

Multuser Simulation-Based Virtual Environment for Teaching Computer Networking Concepts

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Abstract—In this research we focus on primary design principles for creating interactive activities and serious games based on Cisco Packet Tracer tool for the purpose of training in the field of Computer Networks. We present a general architecture for a library of simulation-based interactive activities and games for CCNA-level content. We demonstrate how students' skills in important networking topics such as routing, remote access and security help them succeed in these activities. We discuss various challenges in setting up efficient multi-user environments based on Packet Tracer, and propose solutions for a number of technical problems such as scalable addressing, VLAN handling, individual student monitoring, and offline exporting. Conceptual collaborative activities and their design principles are also discussed in this research. We also provide testing results to evaluate the performance of packet trace in an interactive multuser environment.

Keywords—component; IT learning tools; Serious Gaming; Cisco Networking Academy; Blended Learning.

I. INTRODUCTION

A. Background

Advances in personal computer technology, as well as widespread access to the Internet, have allowed development of new and more efficient approaches for teaching environments. Technology has greatly facilitated the transition from a traditional lecture-style teaching environment in which the teacher had the central role in educational activities and student were merely listener, to a knowledge-centered environment in which students are the main actors and share their process of learning while the teacher mostly plays the role of a mentor and facilitator [1]. Technology often becomes the main tool for creating such environment, and numerous researches have indicated that a technology-oriented, knowledge-centered environment increases student attendance, motivation and self-reliance in the learning process [1].

The use of technology in learning environments provides the opportunity to create virtual collaborative learning environments in which educational interactions between students occur in a designed information space [2] in form of shared online activities. Such interactions must have a carefully designed structure that would promote collaborations and provide incentives for specific learning achievements and milestones. Educational games (a.k.a. serious gaming), for instance, provide such opportunities. In particular, the maturing of the video gaming industry has triggered significant interest in developing simulated and interactive serious gaming platforms. The main advantage of

serious gaming platforms is that they combine in-depth educational topics with goal-oriented and realistic scenarios. To date there have been many applications of serious gaming, spanned over many industries, from urban planning to business, military, healthcare training etc. These applications have provided the means to an individual, or a group of individuals, to engage in an artificial conflict, assess, and learn the complexities associated with each of their individual area of work. Some real world applications of serious games include INNOV8 Business Process Management simulator by IBM [3], physical conditioning games for the general public, e.g. Fitness Shape Evolved for the new Microsoft Kinect hardware platform [4], Foldit for biologists [5], and flight simulator applications for the military [6]. Serious gaming has allowed users of the application to attain skills and knowledge related to a specific activity. The subject can be as difficult as addressing physical and physiological disorders, or be as simple as promoting physical activity. The main goal of serious gaming is to provide a powerful means of encouraging people to learn and provide them with a more entertaining way to obtain the skills and knowledge addressed by the specific serious gaming activities.

B. Computer Networks Training

Interactive learning is particularly becoming more prominent and shows great potential in teaching IT concepts [7] [8]. The introductory computer networking education in colleges and universities typically 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, various routing and switching protocols, and local and wide area network technologies. The sheer volume of technical details in this subject area 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.

In order to create the lab-like interaction in a classroom environment, e-learning tools based on simulation of components and networks have been developed to create a

virtual lab environment. The level of details for modeling each component in such simulators often depends on the desired knowledge and expertise level that the students are expected to achieve. One such tool in the field of computer networking is Cisco's Packet Tracer (PT) simulator [9] that provides a virtual network simulation environment with sufficient details of the network operating system on individual devices that would allow students to test and learn different scenarios in an environment that resembles a real computer network. The PT allows creation of realistic assignments for challenging students' knowledge of networking fundamentals, system configuration and network troubleshooting.

While PT has been used extensively in introductory networking curriculum of the Cisco Networking Academy, in particular for training of networking professionals for industry certifications such as Cisco-Certified Network Associate (CCNA) and Cisco-Certified Network Professional (CCNP) [10], its usage has mostly been limited to individual scenarios in which each student would install and run PT on his/her computer and work independently on the assignment or scenario. This restriction did not allow interactive collaboration among students or between students and the teacher, and thus limited the extent and effectiveness of the virtual learning environment. In 2008, Cisco added a multiuser capability to PT that allowed synchronization and communication between instances of PT that are running on different machines. This new feature has opened the door to develop many interesting new activities such as interactive and dynamic troubleshooting and serious gaming for introductory networking classes.

The objective of this work is to use the new multiuser feature in PT to create in-class interactive learning activities that would enhance students' understanding of complex networking concepts. The multiuser feature in PT allows the 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. The basic multiuser capability in PT merely allows connection of remote instances of PT on separate machines. However, proper design of the interconnected simulation environment and learning scenarios would require a number of technical and educational considerations that is the subject of this study.

C. Related Work

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 [11]. Their results offered an extensive guide to the multiuser architecture as well as the implementation of multiuser over the WAN and the inherent problems resulting from network delays and congestion. 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 [11] 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 [11] [12], 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.

Cisco has also developed a number of serious games for networking education. Most recently, Cisco ASPIRE Beta 4 was released in January 2012 [13]. This is a strategic game that utilizes the Packet Tracer platform to provide the players a role-playing/SimCity-like serious game focused on the business of networking. Players take on the role of a network engineer who applies his/her entrepreneurial and networking skills to complete several contracts that arise during the game. They must purchase the correct hardware and apply the correct configuration schemes in order to complete the contract. For the correct completion of contracts players receive credits which they can spend toward improving their network. Cisco Systems has also released Cisco myPlanNet 1.0 [14]. Players are put into the shoes of a service provider CEO. They must direct their business through various technological ages ranging from dial-up all the way up to the broadband/mobile connected ages. Along the way, players learn about the various technologies that make the networking world possible. The game provides a SimCity-like overlay where issues arise in the city and must be resolved. There is a credit system that players must use to purchase new technologies to advance their businesses and provide better services to the civilians in their cities. There is also a leaderboard to encourage players to attain higher scores and improve their skills. Additionally, Cisco provides many smaller serious games that allow users to improve their skills, such as: Wireless Explorer, Unified Communications Simulation Challenge, Cisco Mind Share, and Edge Quest. The objective of these activities is to provide players with a means to enjoy learning the complicating subjects related to the networking field, albeit on a smaller scale.

D. Contributions

This paper discusses in detail a project at University of Ontario Institute of technology (UOIT), Oshawa, Canada, to develop interactive learning modules and educational games using the virtual simulation environment of packet trace for use in introductory networking classes at the CCNA certification level. We provide the concepts, a client-server architecture and high level design for such activities. We also summarize technical challenges in efficient design and delivery of such modules, and propose methods to deal with them. We also measure the scalability of multiuser PT-based simulation environments, and provide performance results regarding CPU load, memory usage, offline saving time and network resource requirements for such deployments.

The rest of this paper is organized as following. In Section II a brief description of PT multiuser feature is presented and detailed specifications of the learning modules are discussed. In Section III we will have a close look at several technical challenges faced in building efficient interactive virtual environments based on multiuser PT. Our design for serious educational multiplayer games based in PT environment is discussed in Section IV. In Section V we present some extended features that can provide more efficient and comprehensive learning experience for networking student. An analysis of performance and resource requirements is presented in Section VI, and our conclusions and proposed future works are detailed in Section VII.

II. LEARNING MODULE SPECIFICATIONS

The problem of engaging students effectively in the process of learning is normally solved by using blended learning techniques that involve a hands-on approach, such as the PT simulator. However, current PT activities are highly scripted, having little interactivity and class participation. Multiuser activities would allow PT to be used in a more dynamic way, allowing the instructor to affect student's PT environment in real-time. Having multiuser activities as part of a networking course would fill a gap of short, interactive and extensible activities that can be used to promote student participation in lectures.

The multiuser feature in PT uses a proprietary application-layer protocol, PMTP [12], for communication between PT instances. A description of its operation can be found in [11]. PMTP uses TCP as its transport protocol.

The design of the PT-based activities in this work closely followed the framework described in the following. The activities are currently being integrated into the two introductory networking courses at UOIT that cover the CCNA curriculum.

A. PT Multiuser Environment

There are many operational differences between standard and multiuser CCNA activities, as outlined in [11] and described in the following. These differences create a whole new set of factors that has to be taken into account. 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.

PT allows users to use a simple drag and drop cloud icon to connect to peer clouds. Each multiuser cloud supports one-to-one, many-to-one and many-to-many peer-connection configurations. The activities that are created operate on a client-server environment in which most of the complexity and configurations are handled on the instructor side. The central file of the activity scenario is hosted on an instructor PC and the student side file is used by each student to connect to the central PT file hosted on the instructor PC. This instructor/student architecture allows for easy management and control, and provides an overall view for the instructor operating the activity. The multiuser capabilities of PT during testing allowed the connection of

up to 60-75 users simultaneously to a single activity over LAN.

UOIT has a laptop-based learning environment in which all students use pre-configured university-issued laptops in the classroom; this greatly facilitated the implementation and use of the instructor-student model. 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. Student-specific configurations or modifications must be kept to minimum. Figures 1 and 2 show examples of the activity files on the instructor and student sides.

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, personal computer or other device capable of running PT is required for each student. The requirements for the instructor computer depend on the number of students that are expected to connect and will be discussed later in this paper. The number of connections possible is directly limited by the hardware performance of the instructor PC. We will explore this limitation further in Section VI.

B. Multi-user Activity Specifications

To retain student attention, the multi-user activities and serious games were designed to be completed within 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:

- Minimal configuration or Pre-configured Student-side files
- Can be used to assess student progression
- Ensure maximum collaboration
- Task variety between activities
- Easy deployment in large user environments
- Scalability to ensure reusability
- Provide an educational experience

Serious gaming activities have to provide a psychological perception of having won or lost. The psychological perception of win or loss is one of the key elements that make up a serious game. The enthusiasm of a student is very crucial in a serious gaming aspect. It is an emotional driver that encourages students to improve his/her networking abilities in order to better compete against fellow classmates. Implementing this perception improves our chances of encouraging students to participate and learn the skills and knowledge needed to complete the activities and course material more efficiently.

A major limitation to utilizing the multiuser architecture is that PT's non-real time simulation mode cannot be

used during a multiuser session. This mode would allow students to analyze the traversal of packets through a network visually step-by-step. By eliminating the use of simulation mode we lose a valuable option but push the focus of the activities to the real-time interaction between the instructor and student networks further encouraging communication and collaboration.

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 or serious game, it is easiest to first export all configurations of each device into text, and edit the configurations using a text editor. This allows us to either erase the configuration in the old topology later, or load the new configurations. This was found to be the easiest method when altering the game scenarios of the serious games. One must be aware that certain configuration options (e.g. Virtual Trunking Protocol) are not saved in the running configuration and must be configured each time.

The intent of multiuser is not to replace the physical hands-on portions of networking within real lab environments. 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 in the simulation scenario, 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. DHCP mechanisms were implemented inside the simulator wherever possible to ensure that the automatic allocation of simulated IP addresses occurred. The IP addresses (i.e. subnets) that were constructed within the serious gaming activities ensured that a wide variety of network topologies could be supported. Therefore, IP address subnets and schemes could be left unchanged and designing new scenarios would only require changing routing protocols or other configuration parameters. This reduces the time it takes to produce new serious gaming activities, which generally take more time to create than the topic based in-class activities.

Simulated student devices can be assigned simulated IP addresses in a unique network depending on how the simulated Virtual LANs (VLAN) are configured. This feature allows students to configure routing protocols between each other. Alternatively, students can be split up into groups on different VLANs to assign them addresses accordingly.

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. For in-class topic-based activities, students were evaluated based on their

participation in the specific multiuser activity. The TCP traffic between PT instances is unencrypted and information such as hostnames can be found by capturing that traffic. Additionally, PT allows the ability to save an offline file. The offline file saves can be described as a snapshot of the entire network at an instance of time. The file consists of all of the peer connected multiuser clouds and each device in that peer cloud. The offline file saves also includes all of the devices current state, configuration, and connection status. Typically, during the setup phase of the activity students can be asked to name the devices which they configure with their student ID numbers. This method will easily help us later identify each remote student-side network in an offline save for evaluation purposes. The offline file proves to be a great tool to use when assessing the results of an activity or grading students depending on the configuration status of the devices they were responsible for. This method is used to evaluate a student performance on the two serious gaming activities in Section IV, but can also be used on the topic based activities if needed.

III. DESIGN CHALLENGES

In designing multiuser PT activities, several good practices were developed. The main principle is to maximize 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 relates to simulated MAC addressing and VLAN assignment within the PT environment. Layer 3 is responsible for the rest of the connectivity between PT environments such as simulated IP addressing and routing.

A. Layer 1 Issues

Documentation on how to setup multi-user connections between PT instances is readily available [9]. Connections between instances are done by matching IP address, port, specific cloud name, and password parameters from the instructor file. PT offline saving option accounts for the most overhead activity on computer and network resources. Remote student computers are polled at the same time when offline file saves occur. This results in bursts of traffic that is well handled over the LAN but may result in problems in WAN implementations, as reported in [11]. The serious gaming activities require extra explanation from the instructor on how to set-up the multiuser clouds. Each cloud within a serious gaming activity must be renamed specifically to a student name or ID so that the instructor can distinguish which users have successfully gained access into the instructor side network. PT traffic is unencrypted; so if necessary, useful information can be gathered by collecting PT the traffic data within Wireshark; this however can prove to be a difficult task to commit to for 60-75 students.

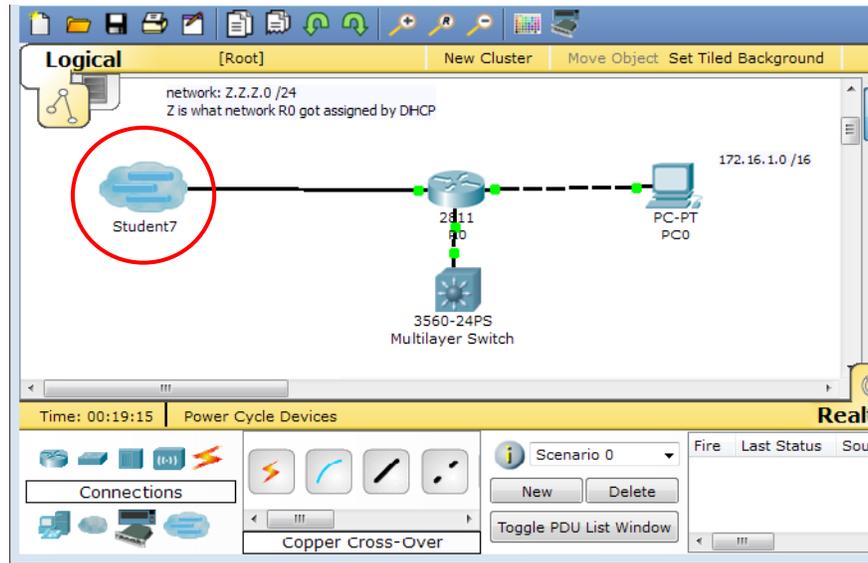


Figure 1: Example of a Student-Side Module

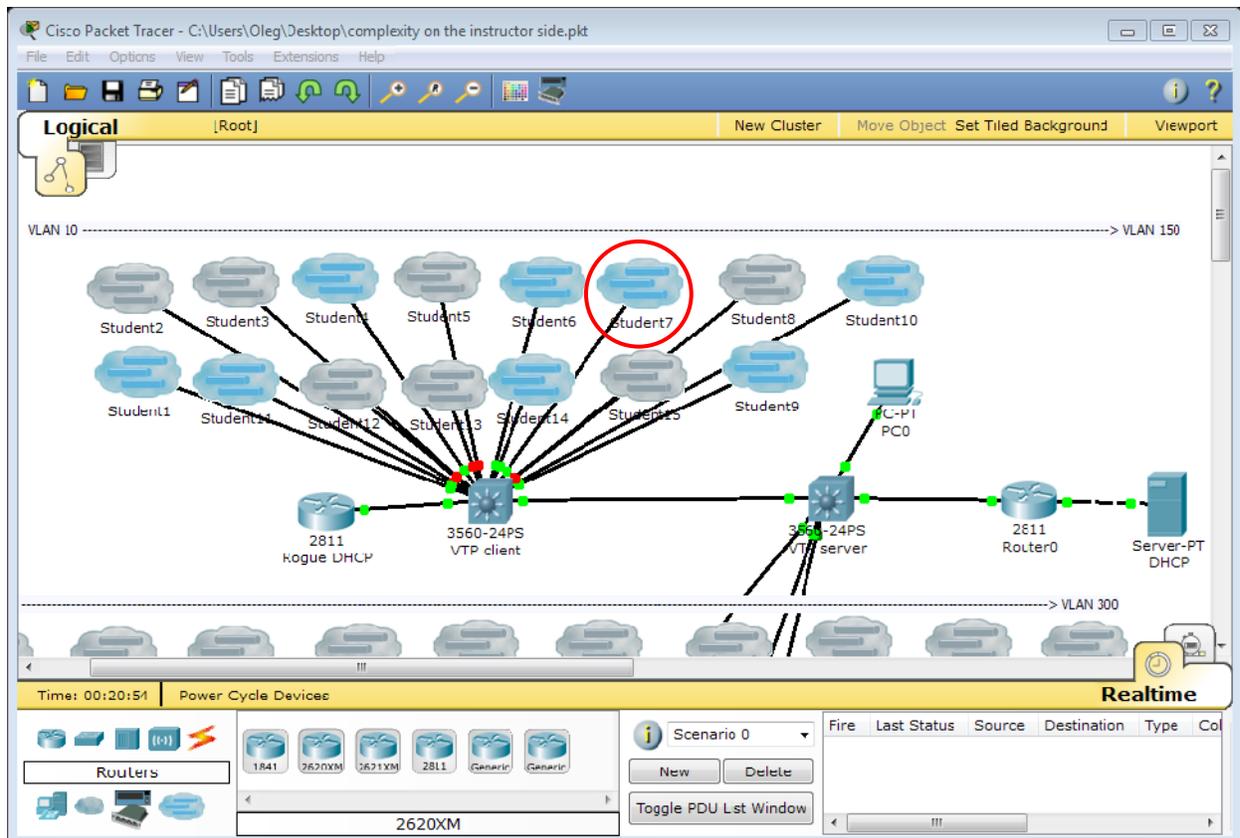


Figure 2: Example of an Instructor-Side Module

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 simulated 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 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 port gets blocked. There have been cases observed during testing periods when STP has behaved incorrectly and unexpectedly.

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` file (stores VLAN information) 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. Activities designed to explore the routing and WAN topics within the course did not encounter many Layer 2 issues. The instructor side file is almost identical for each routing scenario, every student was separated into their own VLAN and router-on-a-stick is used along with a topic specific routing protocol to allow communication between all student files.

The serious gaming activities focused on testing the ability of the students to troubleshoot layer 3, NAT, DHCP and other protocols. Layer 2 issues were largely avoided because creating layer 3 oriented problematic scenarios for students to solve was simpler and much more manageable.

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 issues should be resolved. While DHCP servers can be set up on routers, for classless networks the DHCP has to be setup on a separate server within the instructor file. Although DHCP is not intended to provide IP addresses to devices with identical MAC address, if layer 2 is problem-free otherwise, the only DHCP problems encountered can be solved by issuing DHCP release/renew commands. Instructor-side files for serious games usually have all of the devices that are needed within them, whereas topic based activities have topic related devices configured on student-side files and

devices that allow intercommunication between student side files on the instructor side. With this difference, DHCP services are configured inside each student's cluster within serious games. This ensures easy manageability and provides isolation of student clusters.

D. Scalability, Security and other Limitations

The scalability of the activities is limited. Within a 60 user activity session, the hub/instructor computer will be responsible for any bottleneck encountered. It may be necessary to split the class into a number of 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 the productive use of PT would require mutual trust between the users. Also, offline saving as well as capturing Wireshark traces provide limited logging capability. While specific task evaluations can be automated using PT's Activity Wizard, it is not possible to find a practical method to account for every detailed student action in the multiuser network unless the PT traffic captured by Wireshark is inspected packet-by-packet.

Denial of service is possible; 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 in this work when implementing module activities. The risk of such attacks also depends on the weight of the activity completion in the course grade; if these activities constitute a significant portion of the grade, security measures must be implemented in the activity design.

The limited scope of supported Command-Line Interface (CLI) commands in PT is probably the most common limitation that will be encountered in designing multiuser activities. The level of CLI commands is acceptable for a CCNA level at the student side. However to facilitate large interconnected network, it often requires a CCNP level set of commands on the instructor side, which PT often does not provide. The level of complexity on the instructor side is also much higher than the student side, making troubleshooting more difficult.

The lack of supported commands and the increased level of complexity on the instructor side files limit the creativity that can be expressed while constructing serious gaming activities. Serious gaming activities can only be constructed in linear fashion. The team attempted to explore the idea of creating a network traversal game but was restricted by the lack of logging and management capabilities of PT. Time limitations placed inferred that activities could not be too complex. The team also had to ensure that the educational content being delivered to the students was not beyond the scope of the course.

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 [20] 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. PT does however contain a logging services that logs all of the input typed into any device in no specific format that can be exported. This idea was deemed infeasible for our application and consumed too much time for a limited in-class lab scenario.

IV. SERIOUS GAMING ACTIVITIES

Each of the games presented students with artificial conflicts that resembled various real world networking problems that had to be fixed before achieving the game's end goal. Simulated DHCP mechanisms were used to provide each connected player with a set of unique IP address ranges for management and game play structure purposes. Each activity tested the configuration and troubleshooting abilities of the players while providing an educational experience that was novel and entertaining for the students. A detailed explanation of each game follows.

A. Domination Game

The game topology is broken down into four sections. Each section consists of layer 3 switches, multiuser clouds, and clusters. The Section switches all connect to a central Main Domination Switch. Each section consists of 15 cluster clouds and 15 multiuser clouds, all of which are connected to a Section Domination Switch, as shown in Figure 3. Each cluster cloud contains an identical network topology that presents students with a network problem. Each of the clusters have been assigned a /24 virtual subnet, from which the first host IP is assigned to the default gateway. Student side PT instances connect into the multiuser clouds assigned to them by the instructor. Multiuser clouds are distinguished by the Peer Network Name property within each cloud. The game is initiated by the instructor when all players have obtained a connection to the peer multiuser cloud. Once all students clouds are active, students begin by using the telnet protocol in PT to obtain access into their specific cluster.

1) Domination Gameplay

The student's main goal is to fix the network problems presented to them within their clusters. The problems within the cluster can vary in complexity. By solving their cluster problems, the students eventually gain telnet access into the directly connected section switch which enables them to shutdown all other interfaces except the interface directed toward the main domination switch. Once a student has

managed to dominate their sections switch, they must quickly telnet into the Main Domination Switch and shutdown the three other ports to block other section switches to telnet into the main switch. The first person to quickly dominate their section's switch and the main switch is the winner. The other three that have managed to dominate only their sections switch are runner ups.

The domination game comes with only one student side file that will work with all of the Multiuser clouds within the instructor file. The student file consists of a single workstation and a multiuser cloud to allow connectivity to the instructor file. By providing a standard student file with basic configurations already applied to the workstation allows for easy deployment in large user environments. Furthermore, virtual IP addresses are dynamically assigned by a DHCP server located in each cluster. Simulating DHCP on each cluster eliminates the need for students to configure an initial IP address to their student side PT Workstation.

The complexity of cluster problems that the students must solve can be increased as needed. Additional devices can be added within a single cluster and be duplicated easily across the clusters because of the easy IP addressing scheme. We simulated EIGRP protocol on the multilayer switches to allow virtual telnet capabilities to the students. IP addressing schemes were designed to be as simple as possible to encourage future development within the activity. The number of VTY lines available within each switch limits the section sizes to 15.

2) Domination Educational Value

The domination game allows students to experience the pressure sometimes put on network engineers in the real world environment. It forces students to apply all of their learnt networking knowledge to troubleshoot a problem. By gaining the ability to combine the hands-on and theoretical knowledge learnt throughout the introductory networking course, students will gain a better understanding of how to apply these skills and tools in the real world. Moreover, the game can also be used as an evaluation tool to see if the students understand the concepts delivered in the course.

B. Relay Race

Adapted from the original Relay Race game presented by Cisco, this Relay Race game incorporates new features. The topology is broken down into four sections, each consisting of five Main Line Routers, four network clusters and five multiuser clouds. The whole topology is brought together at a central Finish Line Router. Each cluster contains problematic network scenarios that students must correct in order to allow a Runner, designated in each team, to move closer to the Finish Line Router. The network scenarios within the clusters progressively become harder the closer the cluster is to the Finish Line Router. The five Main Line Routers act as doorways, locked, preventing the runner from moving forward. Figure 4 shows an overview of Relay Race topology.

1) *Relay Race Gameplay*

Although slightly more complicated, the concept of the game remains somewhat similar to the Domination game. Relay Race consists of 4 Teams each consisting of 5 team members. Each team consists of 1 Runner and 4 members responsible for solving the problematic network clusters. Once the problem within the cluster is solved they must move forward to their Main Line Router and no shutdown their routers Serial 0/0/0 interface. This will allow the runner of the team to telnet into their routers in order to move forward towards the Finish Line Router. Several access lists have been put in place so that only the appropriate hosts can telnet into the appropriate devices. For example, none of the team members responsible for solving cluster problems can telnet into the Finish Line Router; only the runner will be able to telnet into that router. The access lists also ensure that telnets to other Main Line Routers will only work from the Runner's Workstation on the student PT file. The Goal of the game is to have the fastest team to enable all of their S0/0/0 interfaces within the Main Line Routers. The Runner must then run (telnet) into the Finish Line Router before any of the other teams and shutdown all of the other interfaces to block the opposing teams' access to the Finish Line Router.

A common student file is used in this game and DHCP has been simulated in PT in a manner allowing the same file to be used among all multiuser peer-connection within the game. The instructor file contains the Relay Race game that students must telnet into. The students connect to the multiuser clouds according to the name of the cloud in correspondence to the role of the student within each team. By providing this instructor/student architecture we ensure easy deployment of the game during play time. The clusters problem can be easily changed if need be.

2) *Relay Race Educational Value*

Relay Race pits students together in a team environment where they must communicate and apply their skills to a problem. The activity will help hone communication skills and also improve the ability of the students to solve network problems. The game will force students to work rapidly and correctly to solve their problems the fastest in order to win. This environment emulates the fast paced environments of the networking world today, where problems arise quickly and must be solved rapidly. The game can also be used as an evaluation tool to see how far student's configuration and troubleshooting skills have progressed.

V. EXPLORING UNIQUE NETWORK ACTIVITIES

This section discusses some ideas for further development of PT-based activities.

A. *Network Traversal Activities*

During this project a small scale network traversal activity was created for one of the in-class modules. The unique PT activity required students to attempt to discover the network by using various telnet and show commands. The goal of the activity was to learn how to fix the router problems they encounter within a topology before moving forward. Most of the devices in the activity are hidden and cannot be accessed by double clicking on them

nor can be moved. The activity forces the students to use various CLI commands that are necessary to know at the CCNA level. Connectivity will be achieved when the lab is successfully completed.

A large scale version of the activity can be created to encompass multiple students. The activity can be presented as a race to the last node within the topology. Each node within the topology would include the privileged password to a router that would allow them to move to a different segment within the topology. The password can easily be stored within the description of a specific link or the router itself. Each segment within the traversal topology would present the racers with a problem that they must solve and traverse to each node within the segment using telnet/show commands. The concept will require an instructor file that contains multiple identical traversal networks. Each identical traversal topology would be assigned to a student and accessed via a multiuser cloud. The start of the race can be controlled by releasing the passwords to the first node to every student simultaneously at the beginning of the race. The main issue with this concept is that the instructors PCs will have to be computationally powerful machines to handle multiple, possibly 60, identical networks containing a minimum of 10 devices each.

B. *PT Plus Web App Activity*

A PT plus Web App activity is a conceptual activity that will be utilized for mid-term or final lab examination evaluation purposes. The concept also relies on a Web based application that has accounts for each student and can process multiple choice questions on it. Most universities utilize online student accounts managing system that can be utilized for this purpose. The concept is similar to network traversal in that at the end of each segment within a network traversal topology a password is given to the student that can be used to unlock a multiple choice question on the Web application as well as allow them to progress through the traversal topology. This way a student can be evaluated for their knowledge in practical configuration expertise as well as theoretical knowledge questions via the multiple choice answers.

This concept can also be used to deliver interactive labs that present students with a situation. The lab can progress online on the Web App as the students complete tasks within the lab. This type of activity is not a collaborative activity however it does deliver content in a different manner that can enable the possible creation of collaborative labs as future experimentation is done with the concept.

VI. RESOURCE REQUIREMENTS AND SCALABILITY

In order to test the scalability of the learning environment, the activities and games were deployed in an instructor set up with multiple multiuser PT clouds connecting to the instructor server and executing the activities from their side. Packet Tracer 5.3 was chosen as the platform for these activities.

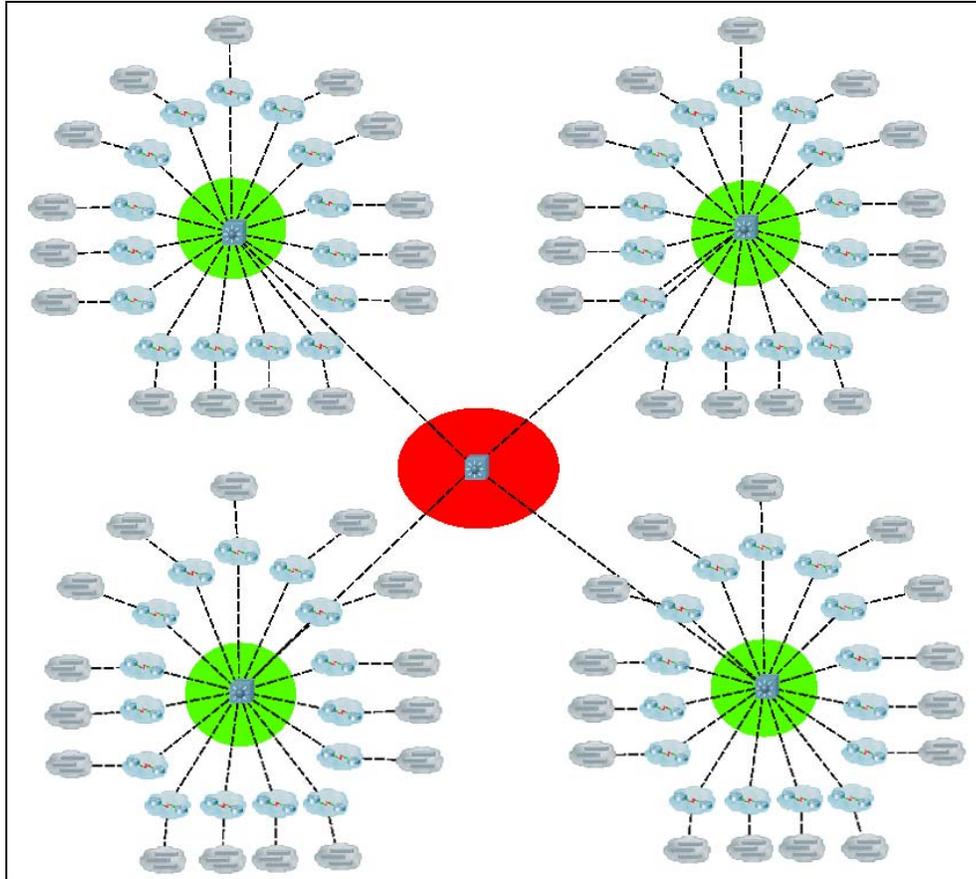


Figure 3: Domination Game Screen Shot

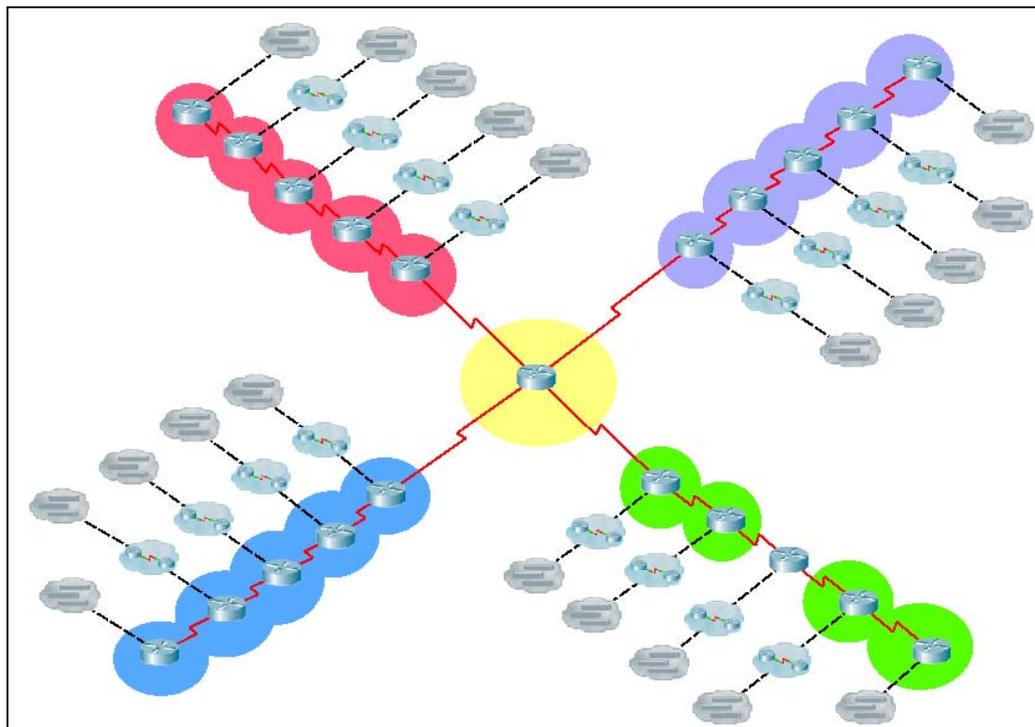


Figure 4: Relay Race Game Screen Shot

A. CPU load and offline save time

In this test case a single prototype activity file was used for all the student connections, and a single instructor file was used that would accept 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.

Figure 5 shows the CPU load and average save time. During this test, frequently the instructor file became unresponsive and the 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. As such, multiuser activities remain most practical in classes that have less than 60 students per instructor server. Likewise, if classes are small, the requirements for reliability can be lower, as technological problems can be easily managed by the instructor.

B. Scalability

Two sets of tests were conducted on each of the two activities instructor files. The first was done using the Domination instructor file and its companion student

file. The second was done using the Relay Race instructor file and its companion student file. During the testing procedure for the Domination game a total of 60 multiuser clouds were connected in increments of 5 users to the instructor file. Each time five users connected to the game, new data was collected. The Relay Race game has a maximum capacity of 20 users playing at the same time therefore, 20 multiuser clouds were connected to the Relay Race instructor file in increments of five users.

The results for this test were very satisfying for both of the activities. Figure 6 shows the CPU utilization for Domination and Relay Race. It is evident that as more hosts connect to the instructor files, the CPU utilization increases in a logarithmic form. This indicates that the instructor side was capable of handling higher levels of stress if need be.

Test results for both activities indicated linear growth rates in memory utilization. Figure 7 shows that growth rate for both the Domination activity and the Relay Race activity is linear as the number of users increases. Although memory is not an issue with 50 users connected to an activity, if we were to connect up to 100 or more users' memory could potentially become an issue. For our university use cases memory does not pose a threat to the functionality of our activities.

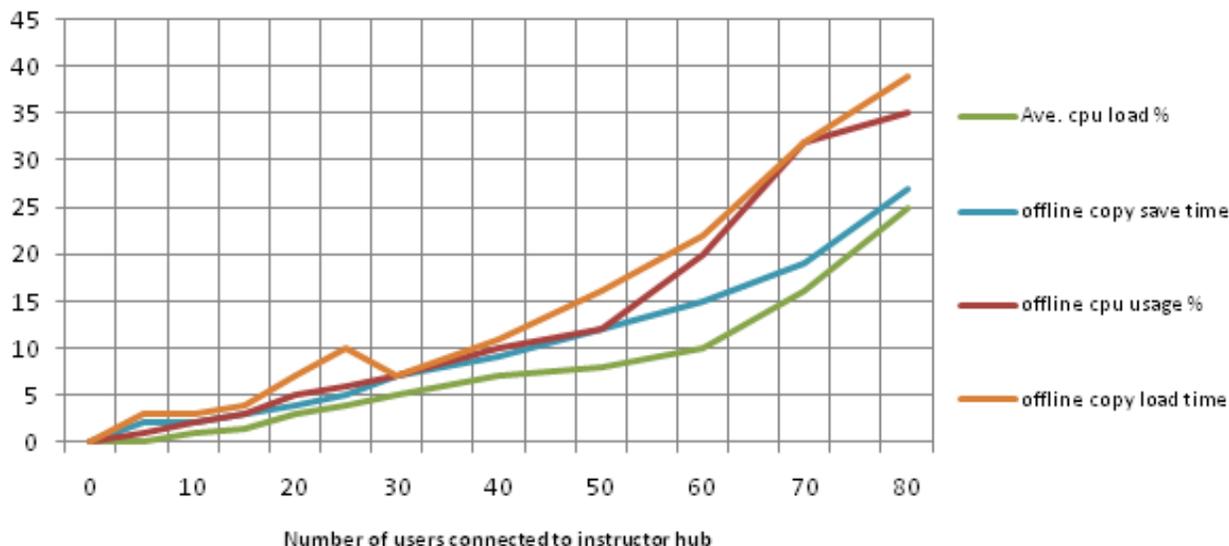


Figure 5: Packet Tracer scalability with 1 hub

We also measured the required network resource and bandwidth for these scenarios, and the test results indicated that the multiuser environment places minimal burden on network resources. It indicated that we could have a large number of users connected to a single instructor file without worrying about the network capacity and bandwidth. The network utilization test increased in a linear fashion and these values are bound to increase as the number of users increase. An important issue to note is that these values are bound to change depending on how actively the students interact with the instructor side network.

The offline file-save for recording students' works could potentially become a bottleneck issue. The offline file consists of all of the peer connected multiuser clouds and each device in that peer cloud. It also saves all of the devices current state, configuration, and connection status. Offline saving times of greater than five minutes for a 30 user Multiuser environment could render useless a 20-minute activity and a class room limited to an 80 minute class. Therefore it is important to test how long it actually takes to create the offline file. The results indicated that for the Domination activity the time to create the offline file grew exponentially. The Relay Race activity indicated a linear growth rate. The exponential growth rate for the Domination file could prove to be troublesome if more than 60 users are connected to the Domination activity. Currently it takes about 25 seconds for a 50 user multiuser environment offline file to save. Although it serves our purpose to provide 60 students a reliable platform to use the activity, connecting more than 100 users to a single instructor file could take much longer and may require multiple interconnected instructor servers. These values are bound to change if the complexities of the problems in each cluster are increased.

VII. CONCLUSION AND FUTURE WORK

Networking courses that cover introductory, CCNA-level course material usually have to cover a large amount of theory for students that may have little prior networking experience. In-class lectures can be improved by using interactive activities that foster student collaboration. Multiuser achieves greater class interaction by allowing students to form what is essentially one large network supervised by the instructor. Using the multiuser architecture we can also develop serious gaming activities that can provide a simple and entertaining solution to present complex networking scenarios to networking students enrolled in our courses. We can train students to not only improve their configuration and troubleshooting skills but also improve communications skills in an IT environment. We can also increase the speed at which they tackle these problems and provide them with the expertise and knowledge to excel in the fast paced networking environments of today.

In this project, we developed a set of modules containing learning activities and educational games based on Cisco Packet Tracer simulation environment for use in introductory networking classes. Along the way we faced and solved several challenges for efficient design of such activities, which we presented here as a guideline for creating efficient multiuser interactive modules in a virtual environment. Our results indicated that the proposed design can be used in medium size classes without the need for significant investment in servers and network resources.

Future work on the multiuser feature in packet tracer could improve 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 client-server 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.

In the meantime implementing some of the new ideas presented in section V may prove to be a challenge worthwhile. 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 implement, such as group troubleshooting, capture the flag, and relay race games. This research has shown the great potential of the topic and the educational values PT holds.

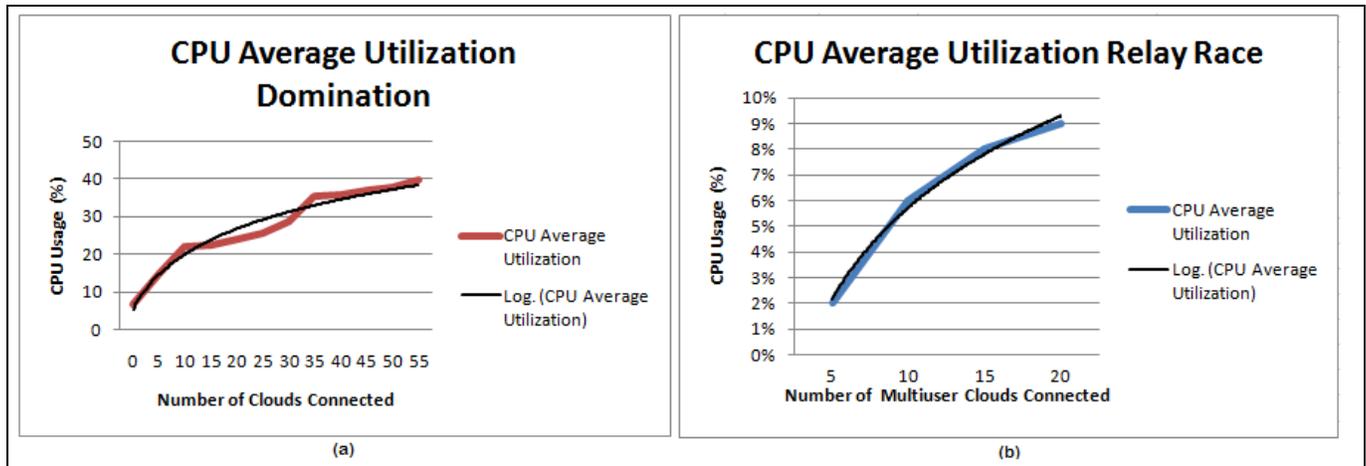


Figure 6: CPU Utilization: (a) Domination CPU Utilization (b) Relay Race CPU Utilization

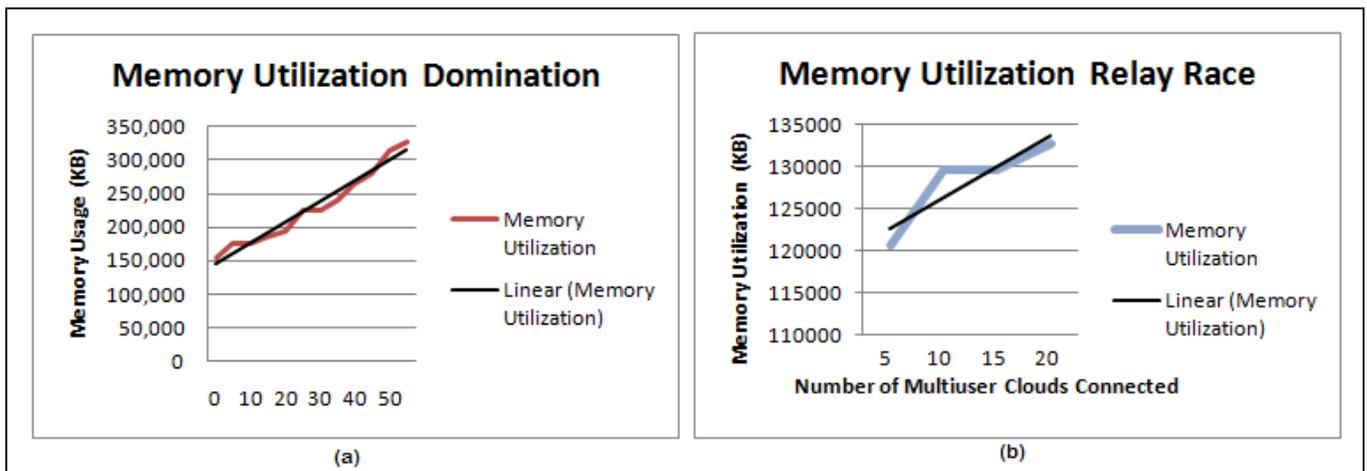


Figure 7: Memory Utilization (a) Domination Memory Utilization (b) Relay Race Memory Utilization

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