Building Interactive Multi-User In-Class Learning Modules For Computer Networking

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***Abstract*—The new multiuser capability in Cisco Packet Tracer tool has provided great potential for developing interactive multiuser activities that can be completed by Cisco Academy students in the classroom. This approach will not only greatly enhance students' interest in the technical topics, but will also allow the instructor to create group activities where student progress can be monitored and tracked easily on the instructor side. In this research we focus on primary design principles for creating such interactive activities. We present a general architecture for a library of interactive modules we developed for CCNA exploration 1-4 topics. We provide solutions for a number of technical problems that must be resolved for multiuser access, such as scalable addressing, VLAN handling, individual student monitoring, and offline exporting. We also provide testing results to evaluate the performance of packet trace in an interactive multiuser environment.**

Keywords-component; blended learning; packet tracer; multiuser; simulation; teaching; ccna; cisco; networking; academy;

I. Introduction

A. Background

Introductory computer networking education (e.g. Cisco CCNA level) focuses on teaching students both the theory and the practical knowledge about networking technology that has rarely been covered at their prior educational levels (high school). Students often have to bring themselves up to speed quickly on a large amount of content that includes the entire OSI model and TCP/IP protocol suite, several routing and switching protocols, local and wide area networks etc. The sheer volume of technical details in this case can quickly result in a dry and non-interactive environment that can impede student learning process. Lab components often improve the dryness of the material by giving students practical examples to reinforce theory. However, more can be gained by increasing the level of interaction during lecture times and in the classroom. This can be achieved by implementing short in-class activities that encourage students to collaborate with their peers throughout the learning process. Interactive learning is becoming more prominent and show great potential in teaching IT concepts.[1,2] Likewise, e-learning tools are used with great benefit to teach CCNA Discovery and Exploration curriculum of the Cisco Networking Academy.[3] One such tool is Packet Tracer (PT), which provides a network simulation environment with sufficient details of IOS for CCNA levels [4].

The objective of this work is to use the recently added multiuser feature in Packet Tracer to create in-class interactive learning activities that would enhance students' understanding of complex networking concepts. The multiuser feature in Packet Tracer allows students to work in an environment that is affected by their peers and is under control of the instructor. Despite some technological problems, PT multi-user activities can make networking more interesting to learn and lead to greater student engagement.

B. Related Work

The Multiuser functionality was added to Packet Tracer in August 2008. However, at the time of writing this paper Cisco has not yet developed any curriculum activities that feature multiuser operation, leaving it up to individual academies. In 2010 the Open University of UK reported on implementation of PT's multiuser functionality into their blended distance learning CCNA courses.[5] Their results offer an extensive guide to the multiuser architecture as well as the implementation of multiuser over the WAN, and the inherent problems. We build on their work by implementing our multiuser architecture in a traditional classroom through a LAN. This method bypasses the majority of the technical limitations in [5] and gives students more interaction with the class.

Basic technical specifications of the Packet Tracer Messaging Protocol (PTMP) and Inter-Process Communication is available in [5,6], and while many proprietary details were not available or could not be made public, the available information helped understanding the communication between two hosts running a Packet Tracer multiuser connection.

The rest of this paper is organized as follows. In Section II we describe our objectives and design specifications for interactive learning modules. In Section III we discuss some technical challenges in creating interactive learning modules and present our solutions to overcome these challenges. This section also includes some performance results. Some performance results are presented in Section IV. Section V includes our conclusions as well as future plans.

II. Learning Module Specifications

The problem of engaging students in the process of learning networking is normally solved by using a blended learning approach that Packet Tracer is already

 ISBN: 978-1-61208-133-5

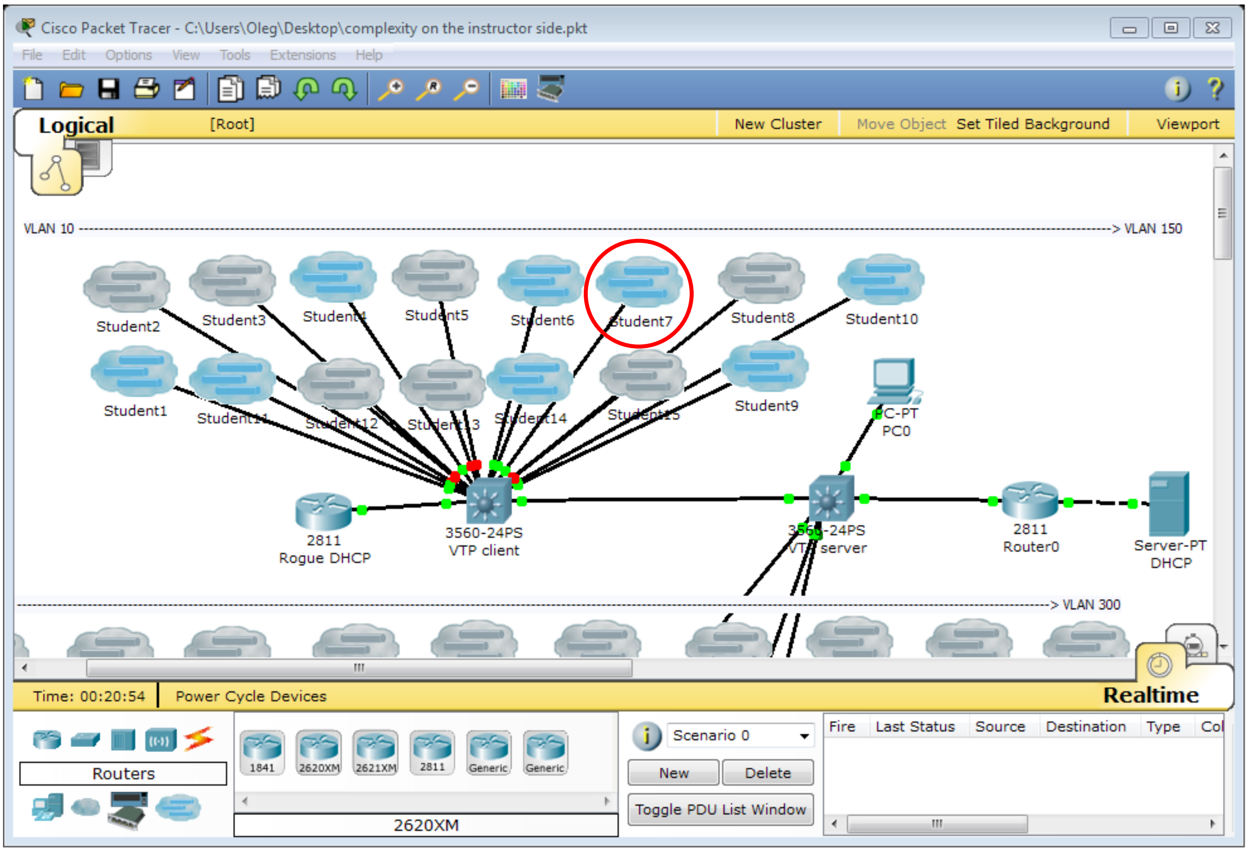

Figure 1: Example of an Instructor-Side Module

part of. However, current Packet Tracer activities are highly scripted, having little interactivity and class participation. Multiuser activities allow Packet Tracer to be used in a more dynamic way, allowing the instructor to affect student's Packet Tracer environment in real-time. Having multiuser activities as part of networking course would fill a gap of short, interactive and extensible activities that can be used to promote student participation in lectures. The activities must be simple and require minimal configuration by the students, and they should be used in-class and be marked through student participation. The result of this project included 40 multiuser activities and two games covering the entire CCNA curriculum. The design of the activities closely followed the framework described in this paper. The activities are currently being integrated into the two introductory networking courses at UOIT that cover the CCNA curriculum.

A. Architechture

Significant differences between standard and multiuser CCNA activities create a whole different set of factors that have to be taken into account in the latter case. The main task is minimizing the disadvantages and limitations of the multiuser feature and maximizing the advantages it offers in interactivity and real-time communication. We achieve this objective by creating a thin client-server environment in which most of the complexity and configurations are on the instructor side. The fact that UOIT is a laptop-based university in which all students use pre-configured university-issued laptop in the classroom, greatly facilitated the implementation and use of this model.

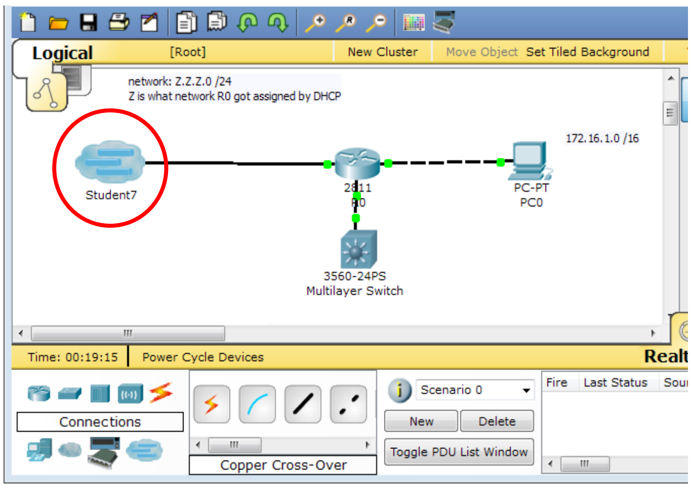

Figure 2: Example of a Student-Side Module

The instructor-side module is responsible for providing the hub part of a hub-and-spoke topology. The students can then start a multi-user PT activity on their respective laptops and establish connections to the instructor side of the activity. This usually involves two PT activity files: the instructor file, and the student file. Student-specific configurations or modifications must be kept to minimum. Figures 1 and 2 display examples of the instructor and student side modules, respectively.

The instructor should also be able to save the student's progress at any point and inspect it on his/her own time. This approach is ideal for completing an activity in the classroom and marking it later. Depending on who the instructor file is released to, the activities are open for modification and can feature any new content that gets added to PT in the future. In general, a laptop per student is required. The requirements for the instructor computer depends on the number of students that are expected to connect and will be discussed later in this paper.

B. Multi-user activities specifications

To retain student attention, multi-user activities were designed to be completed in 10-20 minutes. The activities would be presented in the middle of the lecture and allow the instructor to demonstrate a particular networking concept interactively with the students. The activities assume that the students have limited hands-on experience and are mainly used to demonstrate the networking concept. In general, the activities follow these requirements:

1) Minimal configuration or pre-configured for the student
2) Student tracking through offline saving
3) Allow group work
4) Task variety between activities

The major limitation to this architecture is that PT's simulation mode cannot be used as easily during a multiuser connection. Therefore this architecture pushes the focus of the activities to the real-time interaction between the instructor and student networks.

C. Modifying and extending activities

Creating and editing router and switch configurations in text files is considerably easier and more manageable than working within PT. To create or extend the functionality of a certain activity, it is easiest to first export all configurations of each device into text, and edit the configurations using a text editor. Finally you can either erase the configuration in the old topology and load the new configurations, or simply load the new configuration overtop of the old one. One must be aware that certain configuration options (VTP) are not saved in the run configuration and must be configured each time. Knowing how to effectively use the "find and replace" function featuring RegExp (or similar extended options) is key to creating new activities in a timely manner. Figure 3 shows an example.

The intent of multiuser is not to replace hands-on portions of networking. Instead it is meant to increase student engagement during lectures. As such in multiuser activities the learning curve to get started and the amount of tedious configuration should be minimized. This can be done by putting commonly accessed devices, such as servers and core devices, on the instructor side. To minimize configuration, the student side has devices that are preconfigured, allowing the instructor to limit the focus to a particular topic discussed in class. Minimal configuration from the student is necessary to differentiate the students and allow the networks to communicate.

As we shall explain in the next section, student devices can be assigned addresses in a unique network depending on the how VLANs are configured. This feature allows students to configure routing protocols between each other. Alternatively, students can be split up into groups on different VLANs, and assigning them addresses accordingly.

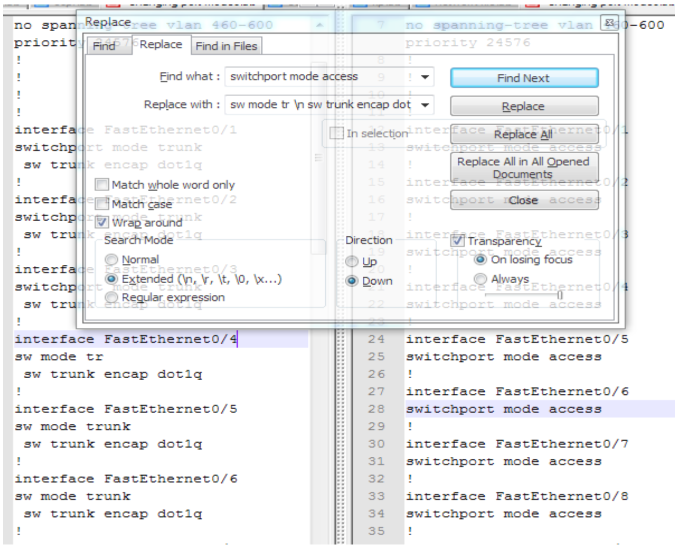

Figure 3: Editing Activities

D. Student Evaluation and Monitoring

PT's activity wizard offers an extensible script-based evaluation system that examines the parameters of each device in the student network. In our work students were evaluated based on their participation in the multiuser activities. The TCP traffic between PT instances is unencrypted and information such as hostnames can be found by capturing that traffic. Additionally, the instructor side can poll the student network and generate an offline copy of the whole network. This offline saving capability allows he instructor to the save the state of the network at that particular time and view the commands that each student entered on their respective activity.

III. COMMON ROADBLOCKS

In designing multiuser PT activities several good practices were developed. The main principle is maximizing the advantages gained by having interactive activities. Configuring multi-user activities can be split into three layers. Layer 1 is the physical and data connection between hosts running the PT instances. Layer 2 is the data connections between switches and

ISBN: 978-1-61208-133-5

relates to MAC addressing and VLAN assignment within the PT environment. Layer 3 is responsible for the rest of the connectivity between PT environment such as IP addressing and routing.

A. Layer 1 Issues

Documentation on how to setup multi-user connections between packet tracer instances is readily available [5]. Connections between instances are done by matching IP address, port, cloud name, and password parameters between instances. PT offline saving accounts for the most tolling activity on computer and network resources. Remote student computers are polled at the same time resulting in bursts of traffic that is well handled over the LAN but may result in problems in a WAN implementations like that of Open University of UK. Traffic encryption is optional and useful information can be gathered by collecting the traffic data in Wireshark.

B. Layer 2 Issues

As mentioned in the previous section, in most activities students start out with an identical student-side file of the network. This presents a problem because all students now share the same MAC addresses within the PT environment. One way to work around duplicate MAC addresses is by using NAT (Network address translation), but this effectively cuts off inter-student communication. Multiple VLAN's on the other hand maintain inter-student communication when configuring routing protocols. Duplicate MAC addresses can still interfere with various protocols on the instructor-side. STP (Spanning tree protocol) must be properly configured on the switches within PT. The switchport connections in Figure 1 can be inadvertently blocked off by STP due to the adjacent port MAC addresses being identical. The switches on the instructor side should be configured with a very low STP priority to guarantee that they become the root and no ports gets blocked.

When designing activities that teach VLAN concepts. Problems can be encountered on the instructor side if past configurations with different VLAN schemes are reintroduced to the instructor network. It is recommended to save the start configuration, erase the vlan.dat and restart all the routers simultaneously to avoid VLAN/VTP problem when reconfiguring VLANs. Despite the additional complexity on the instructor side, in most activities no other changes have to be made on the student side.

C. Layer 3 Issues

DHCP is primarily responsible for achieving layer 3 connectivity with minimal configuration from the students. Prior to developing addressing schemes, layer 2 should be problem free. While DHCP servers can be set up on routers, for classless networks the DHCP has to be setup on a separate server as shown in Fig. 1. Although DHCP is not intended to provide IP addresses to devices that with identical MAC address, if layer 2 is problem free, the only DHCP problems encountered can be solved by issuing DHCP release/renew commands.

D. Scalability, Security and other Limitations

The scalability of the hub and spoke topology in use is limited. During 60 user activities, the hub computer will be responsible for any bottleneck encountered. It may be necessary to split the class into two 30 student groups that will connect to different hub computers (instructor laptops). The hub computers can also optionally be connected to each other, providing connectivity in a more scalable manner than a single hub computer.

Accountability between authenticated users is very limited and productive use of PT would require mutual trust between the users. Although, offline saving and capturing a Wireshark trace provide limited logging capability. While specific task evaluations can be automated using Packet Tracer's Activity Wizard, we were not able to find a practical method to account for every detailed student action in the multiuser network unless the PT traffic captured by Wireshark can be reverse-engineered.

Denial of service is possible because students can configure a Layer 2 loop between switches in PT which can affect the instructor side. Although technological solutions may be written and added onto the PT platform by using the included extensions interface. Due to lack of documentation and added complexity these resources were not considered when implementing module activities. However, if the activities are only used for participation and have a very small academic weight assigned to them, the risk for abuse is much lower than if the activities were worth a significant portion of the course grade.

Using multiuser mode restricts access to the simulation mode, which is available when PT is used offline. This problem restricts students' access to a very useful tool that visualizes many theoretical components of networking. In simulation mode the student can choose to view the level of information that makes them comfortable in understanding a topic. Although it may be possible to use simulation mode on a multiuser network, its integration may not be practical for application in a classroom. Moreover, since students learn at different paces, as activities get longer the gap between the fast and slow learners widens. As such, in our implementation we have limited the activities to 10-20min in length.

 ISBN: 978-1-61208-133-5

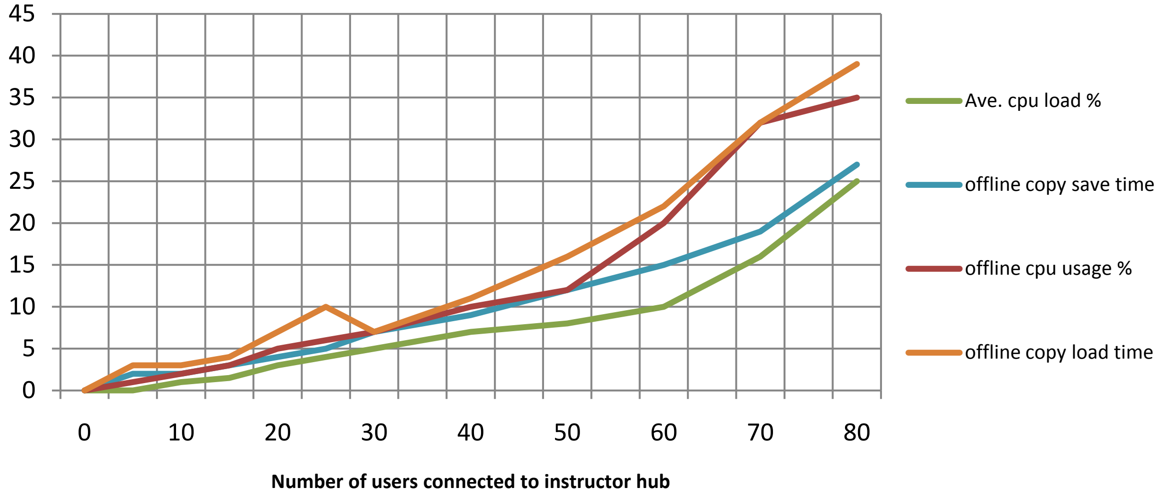

Figure 4: Packet Tracer scalability with 1 hub

Lack of commands is probably the most common limitation that will be encountered in designing multiuser activities. The level of commands is acceptable for a CCNA level at the student side. However to facilitate the large interconnected network, it often requires a CCNP level of commands on the instructor side. The level of complexity on the instructor side is also much higher than the student side, making troubleshooting more difficult. For example for a 60-student class activity: the instructor network makes use of about 60 VLANs that are used to assign different network addresses to each student. VTP will propagate VLANs when they don't have to be, and PT is limited in that you cannot turn on VTP pruning, nor turn off VTP. This often results in needless complexity in the way STP operates (PT by default uses PV-STP), and has on occasion unnecessarily blocked ports and caused loss of connectivity.

E. Exporting

PT is limited to interact only with devices that are simulated in the PT environment; external syslog servers cannot receive logs. Text, such as router configurations is the most easily exportable information, but not all devices have text interfaces. For example, DHCP servers that address all the VLANs can only be configured through a GUI. As such it can be more practical to build on prior versions of the instructor file rather than create a new one. Unlike GNS/Dynagen and other network simulators, PT cannot generate a network from a text file, nor export a network into any other format. The simplest way to save the work of a student is by using the offline saving feature on the instructor side.

IV. Scalability Testing

A. Methodology

A single prototype activity file was used for all the student connections, and a single instructor file was used that would accepts all the connections. Statistics about resource consumption were recorded by observing CPU, memory, and network usage as more and more students were connected to the instructor's simulated network. The hub was based on a school Lenovo T61p laptop (Core 2 Duo T8300 2.4GHz, 2GB RAM). The method of gathering the system information has its limitations in precision but portrays an accurate picture of the increase in system resources as the number of student rises.

B. Results

Several times the instructor file became unresponsive and testing had to be restarted. The growth for memory resource was very scalable to the amount of students. However, CPU usage and loading times grew at a greater rate

C. Discussion

In most cases for the instructor using more than 1 hub would greatly reduce the practicality of multiuser activities. As such, multiuser activities remain most practical in classes that have less than 60 students. Likewise, if classes are small, the requirements for reliability can be lower, as technological problems can be easily managed by the instructor.

 ISBN: 978-1-61208-133-5

V. Conclusions and Future Work

Networking courses that cover CCNA material suffer from having to cover a large amount of theory to students that may have little networking experience. In class lectures can be improved by using interactive activities that foster student participation. Multiuser achieves greater class interaction by allowing students to form what is essentially one large network supervised by the instructor. Unfortunately there is no library of multiuser activities provided by cisco, and the development rests with individual academies. UOIT research has generated 40 activities and 2 educational game activities to cover the CCNA material and provide greater class participation. The activities are implemented as short in-class exercises maximizing the benefit of real-time communication between student networks and working around multiuser limitations. Multiuser does not replace normal PT activities or lab time, and should not be used to significantly evaluate students.

Although PT multi-user activities experience some limitation when used over a WAN[5], as the tool matures multi-user activities may provide an additional level of interactivity for distance-learning. The multiuser architecture does not take account the capabilities of simulation mode and focuses on the real-time communication advantages offered. Simulation mode can offer greater understanding for students but is not fully integrated into multiuser.

Future work on the multiuser feature would have the most impact by improving the quality and user experience offered by multiuser activities. Other academies may seek to modify the instructions in order to change the difficulty of some activities. Student feedback is critical to effectively improving activities and bringing them up to the standard of activities offered by Cisco. In the meantime it is up to the instructor judgment to adjust the difficulty or instructions on the spot.

Various multiuser architectures may be attempted. In contrast to hub and spoke topology in use, ad-hoc PT connections are low resource and can make use of the simulation mode of PT. The problem with ad-hoc connection is that the instructor is not present to assist students and it is difficult to account for the activities completed. This may offer a different learning experience to the student. However user input would be needed for a successful implementation. The activity wizard provided by PT can be used to create more locked down activities for the student and may address certain security limitations. The challenge with using the activity wizard lies with the increased development time and the requirement to account and restrict/facilitate all the student actions that may occur in the activity.

CCNP level multiuser activities are possible as long as the activities are limited in the depth of the topic they attempt to cover. These activities would increase the complexity of the instructor network and be highly dependent on PT limited amount of commands.

Compared to regular PT activities, by being connected to the same network, multiuser allows students to collaborate and work towards a common goal. This allows the creation of activities that have before been impractical to implements, such as group troubleshooting, capture the flag, and relay race games. Under the right conditions PT multiuser activities can be used as another to aid in teaching networking and maintain student interest.

Acknowledgment

This research was supported through a 2010 Teaching Innovation Funding (TIF) grant from the office of the Associate Provost, Academic of the University of Ontario Institute of Technology. Packet Tracer is a product of Cisco Networks and is provided free of charge to Cisco Networking Academy students and instructors.

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