Kennesaw State University

Capstone Project Report

Network Simulation Software Analysis of Alternatives

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**Executive Summary**

The goal of this project was to research available networking simulators to find the one most appropriate for classroom usage. Four of the most popular networking simulators were researched and ranked using a vector shortest distance analysis method. After the most appropriate simulator was found, a guide was created for creating a small network using that simulator.

Four simulators stood out as potential candidates, Cisco Packet Tracer, GNS3, EVE-NG, and Cisco Modeling Labs. 25 requirements were created by the project team that were then ranked by the project sponsor in order of importance. The project team then tested each of the four simulators against each of the requirements and ranked them using the cosine similarity function.

It was found that Cisco Packet Tracer was the simulator that most met the requirements, primarily due to it being freely available and not requiring any non-freely distributable software images, which were the highest ranked requirements. Compared to the other simulators, Packet Tracer feels tailored for educational use and not enterprise-level network modeling.

Using the experience gained during the research phase and prior experience of the team members, a guide on setting up and creating a small network with Packet Tracer was created. This network has three sites, each with individual VLANs (Virtual Local Area Networks) dividing the network. IPv4 and IPv6 routing was set up to connect the sites.

In conclusion, Cisco Packet Tracer would be a great tool to use for classroom use. It would bridge the gap between conceptual and real-world networking and give students a potential pathway for learning real-world networking. This knowledge is crucial for helping the student enter the workforce after graduation.

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# Project Background

Computer networking is a complex and complicated field. It is one of the core tenants of Information Technology. It is also difficult to introduce real-world networking experience to a classroom environment. Because of this, networking simulators are a method to introduce these concepts to students and give them hands-on experience in addition to the conceptual experience gained during traditional lectures and exercise.

The primary goal of this project was to research the various networking simulators that are currently available. The project team would use these simulators to create a small routing and switching based network in order to test their features and efficacy as a classroom tool. The final simulator would be decided using vector similarity methods against a list of requirements created by the project team and then ranked by the project sponsor. After the most appropriate simulator was chosen, the team would create a guide on creating a network with the chosen simulator using switches, routers, and both IPv4 and IPv6 addresses.

# Project Outcomes

## Initial Simulator Selection

**Packet Tracer – Initial Summary**

**Initial Pros**

Cisco Packet Tracer is a network stimulation tool that helps the user to exercise networking skills in a virtual environment. With the help of Packet Tracer, users can simulate and test both simple and complicated networks. It is available for free after signing up for the Cisco Networking Academy. The company provides an E-learning course which provides step by step guidance from installing the product to having 8 hours of video teaching. Microsoft Windows 8.1, 10, 11 (32 bit and 64 bit), Ubuntu 20.04 LTS (64 bit), and macOS 10.14 or later are all compatible with Cisco Packet Tracer 8.2. (64 bit) (*Packet tracer FAQS,* 2022). Multi point-to-point (peer) connections between various Packet Tracer instances are made possible through multiuser communication. Regardless of location or the academic environment, multiuser functionality enables academic institutions and students to construct environments that are interactive (Smith et al., 2010). A new path has been opened to an enjoyable, interactive, social, cooperative, and competitive learning environment by enabling communication between Packet Tracer instances. The CISCO platform provides a community forum to reach out for help from the experienced users of the product.

**Initial Cons**

Cisco Packet Tracer uses proprietary software source code which means it is owned by Cisco. This means that it cannot be modified to accommodate user preferences. The older version of the Packet Tracer is not available in the market to download so running an activity created on older versions in newer versions might restrict the use of features. As Packet Tracer is a widely chosen option for learning the fundamental principles of networking there is no higher expectation in comparison to paid tools.

**GNS3 – Initial Summary**

**Initial Pros**

GNS3 is a network emulator that can run the actual software images meant to run on real hardware. It is free and open source. It can also run operating system images like Windows and Linux. Because of this, GNS3 is an extremely accurate simulator. “GNS3 supports more device commands and parameters. Since GNS3 directly runs the IOS of Cisco network equipment, it is equivalent to the entire system simulating the whole hardware equipment, which is the same as the command of the real equipment” (Liu et al., 2019). Because of this, GNS3 can be used to create extremely accurate networks with hardware from multiple vendors. This could provide students with skills that could be transferred to real-world applications.

**Initial Cons**

GNS3 can be a computationally intensive platform as it must use virtualization to emulate the software images. “GNS3 runs multiple network devices and other virtual systems on a single physical computer, taking up a lot of memory and making the entire computer less efficient” (Lie et al., 2019). This could be a barrier for students with older or less powerful hardware. Testing will be performed to test how well the software can run on these systems. There is also concern as to how certain software images could be used without breaking the EULA of the creator. While GNS3 is distributed under the open-source GNU GPL license, the software images may not be, and distributing them or using them in a manner not approved by the creator could have potential legal ramifications.

**EVE-NG – Initial Summary**

**Initial Pros**

EVE-NG is the first clientless multivendor network emulation software that empowers network and security professionals with huge opportunities in the networking world. There is a free and paid version of this software, and it supports Windows, macOS, and Linux. It also supports Cisco, Juniper, Check Point, Palo Alto, F5, and many more. EVE-NG allows you to reproduce and improve your real architecture in a safe environment without having to touch your real network easily and quickly. It uses a full HTML5 web interface and is simple and fast. EVE-NG offers emulation and virtualization as a service.

**Initial Cons**

The free version has fewer features than the paid version. Also, there are no links other than ethernet available, no fiber or serial links, and it does not supply any software images. The document is difficult to navigate as well. Like GNS3, EVE-NG requires images from other vendors like Cisco and Juniper to have full functionality. Without these images, EVE-NG is severely limited in features and functionality. In addition, because it also uses virtualization to run the software images, lower powered devices could have issues running many lab scenarios.

**Cisco Modeling Labs Initial Summary**

**Initial Pros**

Cisco Modeling Labs is a network emulator made by Cisco Networks, who also developed Cisco Packet Tracer. Like the other two emulators, GNS3 and EVE-NG, Modeling Labs uses software images derived from actual hardware. Unlike the other emulators, Cisco Modeling Labs includes system images for several classes of Cisco devices, including routers, switches, and firewalls. In addition, it also includes images for more advanced devices, like the Cisco Nexus line of datacenter switches. Also included are several endpoint image files based on several different distributions of Linux like Ubuntu and Tiny Core Linux. Modeling Labs runs as a server in a virtualization platform like VMware or VirtualBox.

**Initial cons**

The primary con now is that Cisco Modeling Labs is not a free product. The most basic version is $199 for an individual license that allows the creation of up to 20 running nodes in a network at once. This limitation provided just enough nodes for the test environment. Larger networks cannot be created with the individual license. Enterprise and higher-education options are also available that allow for up to 300 nodes with multiple users able to collaborate on projects. Like other emulation-based systems, there is also concern about resource usage. Paraphrasing from Cisco’s system requirements, the Modeling Labs VM requires at least 4 CPU cores and 8GB of system memory. In addition, only Intel CPUs are officially supported. For enterprise and education options, Cisco only officially supports using their own UCS line of servers (*Cisco Modeling Labs - System Requirements*).

## Testing Methodology

The project team produced 25 features to test each of the simulators against. Each of these were presented to the project sponsor who ranked them in order of most desired to least desired. This ranking was then used to assign a weighting to each feature so that a simulator best matches the project sponsor's needs could be chosen.

For testing purposes, a simple network was created in each simulator. The test network was a routing and switching style network with three physical branches, each having multiple subnets divided into separate VLANs. Inter-VLAN routing was enabled to allow devices at the same branch to communicate while on different subnets. The three branches used static routes to communicate with one another.

## Test Results

**Experience with Cisco Packet Tracer:**

Cisco packet tracer is an immensely popular network simulator that is useful even for beginners. The software has useful tools that allow the user the ability to design a network using simulated Cisco devices. Users can configure routers and switches in the same manner as real-world hardware. The simulation abilities can aid in the simplification of the education process by giving added functions like packet route, which allows the user to track a simulated packet as it travels throughout the network while viewing all the detailed protocol data. Packet tracer is available for both Windows, Mac, and Ubuntu based devices and was light on system resource usage. Packet Tracer enables the teaching and learning of sophisticated technological concepts through simulation, visualization, authoring, assessment, and collaborative project. Compared to the other simulators, Packet Tracer seemed tailored specifically for education and not high-level modeling of real-world networks with all their complexity, making it an excellent choice for classroom use.

**Experience with GNS3:**

Installing GNS3 required the installation of a virtualization platform like VirtualBox or VMware Workstation to run the GNS3 server instance. In addition, the GNS3 client also needed to be installed to access the server. This was a complicated process that could have the potential for many user-experience issues. After installation because of the limitation of not using Cisco IOS or Juniper software images, the functionality of GNS3 was severely limited. Apart from the included non-managed switches with limited functionality, only open-source routers and switch images based on BSD were available. The team concluded that without Cisco IOS or Juniper images, GNS3 is impractical as a network simulator as the open-source BSD-based routers and switches are difficult to use and do not resemble the real world. GNS3 is a would be a suitable choice for those who have access to the proper images for modeling real networks, but its functionality for classroom use seems to be lacking.

**Experience with EVE-NG:**

EVE-NG is one of the most popular and widely used network simulators in the Information Technology industry. Conceptually, it is remarkably similar and uses the same underlying technology as GNS3, and thus has many of the same limitations. It must be installed as a server that virtualizes network device images. This comes with the increased system overhead and requirements. Unlike GNS3, EVE-NG does not need a separate software client. The system is accessed through a web browser. Testing was done using the free community version. There is also a paid version that offers several features that make it more appealing to those who will have multiple users accessing a single server instance. While EVE-NG is overall more elegant than GNS3, it has the same core limitations and issues that will hurt its ranking in several critical areas.

**Experience with Cisco Modeling Labs**

Compared to the other network emulators, Cisco Modeling Labs resulted in very few issues, owing to its background as a commercial product. Like the other two networking emulators, Cisco Modeling Labs requires a virtual machine to act as a server. Initially VirtualBox was used, but issues installing let to using VMware Workstation Player instead. Without the requirement to source images that would not be legal to distribute to students without potentially breaking any license agreements. The sample network was able to be modeled without any issues. Virtually all requirements were met to some degree. The primary limiting factor that hurt its final score was the price compared to the other simulators. Also, even the small network used for testing ran close to the limit of 20 nodes for an individual license. Though the official Cisco requirements list potential issues with AMD CPUs, no issues were found using an AMD Ryzen 1700X CPU for the lab. However, Cisco Firepower and Cisco Nexus images were not tested, which could be areas where AMD CPUs have issues.

## Testing Results

The team was supplied a ranking of each of the 25 requirements from the project sponsor. The team then gave each requirement a score of 1 to 10 for each simulator (See Appendix A). The requirements rankings and the scores of each of the simulators were mapped into separate arrays to be treated as vectors with each of the values as integer vector components. A python script was written to use cosine similarity logic to compare each of the simulator vectors against the ranking vector (See Appendix B). Rounding to two significant figures produced the following ranking:

* + Cisco Packet Tracer: 0.90
  + Cisco Modeling Labs: 0.85
  + GNS3: 0.81
  + EVE-NG: 0.77

From this result, it was clear that Cisco Packet Tracer most aligned with the project ranking. Its free cost and lack of requirements for non-freely distributed software images appears to be the primary factor that led to its higher ranking over the other simulators.

## Simulator Guide Creation

After the test results were confirmed, the team began work on creating a guide for Cisco Packet Tracer. This guide was divided into five individual labs, each building on one another to a final network. The overall structure of what the lab covered was provided by the project sponsor and finalized in the initial project plan. A small network with routers and switches using both IPv4 and IPv6 addresses would be created through the guide (See Appendix C for a list of all files).

The first lab covered the basics of navigating and using Packet Tracer as well as a gentle primer into the Cisco CLI and its various command modes, which would have the potential to be the biggest hurdle for new networking students to overcome. It also covered general usage of the virtual PC devices that will serve as the endpoints in future labs.

The second lab covered data-link layer switching. The student is guided through creating a small lab with a single switch and several PCs. The student assigns an IP address to each of the PCs so that they can communicate and how to view the switch CAM table. The student is then guided through using the simulator feature of Packet Tracer to view traffic as it traverses this network, including ARP traffic flooded to all MAC addresses and ICMP ECHO packets sent to single devices.

The third lab covered more advanced switching and network segmentation through VLANs in order to break up broadcast domains in the network. This lab is where the final network topology is essentially created. The student is walked through creating VLANs on the access and core switches and how to create trunks, so all VLAN tagged traffic is passed between switches. Finally, the student is instructed on enabling inter-VLAN routing on the network core to allow the devices on different VLANs to communicate with one another.

Labs four and five each cover static IPv4 and IPv6 routing respectively. The student is walked through adding routers to each of the physical network sites and how to connect them together and to the three network cores. The student is guided through assigning the links IP addresses and then creating various static routes, including default routes from the core to its respective router and static routes from each router to the two other sites in the network. Both labs were essentially the same with the only key difference being the addressing schemes.

# Project Planning summary

## Overview

Project planning was done using a traditional Gantt chart using Microsoft Project (See Appendix D). A significant weakness was the lack of an Office 365 version of Microsoft Project that made collaborating on the project management documents difficult. A cloud-based project manager could have been a better choice.

## Project Process

Project planning phase - During this phase, the team reviewed the project and created the initial project plan. The team decided how they would collaborate and learned initial strengths and weaknesses in addition to any prior or professional experience that would benefit the project.

Milestone 1 – During this phase, the team researched the various networking simulators on the market to decide the ones to test. This was the most traditional research focused stage of the project as it relied on a significant amount of industry research. In addition, the team created the 25 requirements sent to the project sponsor for ranking. This stage also saw the beginnings of the final project report.

Milestone 2 – During this phase, the team installed and researched the individual simulators. An early issue early on was that NS3, a first simulator choice, was so wrought with issues that it was removed as a candidate and replaced with Cisco Modeling Labs, which was initially not considered as a paid product. The team ranked the various simulators and compared them using the cosine similarity function, which required added research to understand and be able to implement using a Python program.

Final Milestone – During this phase, the team completed the networking simulator guide for Cisco Packet Tracer. The guide was divided into five labs, each written by one of the team members. This section required the more experienced team members to help the less experienced team members with their lab sections. In addition, the C-Day documents and presentation were completed as was the final project report.

## Work Contribution Summary

Justin McCannon – Team Lead and project manager, Networking Specialist, Web Development, Cisco Modeling Labs testing, Advanced switching Lab creator.

Nidhi Marsonia – Cisco Packet Tracer testing, Into to Packet Tracer and Cisco CLI creator, document editor.

Michael McInnis – Cisco Packet Tracer testing, IPv4 Routing lab creator

Tiffany Nguyen – GNS3 testing, Basic Switching lab creator, presentation creation

Azm Uddin – EVE-NG testing, IPv6 routing lab creator, networking specialist

# Team Reflection

## Project Success Factors

One key factor that led to this project's success was the varying levels of experience throughout the team. The team members with experience working with real-world networking equipment provided their expertise throughout the project. Likewise, those with less experience were able to find areas that may have needed more explaining as their experience was closer to that of the target audience for the final guide. In addition, the detailed amount of research, both preliminary and hands-on, that went into deciding and testing the simulators meant that there was little dispute about the final simulator selection.

## Collaboration and Communication Experience

Most day-to-day communication was done using the GroupMe instant messaging service. This provided a quick and easy way to send messages and small files or screenshots. For the twice weekly meetings, the team used Microsoft Teams. This allowed for more direct communication and screen sharing for situations that required more direct collaboration between the team members. It also allowed the group to do group presentations, though this feature made screen recording difficult. Office 365 and OneDrive were used extensively to collaboratively work on documents and share files and resources.

The team generally met twice a week for anywhere from 10 to 30 minutes on Microsoft Teams depending on what needs to be discussed or if there were any issues. Meetings were more frequent during milestone deadlines and before the final deliverables where meetings were held every evening. Overall, this meeting schedule seemed to strike a good balance where the team was up to date on progress without feeling as though the meetings were overwhelming.

## Challenges

Most of this project's challenges were largely due to online education. Most of the team members lived far enough away from one another that in-person collaboration was impractical. In addition, several of the team members have full-time careers which caused occasional scheduling conflicts. The issues with distance were largely corrected though the use of Microsoft Teams, which made distance collaboration significantly easier.

Regarding challenges during the project itself, the choice of networking simulators available was much smaller than initially predicted. Many are more tailored to accurate modeling of real networks in the enterprise or for more low-level research applications, like NS3. In addition, GNS3 and EVENG needing software images that the team did not have access to meant that their functionality was severely limited and made them difficult to accurately assess.

Regarding writing the simulator guide, the experience discrepancy between the team members caused some challenges as the more experienced members did not consider the lack of experience of some of the other members. Ultimately, the more experienced members worked with the less experienced members to help them work through creating the lab and teaching them the foundations of working with networking in a Cisco environment.

## Areas to Improve

The largest area where improvement could be gained was through improvements in writing and editing. Many of the written documents produced could have been greatly improved using proper editing techniques and by having more team-members read and check documents for any issues earlier in the project lifetime could have prevented some potential issues a the eleventh hour.

In the area of project management, stricter adherence to the Gantt chart would have made many aspects of the project go more smoothly. While no part of the project ever fell behind and all milestones were met on time, the actual work that assets performed often never fully aligned with what they were allocated in the Gantt chart.

# References

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*Cisco Modeling Labs - System Requirements*. Cisco Developer. (n.d.). Retrieved November 19, 2022, from <https://developer.cisco.com/docs/modeling-labs/#!system-requirements>

Liu, S., Wang, H., Liu, J., & Xian, M. (2019). Feasibility analysis of network security teaching platform based on KVM and GNS3. *2019 International Conference on Information Technology and Computer Application (ITCA), Information Technology and Computer Application (ITCA), 2019 International Conference On*, 310–313. https://doi.org/10.1109/ITCA49981.2019.00075

“Packet tracer FAQS,” *Cisco Networking Academy*, 17-Aug-2022. [Online]. Available: <https://www.netacad.com/courses/packet-tracer/faq#:~:text=Computer%20with%20one%20of%20the,GB%20of%20free%20disk%20space>. [Accessed: 25-Sep-2022].

# Appendix A

simulatorResults.xlsx - Full simulator results as a Microsoft Excel Document

# Appendix B

cosineSimilarity.py - Python file used to perform Cosine Similarity Calculations

# Appendix C

Below is a list of all of the simulator guide files for the final deliverable in the project folder.

Simulator Guide Lab1 - Intro Packet Tracer.pdf

Simulator Guide Lab 2 - Basic Switched Network.pdf

Simulator Guide Lab 3 - Advanced Switched Network.pdf

Simulator Guide Lab 4 - Static Routing.pdf

Simulator Guide Lab 5 - Static routing with IPV6.pdf

# Appendix D

Project Management Files

Project Plan revised 10-23-2022.docx – Updated project plan

Gantt chart - project 18 - fall 2022 revised 10-23-22.pdf – Updated Gantt chart