

Design of an Introductory Networking subject in advance of the European Higher Education Area: Challenges, experiences and open issues

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Abstract—The field of Computer Networks has evolved quickly during the last years. In this paper we consider different aspects of those changes that condition the design of a subject in Networking; specifically, we discuss social, technological and economic aspects. Additionally, the changes proposed in the University studies for the European Higher Education Area condition the design of any current subject. Altogether, these changes condition the design and implementation of a subject on Computer Networks.

Considering the presented changes we sketch the design of an introductory subject on Computer Networking. The subject is part of a pre-Bologna course, but is designed with the transition on mind. On the paper, we sketch the implementation of the course, designed to simplify the transition to conform the recommendations of the European Higher Education Area. We detail what contents were part of the theoretical or lab sessions, and how we managed to make most lab sessions with mid-class real hardware, introducing relatively complex concepts such as Quality of Service.

Keywords—computer networks; revolution; Bologna process; course design; lab exercises;

I. INTRODUCTION (HEADING 1)

Computer Networks are in a constant evolution. We consider that such evolution during the last decade is not only technical, but also comprises social and economical aspects. These are aspects that should altogether determine the composition of a Computer Networks subject.

The changes in the Computer Networks field themselves are accompanied with a regulatory change in the Education System in Europe. The Bologna process pretends to unify the higher education in Europe, making programs in Universities from different countries compatible with each other. Such change requires a rethinking of each course aspect.

We have considered such the design of an introductory course in Computer Networks before the change to the Bologna requirements, to provide for a smooth transition once a Bologna “grade” course has to be implemented. We describe the course design and how some of our lab courses aim to teach

the most interesting and applicable capabilities of networking devices, using friendly exercises.

The main contributions of this paper are:

- A study of the evolution of the area of Computer Networks, focused on how recent changes affect the organization of an introductory University course.
- A rationale about the design of such introductory course on Computer Networks, including concerns about the division of theoretical vs. laboratory sessions, studying outdated technology or not, using simulation tools or real hardware, etc.
- A presentation of some lab sessions, intended to teach advanced concepts (such as QoS capabilities) using affordable mid-range real hardware and multimedia tools.

Specifically, note that this paper is not about converting a Computer Network subject to the requirements of the Bologna process, although we will refer to them in Section III.

The organization of the paper is as follows. Section II studies the changes in the field of Computer Networks during the last decade. Section III considers the changes required by the Bologna process, specifically in what concerns to our country. Section IV presents a rationale of our course design and the contents covered, including an example of our laboratory sessions. Section V presents our experience with such organization and pending issues. Finally, Section VI concludes the paper.

II. REVOLUTION IN EDUCATION ON COMPUTER NETWORKS

The field of computer networks has evolved quickly in the last years. We will focus in the evolution during the last decade (1999-2009, at the time of writing). Such a timescale is sufficiently small to consider that any field with fundamental changes has suffered a ‘revolution’.

We identify below the three main aspects of Computer Networks that, in our opinion, have suffered a significant evolution during the last ten years. We will first focus on the

social aspects: computer networks have become a commodity nowadays, while access to them was uncommon ten years ago. Next, we will study the technical aspects, arguing how the performance evolution (not only in network speed, but with many new capabilities) has introduced new features and outdated others. Finally, we will discuss the economical aspect that limits the implementation of a certain lab exercises. Given the cost reduction of network equipments, new laboratory exercises can be considered with only a limited budget.

Considering the revolution occurred, based on the following three pillars, we believe that many aspects of any subject on Computer Networks should be reconsidered.

A. Ubiquity of Computer Networks – Social aspects

Ten years ago, the access to Computer Networks was not widely extended, and broadband access was in its earlier stage. Specifically in the case of Spain, in 1999 less than 8% of the population had access to Internet, and there were less than 4000 ADSL broadband accesses [1]. Additionally, many computer equipments were not equipped with networking technology (such as a modem or a LAN card). Therefore, most students had no previous knowledge of Computing Networks, not even from the user's perspective.

Nowadays, thanks to the globalization of Internet as a communication channel, students are familiar with both network-based applications and network management. According to the Spanish regulatory organism [2], there are almost 9.5 millions of broadband accesses, with an overall population of 46 million people. While Spain has been traditionally delayed in the penetration of Internet access, these figures are representative of the radical change. Similar figures can be found for other countries.

Of course, these data differ from one country to another. Spain is in an average position in the European Union. In the United States, studies from the U.S. Census Bureau show that the percent of homes with Internet access rose from 26.2% in 1998 to 61.7% in 2007. In 2007, the most recent year with Census data, 50.8% of the householders had broadband access, and 10.7% had dial-up connections [3].

All of our students are nowadays familiar with email, web and distributed applications. Specifically, they are also familiar with the problems of multimedia applications, such as VoIP, videoconference systems, or real-time gaming. These services require special QoS capabilities from the network and suffer when multiple applications make use of the network simultaneously. Regarding network management, surveys carried at the beginning of the course report that about 80% of the students could deploy a local area network, wired or wireless, although they could miss the internal details. For example, they were used to configure NAT on their networks for P2P systems, but most of them did not know how such protocol worked internally.

B. Evolution of Networking Equipment – Technical aspects

Ten years ago contention-based Ethernet or Fast-Ethernet hardware was the norm. Nowadays students are used to low-cost switched gigabit networks and ubiquitous flexible wireless

accesses. But the evolution of the technology does not come only from the network speed. The Ethernet standard (802.3, [4]) has undergone multiple revisions increasing its performance and functionality.

Contention-based hardware (CSMA/CD Ethernet hubs) was common ten years ago. Nowadays it has been completely replaced by switches (following the 802.3x standard) that do not present collision problems. Apart from the performance benefit, this makes the Medium Access Control mechanism less important, since now the media is no longer shared. However, the Medium Access Control problem still plays a significant role in wireless networks, were it is impossible to provide a switched mechanism.

Besides the advance in contention management, multiple technologies have been developed and integrated to base and mid-range network products. Among them, we can cite the following:

- Optical links, providing more reliable links between network devices with a high speed and a low error rate.
- Virtual LANs (VLANs, 802.1Q), that allow for multiple users from separate networks to share the same physical network switch without interfering or even noticing each other.
- Traffic prioritization for multimedia applications (802.1P). Such prioritization implements a classification of the traffic (which packets should be prioritized, and which not) and a segregation among multiple hardware queues in the network devices. Different priority policies are assigned to each queue so the most important traffic is served first, and it does not suffer from network contention and variable delays.
- Link aggregation (802.3ad), that allows increasing the effective bandwidth between two devices by grouping together two or more physical links and sending traffic using all of them.

All of these technologies are present in today's equipments, and will likely be in future products. Besides, simplified management using web interfaces hides the complexity of the internal design and the requirement to learn commands specific to a single device or vendor.

Of course, we are not the only ones to consider that networking advances should affect the courses. Let us consider the case of Cisco. Cisco is one of the main manufacturers of networking equipments. It also provides certifications [5] about networking, using their own hardware for the examinations. There are different levels of certification, with different contents on each level. The base level has been traditionally the CCNA examination (Cisco Certified Network Associate, [6]). However, in the last years the evolution in computer networks has increased the contents in that examination. Considering the increased difficulties of the additional contents, the lowest level has been divided in two, the CCEnt (Cisco Certified Entry Networking Technician, [7]) and the CCNA levels, with the first one covering the simplest contents.

Finally, this technical evolution has outdated many technologies that were important ten years ago. The list is huge, and includes technologies at different levels, for example: Access to modems using RS-232 serial cables and Hayes commands; network technologies such as Token Ring for LAN or X.25 for WAN; or network protocols such as Novel Netware (IPX/SPX). In our opinion, the inclusion of such outdated technologies in a Computer Networks course should be avoided, unless they have some historical or educational interest.

C. Networking Equipment Cost – Economic aspects

Despite the increases in performance and capabilities presented in the previous section, the cost of network equipments has been constantly decreasing during the last decade, similarly to what happened with most types of computer equipments.

As presented in section B, a decade ago a medium-range LAN equipment could be a contention-based hub with some basic management capabilities. A single of those hubs could cost more than 3000€, according to our University IT staff.

Nowadays, networking systems are much cheaper and more flexible. This allows for flexible mid-range devices to be acquired with a limited budget. In our case, we acquired five switches 3Com Baseline 2916-SFP [8] with optical transmitter modules for less than 5,000€ in 2008. These equipments are suitable for multiple lab sessions, since they have interesting properties such as web-based management, VLAN support, configurable QoS queues, link aggregation, etc.

Fig. 1 shows the basic relations between these three areas. We believe that all the three areas are somehow related with each other. Social aspects are driven by the decrease in the cost of networking products and the increased performance and capabilities. The economic aspects are driven by the advance in technology and the increased market derived by the augmented usage. Finally, technological evolution is driven by the social demand and the market requirements. Altogether, these three aspects should modify the contents of a Computer Network course.

III. THE CHANGES IN THE BOLOGNA PROCESS

The Bologna process intends to provide a uniform framework for University studies across the different countries in the European Union. The current course is currently given in the Spanish “Superior Engineering”, equivalent to a Bachelor + Master (a 5-years degree including specialization). However, the Bologna process aims to provide a uniform framework across Europe, similar to the American style, with 3 or 4-years generic “grades” and 1 or 2-years specific “masters”.

When designing the subject, we considered that, while the course is still part of a “Superior Engineering” degree, we should focus on the *applied* aspects of the subject, especially considering the changes listed in Section II. Therefore, we insisted on the *useful* aspects (such as configuring network devices, QoS or VLANs) and gave less importance to other aspects that have been outdated by the technology (such as CSMA/CD in contention-based Ethernet networks) or are too

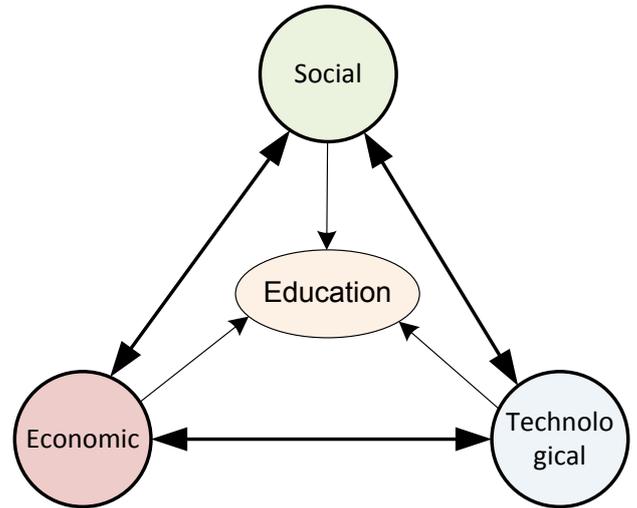


Figure 1. Interaction of the different aspects of the Revolution in Computer Networks that affect Education

specific (such as network dimensioning, which is left for further subjects). Such design aims to simplify the transition to a *less specific* grade course.

Finally, the Bologna system also introduces the explicit idea of competences, divided into specific and transversal competences. While this course, prior to the establishment of the new system, does not need to consider them, we made sure that the proposed model would fit correctly. The core competences are clear, dependant on the course contents. Besides, core competences should be defined concurrently with other courses in the same group. The proposed model, which will be described next, will cover some transversal competences which are commonly discussed in our University: Some lab sessions require the cooperation between the students, exercising the team work; the use of a large amount of proposed problems deals with the autonomous work of the student and his planning of the work. While sketched, all of these competences are left for a future implementation of a grade course.

IV. COURSE DESIGN

In this section we will detail how we have selected the contents of our course, considering the revolution presented in Section II. We present a rationale of different design alternatives. Later, we detail will two advanced lab exercises that show how we exploit some of the switches capabilities: VLAN deployment and a videoconference system with QoS guarantees.

A. Background

The imparted course is part of the “Engineer in Computer Science” degree in the University of Cantabria. It is imparted in the third academic course, out of a total of 5 years in the degree. As observed, current Engineering degrees in Spain are equivalent to a BS & MS in most other countries.

The degree in the University of Cantabria is relatively new; it started in 2005 before any Bologna changes were taken into effect. However, the first time the course was imparted was in 2007, and the European Higher Education Area requirements were already a concern for any course design.

Therefore, the authors considered from the first point the possibility of providing a smooth transition to a Bologna Grade course.

B. Theory vs. laboratory sessions

The course contained as many hours of theory lectures as laboratory sessions. There are two basic approaches:

- Use the laboratory sessions to verify experimentally the theory introduced previously in the class, or
- Use the laboratory sessions to introduce complementary contents that are not necessarily studied in the class.

We decided that we should not restrict to the first case if some contents are more suited for the laboratory rather than the class. This allows us to cover a broader content in the course, since the laboratory exercises are complementary to the class lessons.

C. Bleeding-edge vs. outdated technologies

While many technologies build on previous standards, in many cases it is useless to teach them. We believe that this occurs when the following circumstances concur:

- The technology is no longer in the Market (so it is never employed in new installations or its products can not be bought).
- The technology does not have a significant installed base that still requires maintenance and management. This is more difficult to know since it requires a deep knowledge on the status of the market and how different companies have adopted new technologies.
- The technology is not part of a subsequent technology. For example, ISDN lines are still in the market, but their penetration is really low and they have been surpassed by other technologies, such as ADSL Internet accesses. However, ISDN switching technologies constitute the base for existent second-generation mobile networks, so it makes sense to know the former before studying the latter.

The first point is clear; for example, it is impossible to find Token Ring products in the Market nowadays. The second point is more difficult to check. In the example of Token Ring products, we could still find some companies maintaining old networks based on this technology. However, a quick search on the Internet (if no other resource is available) will show that such cases are really minor, so they do not justify the study of the technology.

Finally, the third point is the more complex to determine. Despite a given technology can be out of the market (such as Token Ring), its basic mechanisms can be worth studying. For example, the token passing mechanism in Token Ring prevents the problems of collisions when accessing a shared

medium. Then, specific parts of a technology can be presented in detail, without the requirement to know the complete system.

In a case such the last one (outdated technology with interesting properties) our approach was the following: First, make a generic study of the possible implementations (in this example, medium access mechanism). Then, discuss the implementation in current technologies.

D. Course expectations

An important point for us was the expected knowledge that a student should get taking our course. Typically, two opposite positions can be considered:

- The student should be able to *invent, design* or *build* a new networking system from scratch, by deeply knowing the involved principles and design parameters.
- The student should know be ready for the day-to-day work, knowing the current technologies in detail and what is currently demanded by the companies.

The first position is the most theoretical one, while the second is the most applied. Both approaches have flaws, since the first case gives no knowledge of the real work, and the second case does not teach the basic concepts in which technology relies.

Of course, we considered that none of these extreme positions gives the best result. In our course, we pretended to mix both approaches. In general, the lab sessions were more focused to the 'real world' approach, while the theoretical lessons would be useful to introduce many of the basic concepts. We further discuss this scheduling in the following subsections.

E. Simulation vs. real-world practices

Simulation tools are widely used to teach the main concepts of Computer Networks. Simulation provides multiple benefits, among them:

- The possibility to deploy a network much larger than what is permitted by our real hardware.
- Faster deployment.
- More data are available after the simulation to understand the behavior of the simulated model
- It allows the students to analyze the implementation of a protocol to better understand the behavior of the system.
- Cheap! Most educational simulators are free.

However, simulation also implies some limitations that we cite next:

- Many network simulators are based on traffic models that can differ from what is found in a real application.
- Simulators present a very simple view of the real system, hiding many characteristics that will affect the performance or behavior in the real world.

- The learning cost of the simulation tool could be used to learn some other, more applicable, idea.

Considering the cited limitations and the studied economic aspects, we decided that in general we would try to stitch to the real hardware to give our students a real view of the technology they would find outside of the University. We would restrict to simulation tools when they can be used to better understand a mechanism or protocol without introducing a significant complexity to the students.

Multiple simulation tools exist. We cite some of them next. C.S. McDonald presented his Cnet simulator in [9]. It is an educational tool mainly oriented to studying link level protocols, allowing the users to implement their own protocol. We use this simulation tool in one of our lab sessions. Comnet III [10] is a commercial simulator oriented to network dimensioning. Domínguez Dorado et al. implemented a detailed simulator for MPLS traffic [11]. It can also simulate QoS capabilities. However, MPLS was out of the scope of our course. Goyal et al. propose [12] a graphical simulation tool to evaluate network performance. However, many of their proposed lab sessions are out of the scope of our subject, and others concern outdated technology such as Token Ring. Surma [13] proposes a set of activities to understand the behavior of some network protocols. While such active learning games are excellent to motivate students, we prefer them being able to study the detailed code in a simulation tool such as Cnet. Finally, virtualization is being widely used in many laboratories as a tool for the student to work with one or multiple computers at the same time. While this could be interesting in other fields, it does not fit with our course since, essentially, it removes all of the networking issues that we study in the course.

F. Course schedule

Our introductory course on Computer Networks belongs to the third year of the degree on Computer Science Engineering. It is followed by a subsequent course in the fourth year. These two courses are complementary: Our course focuses on the main principles of networking (data coding, transmission protocols, multiplexing, etc.) and the first two levels of the network hierarchy: physical and Network access. The subsequent course in the fourth year deals with network layers 3 and 4 (TCP/IP).

The course is divided into three sections. First, theoretical lessons are used to present the contents to the students. Second, we provided a wide collection of problems with the final solution, so the students can apply the theoretical contents. Finally, we developed several complementary laboratory sessions, mostly using real hardware, to complement the other areas.

Theoretical lessons are organized in 9 sections. As commented before, we introduce basic networking mechanism and the two lowest architectural levels, based on the organization in [14]:

1. Introduction
2. Protocol architectures, showing both the OSI and the TCP/IP models
3. Data transmission, including aspects about digitalization of analog data (such as audio or video).
4. The physical layer, detailing multiple transmission medium, data codification mechanisms and signal propagation. Also, we introduce the concepts of structured cabling and ISO 11801.
5. Link layer mechanisms, including flow control and error control mechanisms.
6. Multiplexing mechanisms.
7. Circuit and packet switching.
8. Local area networks
9. Wireless networks

Obviously, the last two sections are the most important ones, but they rely on the contents of the previous ones. Each of these sections, except for the Introduction, is accompanied with a set of problems with a final solution provided, so the student can work autonomously. Problem discussion is derived to a forum on the course website.

We designed 9 laboratory sessions, oriented to complement the theoretical ones, 2 hours each:

1. **Ethernet cable fabrication.** The students have to make a cat5e cable with the proper connections, and validate its correctness. Two tools are used for validation: a naïve pin checker (that checks electrical connectivity) and a Fluke cable certifier used in real installations. This device was borrowed from the University IT service, since we could not afford it, and the high expense was not worth for a single session.
2. **Serial cable fabrication** using DB-9 connectors. While this cable has been outdated, it is still in use in many current devices. Also, it introduces the concept of flow control in a simple manner.
3. **Flow control simulation.** We used Cnet [9] for the study of simple stop&wait flow control protocols. The students have to study and understand the performance of the protocols, and modify the existent code to add new functionality, such as introducing negative acknowledgements. We selected a simulation tool for this session since flow control protocols are difficult to study using real hardware.
4. **Introduction to LAN networks.** The students had to set up a wired LAN network using both hubs and switches. Wireshark [15] is used to analyze the traffic in the network and observe, with multiple PCs connected to the same device, the difference between hubs and switches. The hubs had been also donated by the IT staff, retired from our University, and are used in this session to show contention-based access control.

5. **Switch management and fiber links.** We introduce the web-based management interface for the switches, shown in Fig. 2. The students use it to configure the speed and duplex properties of their own links, and configure a larger network using fiber links.
6. **Security aspects.** It introduces the MAC address learning mechanism and MAC filtering mechanisms to provide security in the network.
7. **Virtual LANs (VLANs) and link aggregation.** The idea of virtual LANs is studied by configuring multiple VLANs in their own switches, and configuring a network comprised of multiple switches with several VLANs, using tagging to propagate the VLAN information. Link aggregation is also introduced, as a way to increase the capability of an individual connection by using two parallel links.
8. **Traffic prioritization.** It studies the prioritization of traffic between multiple flows in a single link. This session is shown with more detail later.
9. **Wireless LAN.** 802.11 wireless networks are introduced. Students configure multiple networks in the lab, and study the available throughput on each case (between wired or wireless clients, in the same channel or a different one).

It can be observed that sessions 5 to 8 use the advanced capabilities of the switches discussed in Section 2, while other sessions are more basic. We detail next two interesting sessions that make use of the advanced capabilities of the switches.

G. Virtual-LAN lab session

This advanced lab session explores the work in groups. The idea is that the students must build a single network in the laboratory, but comprising different virtual LANs. Each VLAN is seen as a separate LAN for the users connected to it, although all of them use the same network equipments to lower the implementation costs.

Fig. 3 shows an example case. Our desired implementation contains two networks, one for management operations, and another one for the students. The equipments in different networks should not access each other, so the simplest

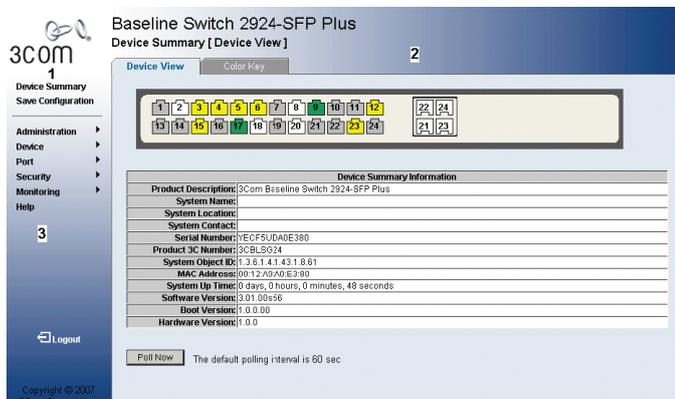


Figure 2. Web-based management interface of the laboratory switches.

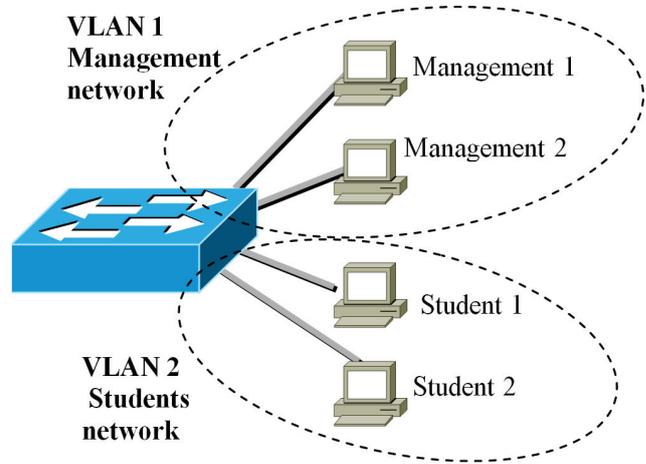


Figure 3. Two VLAN networks in a single switch.

configuration would be to use two physically separated switches. However, a single switch with two VLANs configured, as presented in the figure, gives the same service.

The interesting configuration problem arises when equipments in the same VLAN are connected to different switches. In this case, the connection link between the switches must be configured to transfer VLAN information with each frame. This is a distributed configuration, what forces each group of students to collaborate with the others in the configuration, validation and problem solving phases of the work. Similar problems are faced in the second part of the session, in which multiple links are laid between each pair of switches to aggregate their speeds and provide more performance.

H. Traffic prioritization lab session

We will detail now a session of our laboratory that uses multimedia, switch management and group work to study the effect of network congestion and how to solve it with prioritization at OSI level 2. As discussed in Section 2, the effects of congestion are familiar to the students, since it affects multimedia (VoIP, videoconference, video on demand) and network gaming, among others.

We configured a 10 Mbps link between two switches to model a congested WAN access, as presented in Fig. 4. Multiple PCs used FTP to transfer large files (sustained transfer) across the shared link. Simultaneously, the PCs on port 1 of each switch had webcams that would transfer video between each other. We used the VLC player [16] to encode, transfer and receive video at 4.5 Mbps using MPEG-2. This emulates a videoconference system that runs on the same link as the remaining traffic from the FTP transfers.

Without any prioritization, the video would show clear transmission artifacts, as presented in Fig. 5a. The lack of sufficient throughput and variable network delays affect the quality of the transmitted video. The image shows macroblocking and false colors artifacts.

The laboratory switches provide four hardware queues per port. Traffic flows can be inserted to one or another depending on their input port or their priority tags (CoS at layer-2 or ToS

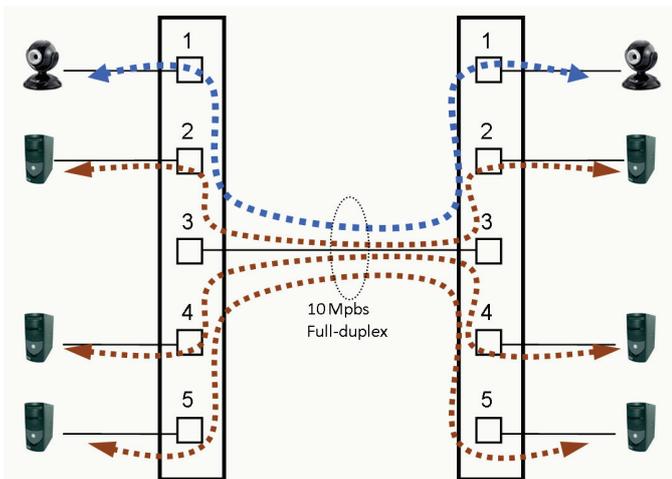


Figure 4. Schema used to obtain congestion in a network link. Both switches are connected through port 3. The computers on port 1 of each switch make a videoconference encoded with 4.5 Mbps. The other computers transfer files on both senses.

at layer-3). Different hardware queues have different priorities (strict priority or weighted round-robin) when they compete to transmit on the same link, in our case, on the link between ports 3 in both switches. By configuring the video in the strict priority queue and the remaining traffic in one of the remaining ones, the students guarantee that the video transmission does not suffer from the concurrent file transfers on the same link. The result when the proper prioritization mechanisms are employed is presented in Fig. 5b, where the concurrent transmission of 3 files does not affect the video quality.

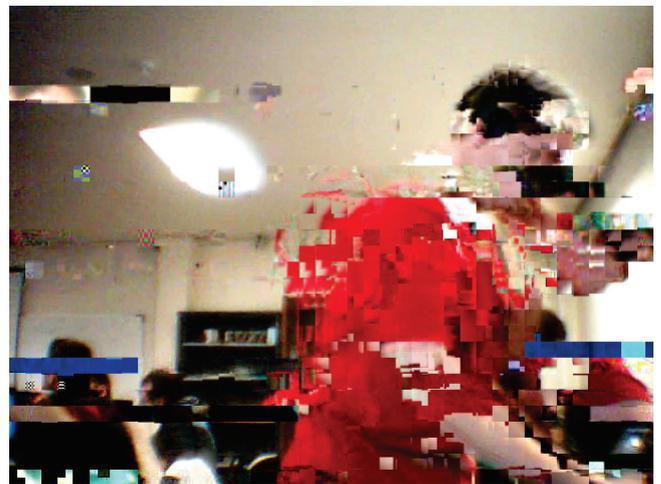
Other approaches study quality of service with a quantitative approach [11]. By contrast, our practical approach is highly qualitative. We believe that this simple and visual approach, with familiar problems (such as video pixelation) that are solved with prioritization, are better suited for the introduction of the problem and associated solutions to the students, leaving detailed studies of the quantitative performance for further courses.

V. EXPERIENCE AND OPEN ISSUES

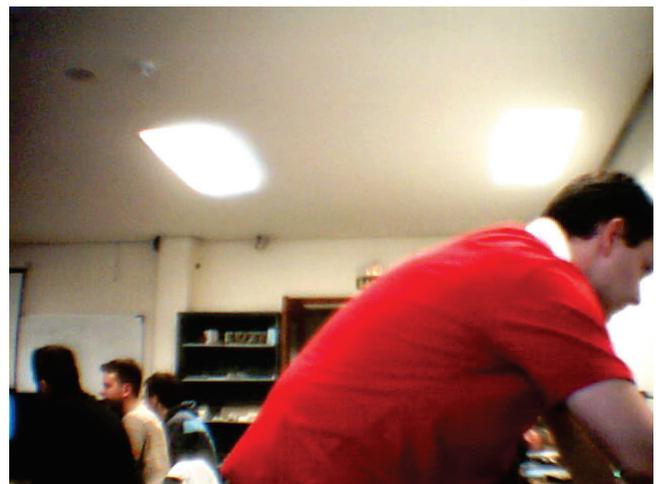
The proposed organization is now running for the second year. We have observed that the students understand the contents presented and can follow the course without major problems.

One of the main issues with the lab sessions is that many of them introduce relatively advanced concepts. Therefore, we have determined two concerns:

1. Special care has to be taken with the synchronization of theory and lab sessions. The start of the lab sessions could be delayed a few weeks until the necessary background has been presented. When the lab sessions refer to contents not yet introduced in the theoretical class, the lab instructions must be accompanied with the necessary contents.
2. It is required for the students to read the instructions before the lab session so they are familiar with the



a) No prioritization mechanism, no QoS



b) With proper prioritization on the shared link

Figure 5. Example of video received when multiple traffic flows share the same link. Case a) shows the result in the default case (without any prioritization mechanism) where packet loss is observed in the form picture errors and macroblock pattern showing. Case b) shows the result when the port queues are properly configured.

exercise and the involved technology. Otherwise, the 2 hour limit is not enough to finish the proposed exercise. We observed that in many cases the students would omit this step, and would have problems in the session. While we have not done so yet, we are considering the idea of adding a quick test about the instructions at the beginning of each session. Such a test, with a low impact on the final grade, would incite the students to prepare the lab sessions thoroughly.

We also noticed that the effort required to prepare the setup of each lab session (prepare switches, cabling, configuring equipments) was relatively high. This is a cost to be paid for the advantage of lab sessions with real hardware.

Our main concern for the future is the adoption of this course to the Bologna requirements once the new 'grade' is working. However, we believe that our practical approach is well-suited for the change.

VI. CONCLUSIONS

We have argued that the evolution in Computer Networks, not only in the technological aspect, must condition the way that corresponding University courses are designed. Specifically in the current context, the technology, economic aspects and students' background allows for relatively advanced contents to be taught without requiring a large effort. We believe that similar discussions should apply to most technological courses.

Based on the previous discussion, we have presented the organization of our course and detailed the laboratory sessions using affordable mid-range hardware. Our experience shows that this approach is affordable for the students and provides better results than using exclusively simulation-only tools.

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REFERENCES

- [1] Foro Histórico de las Telecomunicaciones. "De las señales de humo a la sociedad del conocimiento. 150 años de las Telecomunicaciones en España". Colegio Oficial de Ingenieros de Telecomunicación. 2006.
- [2] Comisión del Mercado de las Telecomunicaciones. "Nota Mensual de Agosto de 2009" Available online at http://www.cmt.es/es/publicaciones/anexos/NM_agosto_09_.pdf
- [3] US Census Bureau. "Current Population Survey (CPS) Report". October 2007. Available online at <http://www.census.gov/population/www/socdemo/computer/2007.html>.
- [4] IEEE. "IEEE Std 802.3 - 2005 Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications - Section Five" 2005.
- [5] http://cisco.com/web/learning/le3/learning_career_certifications_and_learning_paths_home.html
- [6] Odom, Wendell. "CCNA Official Exam Certification Library (CCNA Exam 640-802)", 3rd Edition. Cisco Press, Sept. 2007
- [7] Odom, Wendell. "CCENT/CCNA ICDN1 official exam certification guide (CCENT exam 640-822 and CCNA exam 640-802)", 2nd edition. Cisco Press, Sept 2007
- [8] 3Com® Baseline Switch 2900 Plus Family Datasheet. Available online at http://www.3com.com/prod/en_ap_ap/detail.jsp?tab=features&sku=3CBLSG16
- [9] C.S. McDonald. A Network Specification Language and Execution Environment for Undergraduate Teaching. Proc. of the ACM Computer Science Education Technical Symposium '91, San Antonio, Texas, Mar 1991, pp25-34.
- [10] S. P. Ahuja. COMNET III: a network simulation laboratory environment for a course in communications networks. Proceedings of the 28th Annual Frontiers in Education, vol 3, pp. 1085-1088. 1998.
- [11] M. Domínguez Dorado, F. J. Rodríguez Pérez and J. L. González Sánchez. "Simulador MPLS para la Innovación Pedagógica en el Área de Ingeniería Telemática". IEEE-RITA Vol.2, Num.1, May 2007.
- [12] Rohit Goyal, Steve Lai, Raj Jain and Arian Duresi. "Laboratories for Data Communications and Computer Networks" In Proc. of Frontiers In Education Conference. 1998, pp 1113-1118
- [13] D. R. Surma. "Lab exercises and learning activities for courses in computer networks". In Proc. of Frontiers In Education Conference. 2003, vol.1 pp. T2C-21-5
- [14] W. Stallings. "Data and Computer Communications" 7th edition. Prentice Hall, 2005
- [15] A. Orebaugh, G. Ramirez, J. Burke, L. Pesce. "Wireshark & Ethereal Network Protocol Analyzer Toolkit (Jay Beale's Open Source Security)" Syngress Publishing, 2006. Program and code freely available at <http://www.wireshark.org/>.
- [16] Videolan VLC media player. Program and code freely available at <http://www.videolan.org/>.