Remote Laboratory for Computer Networks

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Abstract: The article introduces the reasons for realisation of the remote laboratory of computer networks which originate from the comparisons of the alternatives of working with the specialised networking hardware. These use the principle of virtualisation or simulation of such devices as an alternative for obtaining competencies from the area of computer networks. Due to this reason, this article discusses other technical solutions and the analysis of usability of such solutions is conducted. For a maximal efficiency of the networking hardware utilization in laboratories it is necessary to make it fully available for students which is the 24/7 regime. This option can be executed using secure technologies and protocols for distant accessing of laboratory hardware. This solution, which is based on using console controllers and single utility interface, is introduced and described in detail in the following paragraphs. Moreover, from the analysis of the pilot operation of remote access to the laboratory equipment of the networking laboratory, suggestions for improvement of the current solution and its usage in fully working condition – access to a greater number of students in unlimited regime – can be obtained.

1 INTRODUCTION

As the reason of the education strategy of the Informatics and Management Faculty of the Hradec Kralove University, which is particularly focused on the practical usage of learning, the Cisco Networking Academy programme was incorporated in bachelor courses called Applied Informatics and Information Management in 2007. Four basic modules Introduction to Networks, Routing and Switching Essentials, Scaling Networks and Connecting Networks are included in the educational process. These modules form the basic elements of the so called Cisco Certified Network Associate (CCNA). In order to enable the teaching of these subjects, it is necessary to have a professionally equipped computer network laboratory with elements, such as Cisco 2801 and 2911 routers and Cisco Catalyst 2960 and 3560 switches. This equipment is essential for execution of above mentioned courses. Students can use these elements when working on laboratory tasks within the practical exercises in subjects of Computer Networks I to IV.

This set of basic courses is followed by more advanced and complex subjects, which go into a much greater detail in many related areas and are called collectively Cisco Certified Network Professional (CCNP). This course contains (Odom, 2010) Cisco CCNP ROUTE: Implementing IP Routing, (Hucaby, 2010) Cisco CCNP SWITCH: Implementing IP Switching and (Wallace, 2010) Cisco CCNP TSHOOT: Maintaining and Troubleshooting IP Networks. These courses are very specialised and difficult for lecturers and students that they cannot be incorporated into a standard education on a bachelor or magister level and are therefore taught in specialized lectures once per two years. The profound knowledge of theoretical concepts of such matters is required, as well as practical skills of students who need to be able to solve within timely laboratory exercises (Browning and Tafa, 2011) the specific configurations and problems on professional network elements that are often used in a job environment. The common solution of one task would take one student even more than 4 hours which means that even with sufficient hardware equipment of the laboratory at the faculty, it is often difficult to compensate students the lack of time for solution of such tasks. This is either due to the lack

of time that the student has or lack of the reserved time for access of the laboratory.

Especially the above mentioned restrictions of physical access to the specialised equipment was one of the main reasons for the suggestion to the execution of remote access to the individual elements and in this way enable the solution of assigned tasks independently of the physical presence of the student in the laboratory. The implementation of this distant access for students would enable the teaching of above mentioned courses more frequently than once per two year and also it would enable distant education of such courses using e-learning tools. This solution also uses individual physical topologies in terms of the taught course where the specification is based on the specialised software configurations of individual elements and not on the physical connection. This represents the solution to problems in real life on the basis of hierarchical network design model.

2 USE OF REMOTE LABORATORY FOR EDUCATION

There are many scientific research and educational institutions which are engaged in the suggestion and solution of distant laboratories, not only in the Czech Republic. The common view on the issue of using distant laboratories and their usage for educational purposes is presented by Barrios, A (2013) who namely introduces the structure and accesses of the distant laboratories systems and their interconnection with Learning Management Systems. The specific solution for using PLC devices is suggested in the article of Chen, X and Gao, H (2012) which also focuses on specifications of distant access to hardware tools of PLC systems. Similar characteristics should be taken into account when finding the solution for access to the computer network laboratories which is aimed at enabling the access to the built physical network topology in the area of Cisco Certified Network Professional certification to students.

2.1 Secondary Access

The teaching of computer networks at the universities requires, even for the basic understanding of the given topic, a complex study access including the opportunities for checking the obtained theoretical knowledge on practical

examples. In this way, the student's competencies can be expanded. The learning of specifications and protocols cannot replace the practical part of the subject which is the previously mentioned configuration of real devices in a tangible topology, ideally with a maximum of real data traffic.

As Bodnarova, A. (2010) presents, in the case when there are no suitable specialised hardware tools for individual teaching, for example in the home setting, it is possible to use simulation or virtual tools. One of the simulation tools is for example Cisco Packet Tracer by Cisco Systems (2104), a proprietary simulation tool for students of the Cisco Networking Academy. The disadvantage of such solution is how abstract the real behaviour of the system is. This can further result in misinterpretation of results. However, it is simply to develop such tools and run them even on basic computer systems due to the fact that they can be used by beginners.

The virtual tools can closer simulate the behaviour of the network device system. However, there are serious problems with licencing of the active elements of operation systems and with high power overload which can generate these devices. One of such devices is for example a freely available virtual tool GNS3 by GNS3 (2014) or IOU as described by Route Reflector (2014).

If the mentioned disadvantages of both approaches should be avoided, it is necessary to compromise and work on real devices which are the only ones that can provide authentic response and realistic (predictable) behaviour. The local connection to the device is usually not the main problem as it can be accessed by standardised protocols, such as telnet or SSH.

However, when not working from the home environment or university environment, but during the home studying, it can be difficult to optimally allocate hardware resources in a way to serve the highest number of students without collisions. Our introduced solution was able to solve this problem to a certain extent and the way in which it was done is presented below.

2.2 Remote Lab Concepts

The purpose of the introduced solution was to create a system for distant access to the specialised network hardware within the previously built physical topology. The philosophy of the pilot project originates from the sample laboratory exercises of the course (Wallace, 2010) CCNP TSHOOT which are used for practical verification of

obtained competencies in the area of advanced computer networks.

The specification of these tasks is that they are executed in one physical topology which is represented in Fig. 1 and is used for various types of configurations and detection of hidden problems in realised network. Three routers Cisco 2801, Cisco 2911, two L3 distribution layer switches Cisco Catalyst 3560 and one access switch Cisco Catalyst 2960 are used here.

A student can request a reservation for specific time for his/hers training and the correction of his/hers knowledge in practical tasks where he/she can choose the particular topic whose pre-configurations are then automatically recorded on the single network elements. Three identical logical topologies which are mutually interconnected (as is described below) are available in the pilot operation. A student can, according to the difficulty of the chosen task, work on one to three topologies simultaneously or up to three students can work concurrently or independently of each other. In the same time, a student has the choice of ten different laboratory tasks which cover the most important topics of the above mentioned course.
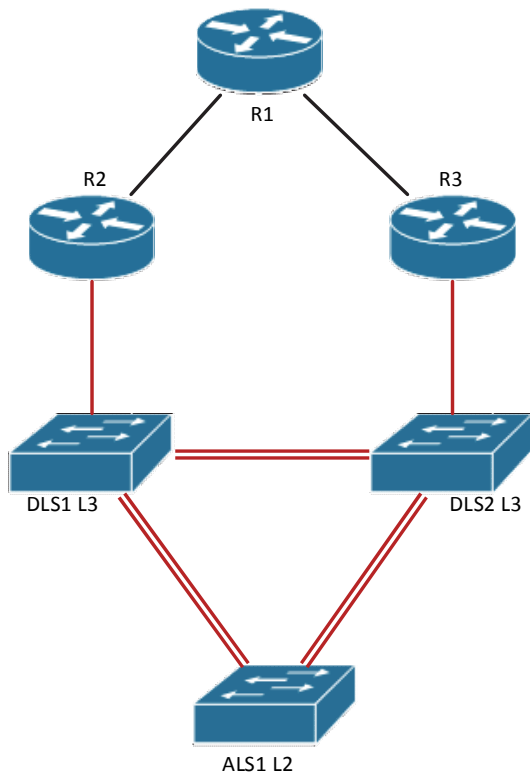

Figure 1: The basic scheme of physical labs topology.

2.3 Remote Lab Structure

The system of the remote lab can be divided into three basic block components, as is shown on the Fig. 2. The first basic component is the virtual server which takes care of the maintenance of the actual remote lab and provides tool for automatic task deployment. The second component is the console server that enables the distant access to the individual devices. The final element is the specialised network hardware and virtual end stations.
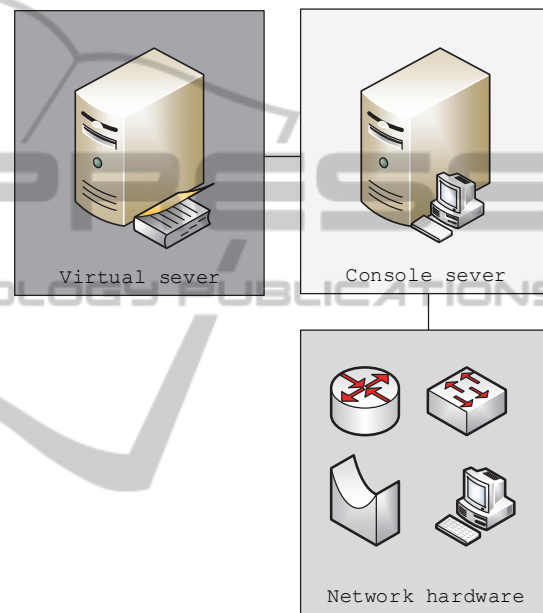

Figure 2: Block diagram of a remote lab.

2.3.1 Virtual Server

The virtual server is the first basic block component and represents the virtual server Linux Debian that is virtualised on VMware ESXi 5.1 on which are run several basic services for ensuring the operation of the laboratory. Firstly, this server provides the platform for verification of users on the basis of RADIUS protocol. Moreover, it is intended for possible controlling of the access of individual students to the infrastructure of the remote lab. The database MySQL, in which the registration details of individual users of the remote lab are saved, is used as the data platform for RADIUS tool. The server also provides the web-interface for operation of the laboratory and networking devices management.

The internet application also offers tools for planning the access to virtual laboratory. The calendar displays the specific detail about when the

virtual laboratory is fully-utilised and when it is free for possible reservation. The admin, who is the lecturer, has the option to add new users, that ought to have a beforehand approved time-slot to access the infrastructure, to the RADIUS database server according to the students' requests.

Working with the distant laboratory requires maintenance of the individual devices in order to always create a new original configuration for each student. This involves the deletion of the configuration after each student's session, as well as the recording of the new chosen configuration before another student starts his/hers session. The system offers this function using the beforehand prepared service package of commands (script). These are run manually on the basis of creating and ending the individual sessions. The system uses the connection through SSH protocol on the console server in the same way as the actual distant access to the laboratory and it maintains the individual devices through this console connection.

2.3.2 Console Server

The console server enables the necessary distant access to individual devices which is not dependent on the actual topology of the remote lab. However, the usage of the standard access through the protocols telnet or SSH can create a problem for the running of such networking laboratory. Any unthoughtful or wrongly configured change of the topology can cause unavailability of a certain network segment and the access to the devices could be only obtained through a physical connection of a serial link.

In our introduced and realised solution of the remote lab connection the serial routes of individual devices are connected to the console server. This server is further attached using the IP protocol to the university network, namely Internet, where it functions as a SSH server. The user, who wishes to access the given network device, is able to connect to the console server using the SSH protocol from anywhere at the university. On the basis of the given port, the user is then connected through the SSH connection directly to the console port of the particular network device. This is the way in which the access to the network device, that is independent of the actual topology of the remote lab, is assured.

The access to the devices through the console is in certain cases necessary even for the laboratory practices. One of the examples can be the situation when the student connects to the bootloader device with the purpose to re-gain the access after

forgetting his/hers password. This can also be the situation related to the maintaining server if the student does not follow the set convention for using passwords during the laboratory practices.

2.4 Network Devices of the Laboratory

The individual network device of the laboratory is composed in the pilot operation of elements which are intended for practicing laboratory tasks of the course CCNP TSHOOT. Specifically, these elements include routers Cisco 2801 and 2911 and switches Cisco Catalyst 2960 and 3560. These are connected into single-type topology which is used across the whole course CCNP TSHOOT and can be also applied for practicing of some of the topologies which are to be found in the CCNP Routing and Switching lectures.

In order to use the distant laboratory, the topology is enlarged to enable the broadest usage of the employed network device. Topology must offer students full-value in terms of its working, in the same way as if the students were physically present in the laboratory and the sufficient modularity for testing of own examples of different types. An important characteristic of the suggested solution is the independency from the specific network elements as the console access is in the enterprise of the network devices used as the standard. Therefore this solution is easily scalable.

Networking devices can be replaced by new ones, or expanded up to number of console ports, that can be handled by a console terminal. The use
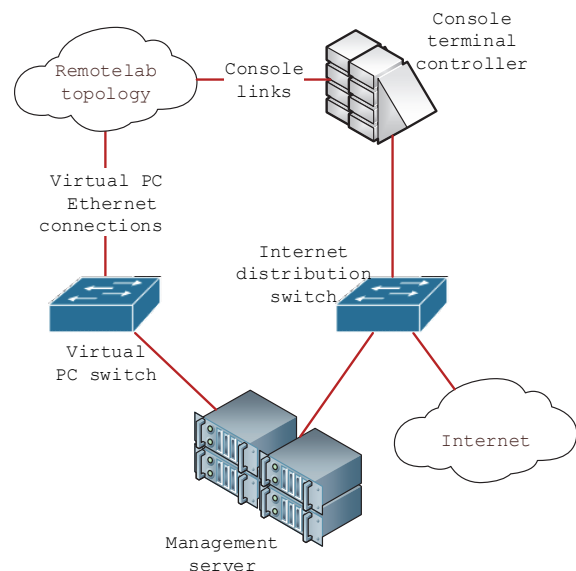

Figure 3: Interconnection between remote laboratory and public network.

of multiple console terminal controllers is possible and the management server is able to handle up to 50+ networking devices.

The basic CCNP TSHOOT exercises (topology) were expanded by multiple end stations. These are created as virtual devices connected into the network topology of the distant laboratory, as well as into the laboratory infrastructure as shown in the Fig. 3. The virtual end stations are currently utilised using Windows XP operating system which is adjusted to minimise the demand on the hardware.

Instead of Windows XP system, it is of course possible to use some other undemanding Linux distributions, such as Puppy Linux or a system without the graphic interface. Windows XP system can be used in this case because for most students it represents a common environment and therefore, students can fully concentrate on the accomplishment of their tasks without having to solve specification of the configurations in Linux systems. Using Remote Desktop Protocol (RDP), students can in this way distantly access devices which function as the local guests in the laboratory network and in the same way as in the case of using console server are available independently on the actual configuration of the laboratory topology.

Another broadening of the former CCNP TSHOOT topology is conducted by the addition of elements from wireless networks. Examples of these are the wireless controller and some centrally-controlled Wi-Fi access points. In this way, it is possible to use the distant laboratory for testing network technologies which go beyond the CCNP

Routing and Switching course and are not usually taught at FIM UHK. Therefore, it is also possible to prepare students for courses which belong to the Wireless family.

The last consistent solution of the topology is the usage of Cisco Advanced Security Appliance (ASA) elements. These offer students the platform for testing configurations with the focus on the security of enterprise networks. Among these can be found the IPS technologies which follow the data running in real time or the possibility to work with powerful point-to-point and point-to-multipoint VPN tunnels.

The actual modularity of the network topology, shown in the Fig. 4., of the distant laboratory is built on the connection of multiple basic topologies CCNP TSHOOT. In the pilot operation three basic topologies enlarged by the wireless device of the virtual end station are connected. It is possible to use these links between individual topologies for simulation in larger networks and they also enable to create complex tasks which can be solved in student teams. This topology was chosen because CCNP TSHOOT course covers topics of both preceding CCNP Route and CCNP Switch and is therefore most universally usable. Interconnection of the topologies and overall size of the remote laboratory is a result of an effort to fully utilize the devices and the amount of devices available.

In order to solve specific problems, for example when finding the correct solution for graduate tasks, it is possible to create an entirely different topology. This requirement demands physical modification of
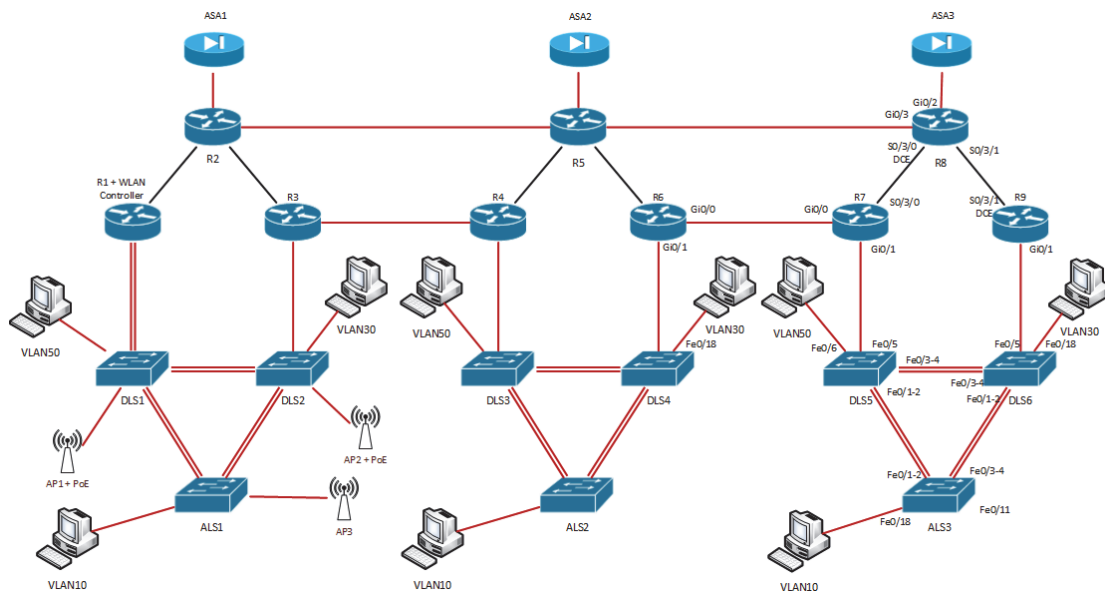

Figure 4: Remote lab topology – interconnection of three isolated CCNP TSHOOT topologies.

the former topology, but the actual topology still enables a broad selection of simulations (i.e. dynamic routing protocol adjustments, L2 redundancy simulations). These specific problems usually require a lot of time and in ordinary functioning of the laboratory even a few students would fill up the capacity of the laboratory. Due to the operation of the distant laboratory, it is possible to add links to the current topology which will be normally turned off, unless they are defined for solving problems in advance. Students who would work on complex problems can solve the problem in a longer time scale during which they gradually create the configuration which can be backed up and reloaded again in the different sessions.

3 EVALUATION OF THE PILOT OPERATION

The used system of the distant access to the laboratory equipment is currently employed in the pilot operation and tested for stability and reliability of accesses. The significant advantage is the utilisation of Remote lab controllers which provides reliable connection with configuration interface of individual elements, as well as it standardly uses the special interface of the console for serial communication. Moreover, remote lab controllers also communicate with Linux server on which are Network Policy Server RADIUS and MySQL database, as well as management application, as described above.

Before connecting remote lab to the educational process of the faculty, it was not possible to use the devices during the lecturers in the laboratory. This presents approximately 6 hours a day during the work days. Furthermore, it was also impossible to access the elements during the hours when the university was closed, which was not a problem during the semester, but mainly during holidays. The physical work in the laboratory also requires the supervision of one of the lecturers or admins of the lecture room. It was possible to eliminate these disadvantages by introducing this system of the distant access to the network elements. Under the pilot operation, a group of students is preparing for the CCNP Route certificate and uses the services of the laboratory during the time when the access is physically unfeasible. On the basis of the messages from the Syslog server, the distant laboratory is used on average 8 hours a day, including weekends. Based on the student's feedback, they sometimes

miss immediate lecturer assistance, such as in standard courses. Overall student's feedback is positive, mainly because of the amount of time, when they can work on the topology and practice their skills. It is sometimes also their only possibility to go through the course, so it is highly valued by the students.

The disadvantage of the current solution is the necessity of administration by lecturer who must manually enable the time-slot of the chosen laboratory task using the special web-interface. This is where the disadvantage of the pilot operation is obvious and it is therefore necessary cooperate with university information systems, especially with directory services, namely the implementation of LDAP address services which opens up the opportunities for full automation of the time-slot reservation of individual elements (whole laboratory tasks). This automation offers the possibility of automatic choice of the type and level of the laboratory task which the lecturer must set for the current configuration during the time-slot reservation of the device.

The current solution still cannot fully simulate the conditions of the production computer network. This is due to the fact that the laboratory network still is not in the realistic operation on individual links. In order to eliminate this disadvantage, one of the possibilities is to broaden the topology by generators of network operation. These can function as a specialised hardware or another option is to use one of the open source tools in form of another PC, such as BackTrack Linux.

4 CONCLUSIONS

The realisation of the distant access to hardware device and automatic pre-configuration of elements for individual laboratory tasks seems to be an ideal option for effective usage of specialised network elements. This approach enables not only to broaden the possibilities for highly specialised education within the CCNP course, but also the possibility for distance learning at FIM UHK. After the expansion and interconnection of current model with authentication systems of the university, it will be possible to use the laboratory equipment even for more complex tasks in courses within the computer network III and IV which currently cannot be realised (other than for practice with lecturer) due to the time limit on access to the laboratory. On the basis of the experiences gained from the pilot operation, this platform can become an essential part

of the education tools in various levels of teaching at FIM UHK. Another important advantage of the remote lab would be the possibility to use it for final academic works which are much more practically oriented because of the emphasis on team work and practical usage. Due to the distant access, the opportunities for effective usage of laboratory equipment at FIM UHK are significantly improving.

ACKNOWLEDGEMENTS

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