Net's places are knowledge to be tested (prerequisites), and its transitions are studying phases. A transition is enabled if all the required prerequisites have been fulfilled (Fig. 6).
Since the system is adaptive, contents will be put at the user's disposal on the basis of his device and access technology.
As far as the underlying e-learning information system is concerned, its architecture has been designed keeping in mind that two kinds of information are involved:

(i) e-learning and assessment material, which is not meant to be frequently updated (named *static data*);
(ii) personalised learning paths and assessment results, which are time-varying (named *dynamic data*);

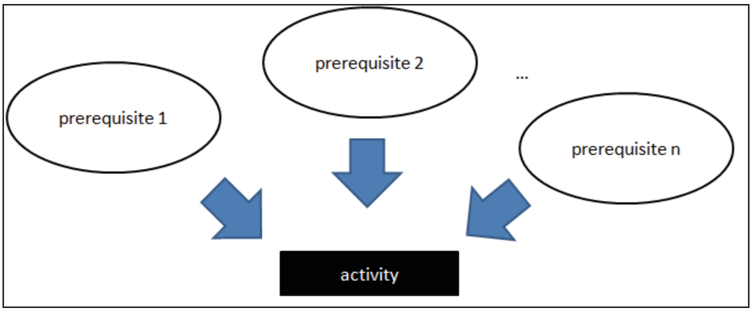

Fig. 6. Didactic prerequisites and activities

It must also be noticed, and considered as a requisite, that e-learning information can be represented by means of a hierarchy of subclasses. For instance, from a subject to its specific issues.

These requirements suggest the use of a hybrid database structure for data storage: an LDAP directory service (Howes et al., 2003) for static data and a relational DBMS for dynamic information.

LDAP provides both a model and an implementation tool which is particularly suitable for web-based e-learning applications, both from the data representation viewpoint and for an efficient web-based access.

As a matter of fact, it is scalable, extendable and optimised for reading operations, so it is particularly suitable for static data. It also supports standards and interfaces of many multimedia broadband applications and integrated access to e-learning services.

Another important feature is that LDAP represents information by means of a hierarchy of classes using very flexible schemata. In the considered environment, this implies at least three advantages.

First, the knowledge that a person acquires on a specific subject can be organized in an LDAP tree as follows: the n^{th}-level class describes the *subject* in general; the n^{th+1}-level classes represent related subjects, issues and related issues, documentation and assessment material, prerequisites, learning paths and assessment tests.

Learning and testing material, as well as paths and tests, are divided in as many subclasses as the number of target levels provided for. In this way, known such level, the middle layer can access the correct material.

As for the second advantage, LDAP was built for the integration of distributed environments, so it also suits the distributed location of documentation very well. As a matter of fact, for applications such as international remote education, e-learning information is distributed by nature.

The third advantage concerns schema management. The schema of the e-learning database is likely to be modified or augmented during its life cycle, for instance due to the addition of new kind of media or information described by means of different properties. A relational system, in traditional settings, does not allow efficient schema revision. Such operations involve high costs in terms of redesigning existent schemata, reloading data and verifying that original constraints and relationships on data are preserved. LDAP, on the contrary, offers high flexibility in modifying data structures.

As far as the dynamic part of the database is concerned, it mainly concerns the time-varying personalised learning paths. In more detail, the dynamic database stores information about the user and his learning phases, such as targets, suggested steps and actual achievements. Other information involve auxiliary services and their booking.
In this case, an SQL database is more suitable. As a matter of fact, such models are optimised for reading/writing operations and time-varying data.
The connection between the LDAP and the SQL databases are LDAP object identifiers which, as identifiers of subjects, issues, etc., are used as key information in the definition of dynamical paths and assessment tests results. They are also used in the joint navigation of LDAP and SQL data.

3. Factors Affecting the Petri Net: Network, Didactic Prerequisites, Cooperation

In this section (De Castro, 2009), the previous approach is revised in order to represent learning paths and their control in advanced e/m-Learning systems. Such environments put heterogeneous data and services at disposal, and different connection technologies can also be adopted.
As already discussed, due to such diversity, the studying paths are not univocal: for instance, some exercises can be made first and cooperative work with fellow students afterwards or viceversa (*"alternative paths"*). Another important consequence is that learning processes have constraints dictated by download time, the network status, other activities and synchronisation with fellow students.
The proposed model proceeds from such observations, states some rules that the learning processes must obey in order to take place regularly and its core is based on graphs and Petri Nets.
Both *contents* and *access modalities* influence the process of learning and, thus, the evolution of the learning paths over time, so they must become an integrant part of the control system.
Some observations about such features will be made in the following, in order to understand their role in the learning process and consequently discuss the basics of the discussed approach.

3.1 Carrying Out Activities: Heterogeneity and Synchronisation

As far as functionalities and contents are concerned, it is becoming more and more important to involve the user actively, and adapt the studying process to his needs. It must be noticed, though, that such requirement implies a tailored and increasingly complex definition of learning paths, assessment phases, as well as an efficient control of the whole course of action.
As for contents, modern learning systems put a wide range of heterogeneous data and activities at disposal, such as videoconferencing, remote laboratory, chat for cooperative work, textual exercises, tests, storytelling and so on.
Some observations can consequently be made that will be of help in the definition of the learning process, by giving birth to constraints which will be progressively added to a first, rough version of the overall architecture.

1. The data format of learning material is intrinsically heterogeneous, ranging from plain documents to multimedia files;
2. Some activities need to be synchronised, while other do not. For instance, an interactive remote laboratory experience must obey precise timetables, and the same applies to cooperative work with fellow students or examinations. On the contrary, some laboratory training or exercises can be made with a certain degree of independence from other people and other tasks;
3. There can be many ways to achieve the same target, each corresponding to different data formats and technologies. For instance, a lesson can be followed using on-line videoconference or studying the course's material (slides, etc.).

The main architecture can be roughly revised as in Fig. 7, where the user asks to access the system and perform an activity (*query*). On the basis of the *synchronisation constraints*, he can be allowed to carry this task out or not. Furthermore, his background and the *didactic prerequisites* for the requested activity are analysed and he is submitted to a testing phase (*assessment*) before accessing new *learning steps*. The whole architecture lies on a database storing learning contents and their prerequisites, as well as assessment material and is guided by a *"Control Module"*.

As for network access modalities and m-learning facilities, they should be as diversified as possible, on the basis of the student's aims, ties and timetables, as well as his location and kind of technologies at his disposal. All such factors are decisive in order to reach a good compromise between quality and studying conditions. In more detail, the following scenarios are taken into account:

- UMTS: this can be the case of accessing the system through PDAs, for instance if some exercises must be made;
- DSL: it is quite typical when users access the system from home;
- WiFi: this is quite common within a campus, in study lounges and libraries;
- wired/fiber: it is generally the case of universities, for instance within laboratories

Some rules are now stated, which are the counterparts of (1)-(3) with respect to connection technologies, and mean to be of help in the design of the Control Module of the proposed architecture.

Among all the activities that a student can undertake, only those can be performed that obey to the following constraints:

a. A connection technology can not always be chosen freely; as a matter of fact, there are tasks that require a minimal connection speed. For instance, a remote laboratory experiment in cooperative modality can only be fulfilled using at least a good DSL technology. On the contrary, simple exercises can be made using a PDA;
b. Only those activities must be made available which are:
    i. compatible with the student's current technology;
    ii. compatible with the e-learning plan;
    iii. asynchronous or
    iv. can be synchronised with other tasks;
c. If a task can be faced by means of different technologies, data must be organised in such a way that the format is adapted to the technology itself (e.g. video vs text), or

a choice can be made between material of different nature (e.g. lesson on videoconference vs slides).

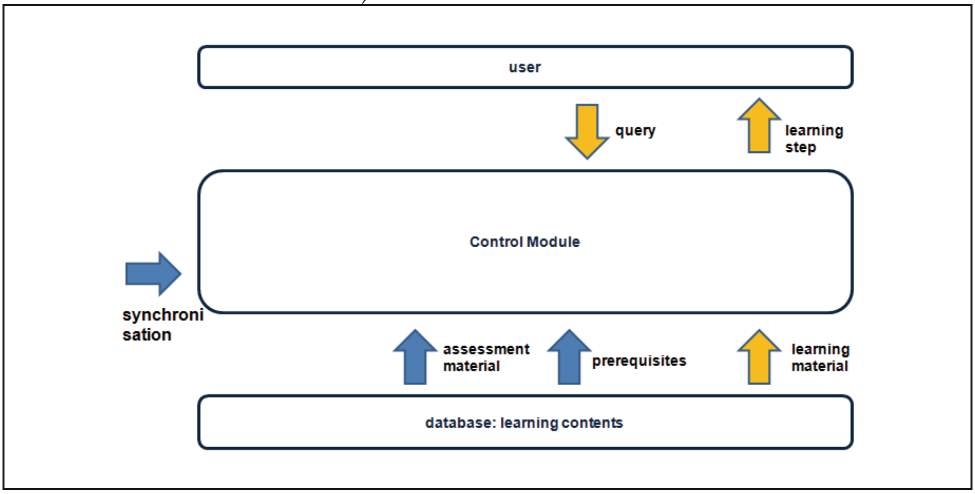

Fig. 7. Constraints on the basis of contents and cooperative work

These rules define alternative paths and state whether an activity can be currently carried out or not by a given person who is using a given network access technology and device.
Fig. 8 represents the further parameters that must be added to the architecture in Fig. 7: the synchronization factor had already been represented, but its role has been more precisely defined. The *device* and *minimal connection required* have become new input data for the Control Module.

3.2 Control System

First of all, the graph structure will be defined, since it is the core of the e/m-Learning model. Afterwards, the whole architecture will be completed and its components represented and discussed, first with respect to I/O, then with respect to the overall process.
First of all, let us give the following definition:
D1 - due to (1-3) and (a-c), learning paths are time-labelled graphs, whose nodes' are tasks associated to the following information: data, data format, minimal connection technology required, possible alternative contents of different format, prerequisites.
D2 - Compatibility controls can be defined by the edges themselves: there is an edge from N_i to N_j at time t if N_i and N_j obey (a-c). This can be achieved by guiding the graph through an appropriate Petri Net.

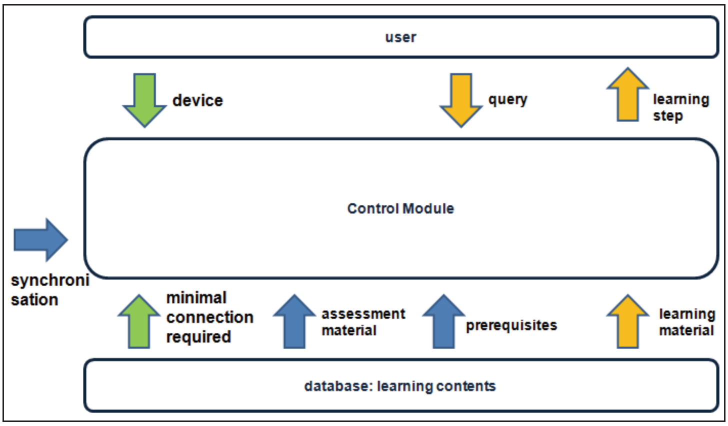

Fig. 8. Constraints on the basis of access technologies

D3 - Network load is a constraint itself in the progress of a learning activity. On the basis of the user's IP, his location is known and the available bandwidth determined. Only those tasks will be made available whose minimal bandwidth required is compatible with such conditions.

Taken all such factors into consideration, the proposed architecture consists of four layers. These components and their interaction are described in the following (Fig. 9).

User-System Communication Module: this module makes the user and the system communicate and, in particular, through different devices. The user sends his target to the Network Analyser Module by means of a query and is localised through his IP. The device is also determined.

Network Analyser: the network load and available bandwidth of the user's current location are determined on the basis of his IP and so is his device. All such data are forwarded to the Petri Net Module.

Petri Net Module (Control Module): this layer is a Petri Net which guides access to activities: given the user's query and all the constraints discussed above, this module returns a learning step among all the available ones. A transition is enabled if (a-c) are met, if the available bandwidth is greater or equal to the minimal bandwidth required and if the user has passed the necessary assessment tests.

Database layer: the data repository is a multimedia database whose contents are represented through a hierarchy of subjects and tasks. Each task is associated to the following information: data, data format, minimal connection technology required, possible alternative contents of different format, prerequisites and assessment phases.

3.3 Places and Transitions

As discussed above, the Petri Net will have three kinds of places: network prerequisites, didactic prerequisites and cooperation prerequisites. In order to define the generic places-transitions block which, from prerequisites, guides access to activities, the following considerations can be made.

Let us consider a single activity, available in more scaled formats. Each activity has at most three prerequisites and some alternatives. Suppose it is available in two formats. It gives birth to two different parallel transitions having the same input places. On the basis of marking and weights, the one or the other will be feasible. For instance, given the same didactic and cooperative prerequisites, if the device is a PDA, the only activity will be at disposal which requires less bandwidth.

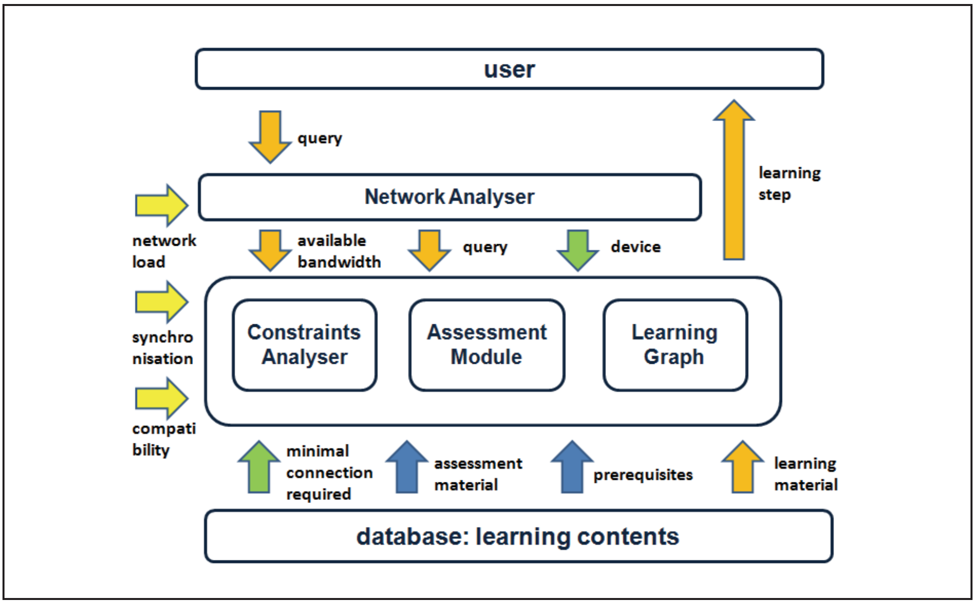

Fig. 9. Main architecture

The second viewpoint is that of alternative activities: the same places are connected to different kinds of activities. Each of such activities will be at disposal in many different formats, as above. Suppose the previous activity has one alternative, at disposal in one format.

The above situation is depicted in Fig. 10; the Petri Net will have as many blocks of such type as the number of activities at disposal. Not every transition will have all the prerequisites and will be at disposal in every format possible (there are activities that can not be scaled). In short, the generic block is made of three places connected to many transitions, each representing the same activity in different format or a different activity.

As for the marking of network places, it is a function of two variables: network load and device. Its value is the bottleneck between the two.

The didactic prerequisites places contain all the issues necessary for facing a new activity. Marking can be thought as a sort of result of the testing phase, leading to an activity or a different one. If transitions represent activities of scaled formats, the weighting of didactic prerequisites will be the same. It will be different in the case of different activities.

As for cooperation places marking, it is simply a boolean function representing readiness of participants or not.

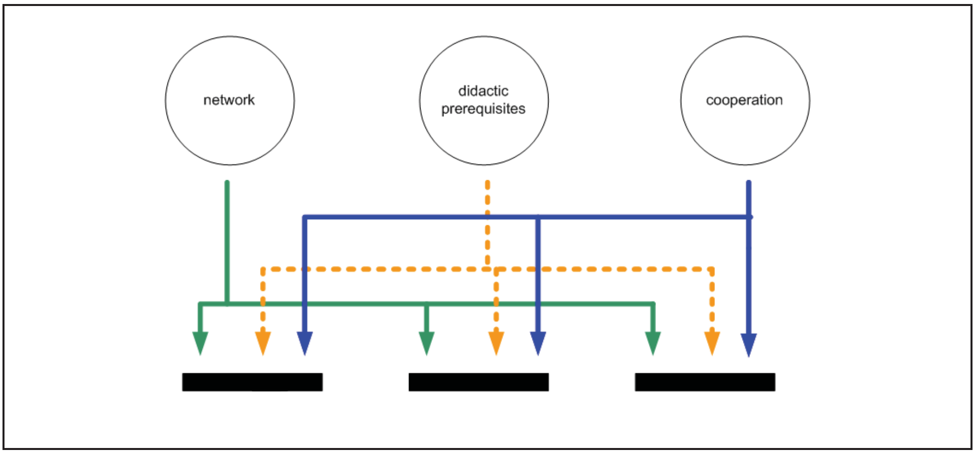

Fig. 10. Places and transitions

4. Conclusion

Modern e/m-learning systems must take many factors into consideration, such as functionalities offered to the user, organisation of contents, service fruition modalities, as well as network load. As a matter of fact, not only has the nature of e-learning material changed deeply over time, but so have devices and connection technologies for accessing services. Furthermore, in context of mobile learning based on multimedia broadband services, the network load of the location from where the user has logged on must also be taken into account.

In this work, these features and their relationships were analysed and an architecture was consequently proposed which aims at reaching a good compromise between quality of learning and studying conditions. The whole system is controlled by a Petri Net defined on the basis of the above factors. The definition of the Petri Net by means of such dissimilar kinds of constraints is one the main novelties of the proposed approach.

Future work will be devoted to the application of the discussed architecture to the Teledoc2 and Cooperative Telemeasurements environments, which aim at defining specialised learning paths in Information and Communications Engineering for PhD students and accessing laboratory experiences and equipment remotely through multimedia services.

5. References

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Petri Nets are graphical and mathematical tool used in many different science domains. Their characteristic features are the intuitive graphical modeling language and advanced formal analysis method. The concurrence of performed actions is the natural phenomenon due to which Petri Nets are perceived as mathematical tool for modeling concurrent systems. The nets whose model was extended with the time model can be applied in modeling real-time systems. Petri Nets were introduced in the doctoral dissertation by K.A. Petri, titled "„Kommunikation mit Automaten" and published in 1962 by University of Bonn. During more than 40 years of development of this theory, many different classes were formed and the scope of applications was extended. Depending on particular needs, the net definition was changed and adjusted to the considered problem. The unusual "flexibility" of this theory makes it possible to introduce all these modifications. Owing to varied currently known net classes, it is relatively easy to find a proper class for the specific application. The present monograph shows the whole spectrum of Petri Nets applications, from classic applications (to which the theory is specially dedicated) like computer science and control systems, through fault diagnosis, manufacturing, power systems, traffic systems, transport and down to Web applications. At the same time, the publication describes the diversity of investigations performed with use of Petri Nets in science centers all over the world.

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