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Hardware-Free Network Internals Exploration:

A Simulation-Based Approach for Online Computer Networking Course

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ABSTRACT

In undergraduate computer networking courses, the ideal scenario involves demonstrating network communications with multiple interconnected computers and a packet sniffer tool. However, practical challenges arise when attempting hands-on exercises, such as accessing or reconfiguring physical computers for online networking practice. Additionally, certain network concepts, like routing and switching, are typically discussed theoretically due to the limitations of observing external network packet transfers and the constraints faced by institutions in maintaining the necessary hardware for hands-on practice. This paper introduces a simulation-based approach to facilitate the teaching and learning of computer networking internals in an online environment, eliminating the need for dedicated hardware devices. The paper outlines various simulation activities and experiments designed to assist instructors in teaching and enable students to explore these internal networking concepts effectively.

KEYWORDS

Computer Networking, Network Internals, Online Environment, Routing and Switching, Simulation

INTRODUCTION

In computer networking courses at undergraduate level, the traditional teaching and learning method involves connecting several physical computers to form a small Local Area Network (LAN). Packet sniffer tools, such as Wireshark software (Wireshark Foundation, 2024), are then installed on those computers to capture networking packets within the small LAN, helping students comprehend networking abstractions in a visualized way. However, the internal processes of computer networking, such as how networking packets are forwarded within internal network locations and routed over the Internet, are usually discussed theoretically with little or no hands-on practice due to several reasons, including students cannot directly observe how networking packets are transferred across the internet due to security concerns and infrastructure limitations, and maintaining a dedicated LAN can be

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costly and resource-intensive for schools, making it challenging for some institutions to implement this traditional teaching and learning method.

As online teaching and learning has surged in recent years and has become the lifeline of education during the COronaVIrus Disease of 2019 (COVID-19) pandemic, the traditional methods of in-person instruction have faced significant hurdles. Even with the reopening of higher education institutions in many regions after the pandemic, a substantial number of courses continue to be offered online or in hybrid (half online half in-person) formats. In the authors' state, public universities and colleges offer many courses in these two modalities. This shift has presented unique challenges for teaching subjects like computer networking, which traditionally relies on hands-on labs and practical exercises involving physical network setups, but now becomes impractical in the online environment. In a traditional classroom setting, students can connect their computers to a dedicated LAN and engage in activities like packet sniffing, device configuration, and troubleshooting network issues firsthand. This immersive experience allows them to visualize and understand abstract networking concepts in a tangible way. However, replicating such a setup in the online environment is cumbersome, and rewiring devices remotely, let alone practicing those networking internals discussed above, is impossible. These limitations of online teaching and learning environments pose significant challenges for instructors teaching computer networking courses. Traditional labs and exercises must be redesigned or replaced with alternative approaches that can effectively simulate real-world network scenarios and provide students with the necessary hands-on experience. This necessitates the development of innovative online experiments and interactive simulations that can bridge the gap between theoretical knowledge and practical application.

This paper addresses this challenge by proposing a simulation-based approach for teaching and learning those network internals, such as routing and switching, Address Resolution Protocol (ARP) internals, and packet metadata alteration during transfer. We begin by conducting a comparative analysis of several popular simulators and identifying the one that demonstrably excels in simplifying and visually illustrating those network internals. This chosen simulator then serves as the foundation for our proposed approach, which is specifically designed to facilitate effective teaching and learning of network internals within the online environment. By seamlessly merging theoretical knowledge with hands-on experiments, this simulation-based approach empowers students to grasp network internals in online environment without requiring or accessing dedicated hardware devices, paving the way for a more accessible and flexible approach to computer networking education.

LEARNING OBJECTIVES AND SIMULATOR COMPARISON

Table 1 outlines the specific learning objectives related to the network internals our approach targets. In our undergraduate-level computer networking course, students learn and practice the layered architecture and protocols of the Internet model, gaining an understanding of network fundamentals, the Internet protocol suite, routing and forwarding principles, and the socket Application Programming Interface (API). Access to dedicated hardware devices for teaching and learning those network internals poses a significant challenge in both traditional LAN-based and online environments. Network simulators address these limitations by providing a versatile and accessible platform for visualizing these internal processes and enriching student learning.

We evaluated several free network simulators to identify the most suitable one for our simulation-based approach in online environments. Our focus lies on simulating functionalities within the link and network layers, addressing crucial network internals often overlooked for hands-on practice in traditional in-person courses. Students in traditional courses often take for granted the seamless operation of these "lower layer" internals, assuming they simply "work perfectly" all the time. A profound understanding of these foundational internals enhances comprehension of the entire network communication architecture, while also equipping students with essential skills for tackling