Mesopotamian Journal of Computer Science
Vol.2024, **pp.** 176-203
DOI: https://doi.org/10.58496/MJCSC/2024/015; ISSN: 2958-6631
https://mesopotamian.press/journals/index.php/cs/about

Review Article

Computer Networking and Cloud-Based Learning/Teaching Environment Using Virtual Labs Tools: A Review and Future Aspirations

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ARTICLEINFO

Article History
Received 25 Aug 2024
Revised 26 Sep 2024
Accepted 25 Oct 2024
Published 24 Nov 2024

Keywords
Automatic elasticity
AWS
Amazon machine image
Computer education
Laboratory networks

ABSTRACT

Physical laboratories for practical classrooms in computer networks can be prohibitively expensive, as well as requiring regular hardware/software upgrades. With Netkit and similar software, network laboratories can be set up in a computer lab, but the setup is complicated and each student still needs their own computer. Thanks to the Cloud-based infrastructure, Netkit is now available in pre-configured Amazon elastic compute Cloud (EC2) instances. This research reviews and introduces educational computer networks. Furthermore, a web interface is used to allow remote access to numerous lab scripts instantiated on the Cloud. This study also describes how to use the Cloud to set up and access Netkit, which is open-source and free, but only supports Linux computers. By hosting Netkit in the Cloud, where it can be accessed from any Internet-connected device regardless of the user's device or operating system (OS), we have made Netkit portable. It was shown how the Cloud architecture of Amazon web services (AWS) holds NetKit-capable virtual machines that instructors and students can create on demand. This eliminates the need to set up specialised labs and enables students to gain practical experience with the principles presented in seminars on computer networks from any Internet-connected computer. Two other Cloud selling advantages are scalability and on-demand pricing. The horizontal elasticity of the Cloud service allows the system to be replicated to serve a much greater demand from users, so we need not worry about its physical configuration/structure. In addition, there is no need to worry about being charged for time not used. Finally, this research provides perspectives, obstacles and open issues that could present useful information for researchers in future studies.

1. INTRODUCTION

The decision to teach a specific subject/topic on a computer network can be difficult for teachers across the country. The predominant theoretical course is complemented by programming practices that provide additional, albeit incomplete, information about the challenges involved in telecommunications and the Internet. Education institutions lack specialized laboratories. When a instructor or teacher is not present to assist with tasks in distance education, this difficulty is greatly exacerbated [1]. Due to previous experiences with technical components in teaching informatics, evaluations

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of the teaching-learning process show lower levels of success. The teaching of computer networks is also affected by two significant factors that justify this investigation: First, the presence of abstract concepts; and second, the lack of computer labs in schools that allow students to apply concepts in real-life scenarios [2]. Computer network students need to develop fundamental technical skills by participating in practical activities [3]. As a result of the high demand for students at educational institutions, most students do not have a complete physical space that supports the development of the practices required by the discipline. The rapid advancement of technology makes the components obsolete in a short time, even in computer labs, due to the wear, break, and tear of tested materials. The student may also accidentally make a configuration in an academic laboratory that will prevent the immediate use of the lab, resulting in the need for maintenance and possibly disrupting the next class' progress [4]. Because of the inflexible teaching-learning model, these obstacles in computer courses have long been perceived. Virtualised networks have been adopted by some groups in network disciplines, with tools like Netkit [5] being used with relative success, virtual network user mode Linux (VNUML) [6] and manage large networks (MLN). Practical experiments can be conducted on networks using such tools without the need for expensive equipment [7]. Nevertheless, some challenges remain, such as preparing experiments appropriate for the content being taught, correcting works and practical tests developed with such tools, and using them in platforms other than those mentioned.

A network emulator, Netkit, allows the creation of virtual computer networks and virtual links between them [8]. The importance of free software can be summed up in the fact that it allows institutions with limited financial resources and students to have access to it without having to pay licensing fees [9]. When the software reads Netkit labs, virtual machines (VMs) are emulated according to preestablished configurations based on folders and text files. VMs running text-mode Linux are based on Debian distributions. It is possible to configure network interfaces, firewalls, proxy servers and other network functions through a Netkit virtual machine, once it has been launched [10]. Teachers and students can also emulate hubs, switches, and routers using Netkit, in addition to virtual computers. Multiple hosts and virtual devices can be run simultaneously, creating a complete virtual laboratory that can be used in the classroom to practice computer networking disciplines. Besides folders and text files, Netkit laboratories require a didactic script to make sense to learners. This is a step-by-step guide to emulating the machines. As the disciplines progress, the teacher can make available the files of the virtual machines, followed by the didactic sequence, creating a whole learning strategy. The transition from theory to practice will be more dynamic in this way. Consequently, many studies [11–13] provide a web portal with several types of virtual laboratories, which can be used as a didactic tool for teaching Netkit-based computer networks. By using the web portal, teachers can create class categories and post laboratories based on the content and knowledge to be practiced. The sequence of practical laboratory classes will be arranged in this way. Using computers with Internet access, the platform and its tools can be accessed online, and virtual machines in the Cloud can be used to run laboratories.

The researcher in [14] presents percentages of employing virtualisation technology instructional issues in the labs of schools and educational institutions. Figure 1 presents three sub-figures (a, b and c) that express the use of virtualisation technology in educational institutions. Each sub-figure (a, b and c) contains three choices (Do not know, Yes and NO). The first option (Do not know) expresses that students are not aware of virtualisation technology, the second option (Yes) expresses students who use this technology and (No) do not want to use virtualisation technology. Figure 1 (a) relies on 42 educational institutions in its statistics, Figure 1 (b) relies on 19 educational institutions while Figure 1 (c) relies on 5 educational institutions in its statistics. Just 19 (or 45.2%) of the 42 examined schools in Figure 1 (a) use virtualisation technology. Because of this, the schools that stated in the opening question that they did not use virtualisation technology (a total of 21 schools, or 50%) or that they were unaware that they did (a total of 2 schools, or 4.8%), were disqualified from further consideration. Figure 1 (b) further demonstrates that 5 (or 26.3%) of the 19 schools that acknowledged using virtualisation technology also utilise them to run their educational information systems. To be more precise, it is vital to state that of the 5 institutions indicated above, 3 were universities, 2 were secondary schools and no primary school among them. This may be demonstrated by the intricate nature and complexity of higher education's information approaches, which need the virtualisation of some components in order to streamline their management and operation. The funding scheme for regional schools, which in fact prevents primary schools from amassing the required funds for the construction of the requisite data centers, is undoubtedly another factor contributing to the current state of affairs. Figure 1 (c) shows that 12 schools (or 63.2%) really use virtualisation technology to educate about it, compared to 7 schools that either confess not utilising them or are unaware that they are using them. In order to be thorough, the above Figure 1 (c) states that of these 12 institutions, 3 were universities, 4 were secondary schools, and the remaining 5 were primary schools.

Scientists and companies in the computing industry are exploring the Cloud computing paradigm since it is a new concept. Amazon, Google, IBM, Microsoft, and Salesforce offer a wide range of services to their customers, from simple data storage to geolocation [15]. Due to the increased availability of the Internet, users are consuming more computing

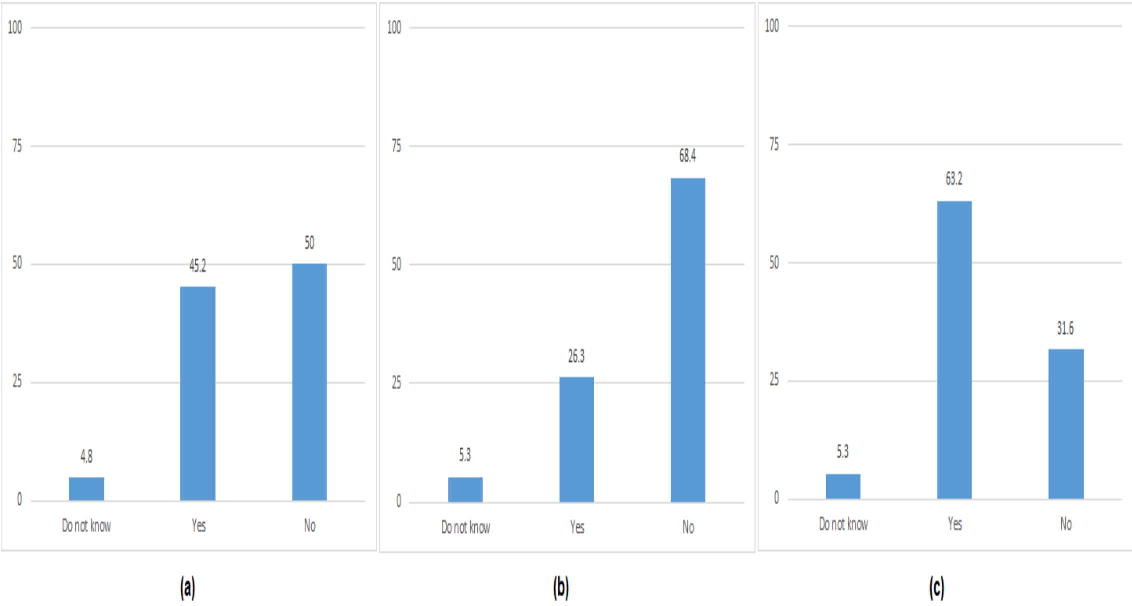

Fig. 1. Using virtualisation lab in educational institutions

resources. It is easy to observe this reality by taking a look at the number of services available on the most diverse fixed and mobile devices in common use today. An example would be the increase in online financial transactions, the exchange of electronic messages, and video and audio streams on the most diverse channels available on the Internet. Cloud computing must be considered in this context since in most cases, it represents the current large repository for all these services. A Cloud computing philosophy aims to permit access to a wide range of resources, such as music, videos, photos, and text, through any device connected to the Internet, without any restrictions. As a default, the Cloud must envision "infinite" computing resources. There must be space available, regardless of the computational power required or the amount of information to be stored [16]. Globally, there are many computers connected to one another through the Internet, which makes this concept possible. Cloud computing has transformed on-demand information technology services and products into utility computing [17]. Using specialised providers, utility computing can offer basic network services, such as storage, processing, and bandwidth, at a low cost per unit [18]. Based on the aforementioned information, these advanced technologies (virtual environment tools, VM, Cloud, computer networking, web portal, etc.) can provide a suitable teaching/learning environment for teachers and students through the creation of virtual laboratories.

1.1 Major Contributions

This research reviews recent surveys on the use of electronic learning/teaching through virtual laboratories. Thereafter, this review proposes a approach for teaching and learning computer networks, aimed at undergraduate, technological or even technical level courses in computing, computer networks, or telecommunications. This approach promotes itself as a collection of technologies that enables the implementation of network procedures in a computerised Cloud environment. The work also emphasizes the usage of Netkit, a free program that simulates whole network environments with a wide range of topologies and peripherals, including computers, routers, switches, and an interface for setting different communication protocols. The current proposal goes beyond simply presenting the Netkit as a didactic tool for courses in computer networks by offering a teaching environment for networks based on a Cloud of computers, here known as the NetEnsina Cloud, making it widely accessible and allowing instructors and students to conduct labs and lectures from any computer with Internet access. Moreover, the approach was carried out using the Amazon web services (AWS) Cloud platform, where computer virtualisation was used to establish an environment for teaching computer networks. One of the most noticeable characteristics of distributed Cloud computing is the ability to reproduce virtual machines utilising the idea of horizontal elasticity. Virtual machines have Netkit loaded [19]. The reason for using Cloud computing in this proposed approach is because, while Netkit is a helpful tool for teaching networks, it can only be used in Linux settings, which deters many users from used to other technological platforms. The virtual lab may be accessible from any computer with an Internet connection when it is made available in the Cloud, independent of its operating system (OS). This review illustrates how such technologies might enhance the activity, utility, and participation of computer network courses. With widespread, cost-free, and straightforward access to technologies that were previously only available to a select number of

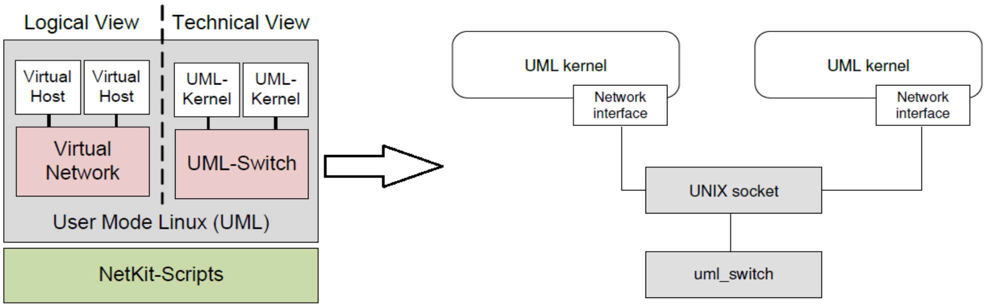

Fig. 2. Netkit architecture with virtual machines

instructors and students, it is hoped that this review will considerably help the distribution of information about computer networks.

1.2 Review Organization

This section provides a description of the review structure. In Section 1, a thorough introduction is given. Review the basic information of the virtual lab tools in Section 2. In Section 3, we critique recent surveys about electronic education with virtual laboratories. In Section 4, the review methodology is explained. Section 5 provides a discussion about the environment used. The topic of viewpoints used in topics is examined in Section 6. The challenges we ran upon throughout our review are detailed in Section 7. Section 8 provides a set of recommendations for educators and institutions in adopting virtual laboratories. In Section 9, the open issues are described. The review's conclusions are presented in Section 10.

2. VIRTUAL LABORATORIES TOOLS

This section will include important details about the most important teaching/learning tools (Netkit, VNUML and MLN) based on virtual laboratories.

2.1 Netkit

An emulator called Netkit makes it possible to build virtual computer networks for experiments, together with the hardware components required to support them and the virtual links that connect them. The Netkit was created as an open-source in 1999 at Rome Tre University in Italy, and the scientific community afterwards supported it. Even if a student only has access to one computer at home, the virtual machines offered by Netkit are started and, once operating, give students and teachers actual experience. Fully functional Debian GNU/Linux is a Netkit virtual computer. These virtual computers may function as any unique network equipment, such as switches or routers, with the help of the proper software. Eleven virtual laboratories were created in order to conduct actual experiments in computer network disciplines at ICMC and USP [20]. When additional technologies are required for specific network experiments, Netkit may handle experiments using other network technologies as well. Test of the Netkit emulator implementation requires

- A lab with network routing configuration and implementation,
- Network devices copy and operate on the Netkit emulator,
- Then the performance of the Netkit emulator implementation is examined in a virtual lab [21].

With Netkit, network experiments may be set up and carried out quickly and cheaply. University lecturers that use it as a teaching tool developed the open-source Netkit network simulator. Multiple virtual network devices (routers, switches, computers, etc.) can be connected to one personal computer (PC) to form a network. The setup interface is one of the unique features of the virtual network equipment [21]. The virtual lab is built utilising Netkit emulators and user mode Linux (UML) virtualisation technologies. Figure 2 depicts Netkit architecture with virtual machines. A command line interface may be used to transmit Netkit Virtual Machine settings to UML. Although this is a useful method for supplying configuration options, users who are only interested in simulating networks frequently do not want to deal with tricky kernel invocation instructions. Additionally, it is difficult and time-consuming to compile a UML kernel. Moreover, creating the disk image is not a simple operation. To provide a higher-level user interface for UML, a software program named Netkit was created at Roma Tre University. The purpose of Netkit is to offer a pre-built virtual environment based on UML. A preconfigured disk image (filesystem) containing most of the latest networking tools is included with Netkit as part of its intuitive interface [22].

Several of the capabilities of the Linux OS are emulated by Netkit, together with hardware from actual computers. Firstly, Netkit is a simple, lightweight and quick open-source network emulator. It is made up of a kernel, a file system image, virtual hub platform, and a collection of end user space instructions, among other things. Secondly, Netkit is ready to use right out of the box; it comes with everything required to establish an emulated network on a typical workstation and offers a selection of virtual laboratories that are set up and ready to go for conducting experiments on engaging case studies. Thirdly, as neither of these tasks requires administrator access, Netkit is designed for simple installation and usage. Emulated Netkit hardware is built on the UML kernel [23].

Each virtual machine includes a dedicated file system with a fully-featured GNU/Linux installation that is based on the Debian distribution and has been adjusted to work with Netkit's commands and function within UML. On the host, a backup file with a size of about 600MB contains the file system. In contrast, Netkit enables the execution of complicated network scenarios without requiring the usage of separate backup files for every virtual machine. Every virtual machine in Netkit reads from the same underlying file, but each one copies its modifications to its own copy-on-write (COW) file using the copy and write methods. Every virtual machine's file system is shown consistently by the UML kernel. A COW file generally has a size of 10MB. As a result, a Netkit installation requires around 600MB of disk space for the backup file and an additional 10MB for each virtual machine that is started. The major memory needs are also modest: The default setup requires 15MB of RAM for each virtual machine operating [23].

2.2 VNUML

Open-source software called virtual network user mode Linux (VNUML) possesses a long history in both research and instruction. VNUML was developed as part of the Euro6IX project to simulate complicated Internet protocol (IPv6) network scenarios. It has since been used in a number of research projects, including the ADRENALINE testbed, a GMPLS-based automatic switched optical network (ASON), to experiment with various constraints-based routing algorithms. In addition, VNUML has been widely utilised in university computer network labs to let students work with complicated network scenarios. A general-purpose open-source program called VNUML was created to aid in automatically creating virtual network scenarios or network testbeds. In essence, VNUML is a user interface for UML, a virtualisation approach to run virtual Linux machines over a Linux host that enables the user to create, launch, and engage with virtual scenarios comprised of virtual Linux computers connected by virtual networks. The ability to connect virtual environments made with VNUML to external devices and networks creates the potential for mixed virtual/real testbeds. Functional testing is the primary use for virtual network scenarios. Because physical resources are shared by virtual machines under virtualisation, performance measurement is challenging to do. Nonetheless, with proper preparation and oversight of experiments, some approximate ratings can be produced. In [24], a resource consumption and performance comparison of several virtualisation methods used to build a virtual network scenario, is presented.

By relieving the users of all the intricate UML details necessary to create virtual network scenarios, VNUML enables them to focus on the testbed's intended application rather than the process of building and maintaining it. The tool is composed of two major parts: the VNUML language, which is based on XML (eXtended Markup Language), and the language interpreter, which parses the description and creates and controls the virtual network scenario. Virtual networks and virtual machines make up the two primary portions of a VNUML definition. Virtualisation and VNUML have an emphasis on reducing infrastructure costs, making better use of resources, streamlining administration, and speeding up security copy processes [25, 26]. A service called virtual network - User Mode Linux has been put up on the Linux platform in order to replicate a traditional network's infrastructure and platform (VNUML) [27]. However, VNUML needs more resources (such as memory and processor) than Netkit. Therefore VNUML provides lower performance than Netkit when dealing with virtual laboratories. Figure 3 depicts VNUML procedures with example.

2.3 MLN

In networking labs, manage large networks (MLN) virtualisation is used to provide students with hands-on experience with virtual networks that are constructed on-demand to explain frequently used networking protocols. The open-source software program MLN offers a simple, user-friendly way to define virtual networks. Students define networks of

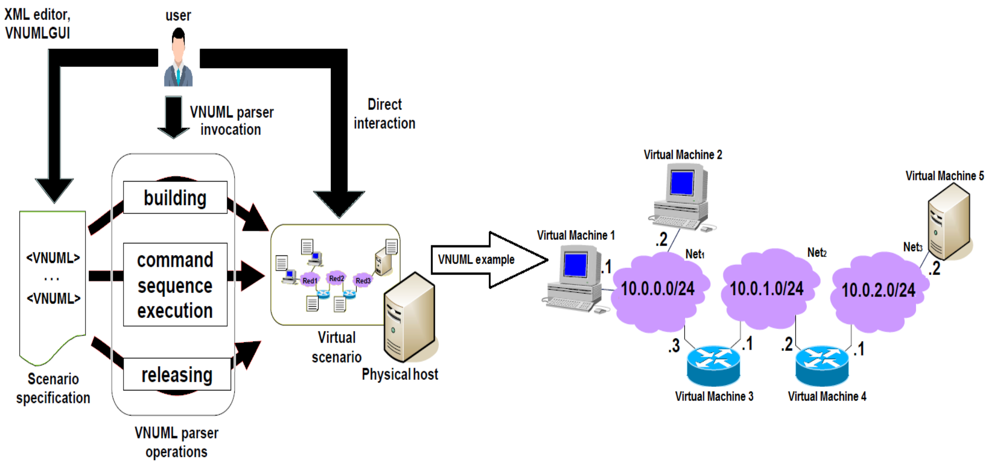

Fig. 3. VNUML with example

arbitrary complexity by creating (or using predefined) simple text files. These networks, which are made up of UML switches and workstations, may be built, operated, and shut down with a single command provided by MLN. The features included in UML implementations on our infrastructure allow for complete access from wherever on campus or online, maximizing the use of resources and paving the way for the delivery of distant learning [28].

Commercial solutions (like VMware virtual labs manager) or the MLN open-source effort (My Linux Network, mln.sourceforge.net, aka MLNs and Netkit) can also address multiple VMs. MLN was created for quick, template-based provisioning of virtual Linux networks and has a high degree of synergy with UML. A straightforward yet effective network description file is needed for MLN's input. This file contains information on the UML systems and switches that will be used, along with network addresses, system sizes, file system templates, and other relevant information. In addition to showing students how to describe whatever networks they desire to construct, instructors may specify networks with ease. This file is used by MLN to automatically generate the necessary scripts to launch and terminate UML-based virtual networks. The creation of extremely lightweight UML systems for tasks like routing may be accomplished by using "templates", which are really just pre-configured Linux file systems. Because MLN templates are normal Linux systems, they can come pre-configured with any program that can be used to define virtual systems on a Linux system. Zebra is one such piece of software (http://www.zebra.org). The operating system concepts (OSC), enterprise Linux system administration (ELSA), and networking labs were developed by the researchers using UML and MLN. To overcome the learning barriers associated with production OS usage, users should build a UML VM from scratch and use Loadable Kernel Modules (LKM) technology. Instead of learning how to utilise a emulator or even how to utilise UML instructions to construct a virtual network, students may focus on the procedures of computer networks thanks to the simplicity of MLN-based virtual networks [29]. Figure 4 shows virtual MLN lab system.

A simple, user-friendly technique for defining virtual networks is offered by MLN. Together with that, MLN now supports Xen, enabling it to incorporate networking experiences involving OSs other than Linux. There are more "UML facilitators" accessible nowadays than MLN. Another such is the free software program known as Netkit and VNUML, which were created as a result of the advanced research projects. These tools were extendedly used in educational networking laboratories to simulate and investigate complex and different scenarios such as IPv6-based Internet [30].

2.4 Comparison of Virtual Laboratories Tools

In this section, we will compare Netkit, VNUML and MLN virtual lab tools as well as a set of other virtual tools [31–37]. Table I shows comparisons between these tools to distinguish the preference for these tools in electronic learning. Through Table I, it becomes clear to us that Netkit is the best choice for dealing with virtual laboratories. We can see also from the table that Xen also offers efficient features. Therefore, we explain some important differences between Xen and Netkit.

- Purpose: Netkit is made for testing network setups and modeling virtual network environments, While Xen is primarily made for building virtual environments that run different operating systems on a single physical computer.

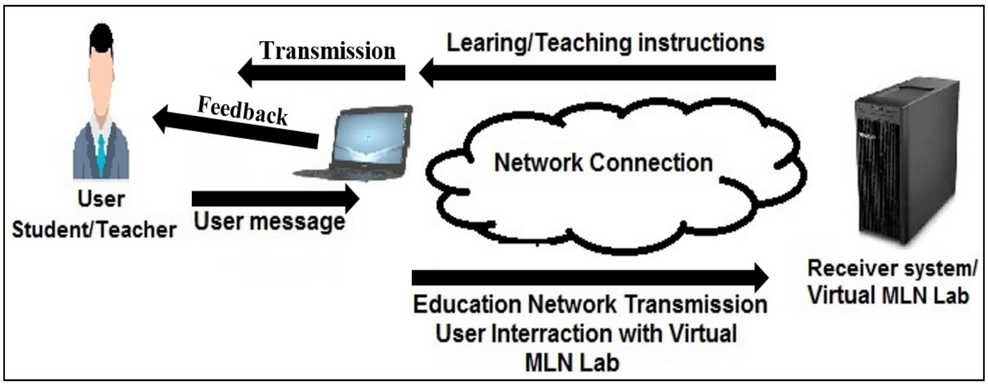

Fig. 4. Virtual MLN lab system

- Resource requirements: Netkit only simulates network devices, so it can run on a less powerful machine, it allocates a fixed amount of memory for each VM. Similarly, Xen requires a physical machine with low memory (allocate memory to each individual VM) and CPU to run multiple guest operating systems. It is important to note that the actual RAM usage for both Netkit and Xen will depend on factors such as the number of virtual machines, the memory allocation for each VM, and the specific workload and applications running within the VMs.
- Netkit offers a command-line interface and web-based tools, including WNI, NVLab and VNX, for managing virtual networks, while Xen offers a variety of management tools for building and administering virtual environments, such as XenCenter and XenServer.

Some advantages of Netkit compared to Xen:

1. Lightweight: Netkit is designed to be a lightweight virtualisation solution compared with Xen, primarily focusing on network simulation and teaching purposes. Because of its User-mode Linux (UML) foundation, it has quick startup times and effective resource utilization.
2. Network Simulation: Designed with network simulation in mind, Netkit offers an easier-to-use environment for building and configuring virtual networks. Unlike Xen, it enables users to test and simulate intricate network setups and topologies without requiring actual hardware.
3. Educational Focus: To educate networking fundamentals, Netkit is frequently used in educational environments like colleges and training programs. With its comprehensive documentation and user-friendly interface, it makes it simpler for novices to learn about and experiment with network technologies.
4. Simplicity: Netkit requires no changes to the host kernel or operating system and has an easy-to-follow setup procedure. It offers a collection of virtual computers that are already established and ready to be tweaked or linked together to create intricate network scenarios.
5. Compatibility: Integrating pre-existing network applications into the simulation environment is made simpler by Netkit virtual machines' compatibility with widely used networking tools and protocols. Network configurations may be thoroughly tested and validated thanks to this compatibility.

Furthermore, the table indicates that Kathara provides effective characteristics as well. As a result, we clarify several significant comparisons between Netkit and Kathara.

1. Regarding virtualization techniques, Linux containers (LXC) are used by Kathara to build the virtual network components. While Netkit builds the virtual network pieces using virtual machines (VMs) running Linux. Netkit's VM-based approach provides more flexibility and control over the virtual network environment than Kathara's use of Linux containers. Users of Netkit can more accurately modify the parameters and settings of each virtual machine.
2. For the purpose of constructing and managing virtual networks, Kathara provides both command-line utilities and an intuitive graphical user interface. While Netkit is completely command-line oriented and has a more sophisticated interface than Kathara, some users might find it more challenging to learn.

TABLE I. Comparison of virtual lab tools

Lab tool	License	Configuration	Implementation	Virtualisation	Memory consumption	CPU consumption	Performance	First version
Netkit	GNU GPL	Various files	CL/NWI	Extended	Low	Low	High	1999
VNUML	GNU GPL	Single file	CL	Extended	Moderate	Moderate	Moderate	2004
MLN	GNU GPL	Single file	CL	Limited	Dependent	Moderate	Moderate	2000
Velnet	Restricted	GI	GE	Dependent	Moderate	Moderate	Moderate	2003
Imunes	BSD	Single file	GS	Limited	Dependent	High	Low	2004
Dynamips	GNU GPL	Single file	CL	Limited	Moderate	High	Low	2005
NVLab	NotAvailable	WI	GE	Dependent	Dependent	Moderate	Moderate	2014
VMware	ESXi-vSphere	Single file	GE	Extended	Moderate	Moderate	Moderate	1999
Qemu	GNU GPL	XML files	CL	Limited	High	High	Low	2003
Xen	GNU GPL	Various files	CL	Extended	Low	Low	High	2002
Kathara	GNU/GPLv3	YAML files	LXC	Extended	Low	Low	High	2016

3. While Kathara has some limited compatibility with Windows, Kathara is primarily meant to operate on Linux-based operating systems. Even though Netkit was initially designed for Linux-based operating systems. Netkit outperforms Kathara in terms of more robust Windows compatibility. This makes Netkit more accessible to users using Windows-based devices.

4. Netkit is more widely accepted than Kathara since it has a larger user base and has been around for a longer time. This implies that there may be more community support, documentation, and resources available for Netkit. The larger community can also contribute to Netkit's development and enhancement over time.

5. Netkit could provide more advanced networking features and functionalities than Kathara. For example, Netkit could provide a larger range of network protocols, technologies, and configuration options. This might be useful for users that want more complex or specialized networking simulations.

6. Netkit's VM-based design facilitates easy customization and integration with other tools and systems. There might be additional choices available to Netkit users for growing and modifying the platform to meet their own needs.

Some of the abbreviations in the table should be defined, such as graphical interface (GI), web interface (WI), Netkit web interface (NWI), graphical execution (GE), graphical simulation (GS), and command line (CL).

3. REVIEWING SURVEYS IN THE AREAS OF VIRTUAL LABORATORIES

The current growth of network connections demonstrates the structural axis of technology, and instructors have a crucial obligation to consider and understand how technology may facilitate learning in the pedagogical area [38]. Much research on the topic, including non-informatics studies, has been published in a number of different fields. Articles from a number of the study's sectors show how technology may be used elsewhere. Computer-mediated interaction (CMI) is discussed in [39]. Their conversation suggested reciprocal and reactive connections. This typology examines the interaction potential of educational informatics systems including email, discussion lists, chat, ICQ, forums, and web pages. Discussion and group work are important in distance learning. Students can learn the subject more naturally and realistically in an immersive environment thanks to computer networks [40]. The instances in the tool instruct the student. The study found that giving students access to a variety of resources emphasized the potential for using intelligent agents in education with realistic virtual environments. The researchers are able to adapt virtual world (VW) material, resources, and activities to student preferences since they comprehend their users' circumstances [40]. Prvan and Ožegović [9] investigated the use of Netkit as a critical tool for teaching computer networks due to the possibility of unrestricted experimentation via laboratory virtualisation. They did not, however, list any unresolved concerns for the creation of the virtual lab. The researchers asserted that learning must be reinforced through computer network lab practice. Due to the actuality that educational institutions do not always possess modern labs, they look at the problems that such a practice may have with the courses. According to research [41], a technology education based on Cloud education is the best way to meet the needs of a technological society. However, they did not use an efficient tool for the virtual laboratory.

A case study that evaluates the cybersecurity expertise of juniors and seniors in a one-semester software engineering degree program is provided [42]. According to researchers, students can gain cybersecurity skills and principles as they transition into the workforce. Their activity is intended to test students' ability to assess control structures by finding faults and the proper output. The particular goal is to find ways to improve beginner software developers' cybersecurity understanding, including university juniors and seniors enrolled in programming-focused courses. Nonetheless, their study focused only on security issues and ignored the management and performance of the virtual lab. Haag et al. [43]

described a distributed virtual PC lab for cybersecurity education. The next step was to add educational upgrades to this virtual lab, such as a smart tutoring manner, which produced a template for virtual cybersecurity schoolroom instruction. In their study, a virtualised learning environment for cybersecurity education was established. They discussed the distributed virtualised computer lab's technological elements, which they designed. Evaluations of students' experiences in their lab revealed that they valued hands-on learning, which effectively embodies the idea of edutainment. As a starting point, they used the virtual security lab (VCL), which they had created as a standalone system. By tying up two (VCLs) on the network level, they first made group work for students possible. However, their study did not provide review challenges when using virtual laboratories.

Bonaventure et al. [44] reported an initiative to produce an online interactive textbook for computer networking. It differs from conventional textbooks in a number of ways. It is first and foremost free and accessible to everyone on the globe, regardless of capacity to pay. Moreover, it is accessible instantly and everywhere since it is online. Furthermore, it is interactive. It is more than simply a textbook; it is a platform for participatory learning about computer networking. In addition to contributing to the enhancements of the book (35%) and exploring other open-source projects (37%) that were made available to them, students remarked that having access to the book sources inspired them to get involved with the open-source movement. They listed a few virtual testing tools, including Netkit and Mininet. However, their study did not indicate which virtual laboratory tool was best. Letowski et al. [45] suggested a completely open-source remote laboratory for general practice, in all areas of applied sciences or engineering education. Their approach is based on a Python-programmed open-source supervisory control and data collecting platform. In order to achieve widespread compatibility with the many communication protocols and devices used in actual lab work, interoperability is one of the key concerns taken into consideration here. The utilisation of virtual laboratory tools like Netkit, VNUML, and MLN, which offer tremendous advantages for students and teachers such as ease, flexibility, simplicity, speed, etc., was ignored by the authors as they concentrated on the topic of open-sources.

Rahman et al. [46] concentrated on virtual reality (VR)/virtual Laboratories (VL), which aims to understand the work done in high-quality education from a distance using VR. By supplying users with an interactive experience in which they may participate and learn more successfully, they argued that using virtual reality in education can help students learn more efficiently as well as boost perspective, excitement, and mastery of complicated concepts. They concentrated on developing virtual environments where students may engage in their lab performances, whether they be in biology, chemistry, or physics. Also, they discussed technological and pedagogical needs, such as various objects, OSs, resources, and oriented systems, and how VR techniques may enhance the development of these processes as well as how they might upgrade the created system in the future. They emphasized that the platforms' lack of agreement may be seen in the failure to define a development plan. However, their study did not address the large and huge services provided by organisations (such as Amazon, IBM, Google, Salesforce, and Microsoft) that have a great deal of experience in dealing with virtual laboratories.

The evaluation of pharmacy students' views toward a computerized microbiological simulation was studied by Baumann-Birkbeck et al. [47]. A year-second incorporated pharmacotherapeutics semester for bachelor of pharmacy students contrasted the traditional wet laboratory (lab) with the virtual microbiological simulation (VUMIE). Surveys were used to gather data at the pre-intervention (baseline), post-intervention (VUMIE or wet lab), and endpoint (post-interventions). The analyses used were quantitative and qualitative. Although technology-enhanced simulation can offer an educational experience comparable to a typical wet lab, Despite this clue, traditional lab experiences cannot completely replace clinical courses of study. Simulation of technology-enhanced might be taken into consideration for just-in-time training prior to exposure to conventional lab activities, for the purposeful practice of specific skill acquisition, and possibly for standardized evaluation for clinical microbiology education. However, their studies are directed to a class of university students and not to laboratories that include all types of students' majors, which confirms that their studies address virtual laboratories for pharmacy students. Ishak et al. [48] presented a study similar to the previous research but for a different class of students relating to distance learning in pathology at the medical school field. Similarly, Hassan et al. [49] introduced a review for virtual laboratories in tertiary education. They provided two case studies that make use of both pre-built and specially constructed VLs and are examined from the perspective of learning theories. As a result of the analysis, readers are informed that VLs (a teaching platform) and instructors' support (a human mediator) are dialectically related, which is a crucial factor in achieving good learning outcomes. These articles demonstrate how technology may improve education and knowledge. Additionally, Cloud computing, a new paradigm in teaching and learning, makes knowledge more widely available. Simulators have evolved and drawn students from a range of professions who are interested in learning. Realistic data is sought in these simulations to facilitate participation in real-world situations. However, their review did not investigate AWS services issues and security issues in the virtual labs.

3.1 Reviewing Virtual Classes Advantages and Disadvantages

To be comprehensive, we explain the pros and cons of virtual classrooms from the perspectives of the teacher and the learner.

3.1.0.1. Advantages:. Significant improvements in educational models and communication tools that are easily adjusted to learning techniques have been brought about by the usage of the Internet and the web. A novel concept in e-learning is virtual courses/classes, where students participate in a classroom setting with their instructor and other students online. Another advantageous aspect of synchronous online classrooms is the availability of various communication tools between lecturers and students. It is crucial for sustaining communication. Additionally, the relevance of learner-learner, learner-instructor, learner-content, and learner-interface interaction inside the virtual classroom, as well as the synchronous virtual classroom's interaction capabilities [50–52]. Among the important advantages of virtual classes are:

- Removing obstacles based on distance,
- Easiness of recording/storing the lecture,
- Activities to reduce anxiety and increase motivation,
- A notable impact on enhancing teamwork and communication,
- Useful as an emergency solution during pandemics and calamities to continue schooling,
- Getting free time for study,
- Exposing students to innovative and fun learning methods,
- Preserving one's health and the security of the community,
- Enabling the teacher and the learner to travel,
- Continuing with the semester's authentic curriculum,
- Being able to quickly access Internet resources (information, services, programs, platforms, applications, etc.).

3.1.0.2. Disadvantages:. For the fairness of the review, we should point out the disadvantages of using virtual classrooms. From the perspective of the learner, the students complained about the lengthy online sessions, which led to fatigue, boredom, and a lack of attention [52, 53]. The electrical equipment heating up after prolonged Internet communication is another issue. Some students recommend setting the maximum interaction duration for each online lecture at a hundred minutes. From the perspective of the instructor, the difficulties in administrating virtual courses are by far online teaching's biggest drawback. The majority of the time, students arrive late for class and leave in the middle of the course. Additionally, many students in virtual classrooms choose not to activate the camera, which makes it more challenging for the teacher and students to communicate. According to [54], only 18% of participants are willing to activate their smartphones' cameras in virtual classrooms, and 96% of participants do not perceive the necessity of doing so. Among the important disadvantages of virtual classes are:

- Power usage, financial expenses, the limited number of devices, sustainability, and distant access,
- Spending a lot of time looking at screens,
- Absence of movement,
- Inadequate circumstances for learning social interactional skills,
- Experiencing a lack of attention,
- Virtual classroom lacks peer interaction,
- Hearing issues with the teachers' voices,
- Inability to communicate with classmates and instructors because of time constraints or physical wellness,
- Difficulties learning the lesson's contents,
- Inability to stick to study routines and a lack of self-obligation,
- Technical difficulties/issues and the need for training/skilling.

4. REVIEWING PROPOSAL FOR TEACHING/LEARNING APPROACH FOR VIRTUAL LABORATORIES

This section will address the methods used to build the platform for teaching/learning for educational institutions. This section includes Netkit implementation procedure, Amazon web services Cloud provider, virtualisation in education labs, setting up and connecting of simple networks, service of elastic compute Cloud (EC2), identical instances by Amazon machine image (AMI), simple data storage service, data storage volume, Cloud/AWS horizontal elasticity and lab services security.

4.1 Netkit Implementation Procedure

In this subsection, we will briefly describe the Netkit implementation procedure. With Netkit, users can create a network topology, configure network devices, and test network applications in a safe and controlled environment. The following are the steps involved in implementing Netkit:

- Installing Netkit: Users can download Netkit from its official website (https://wiki.netkit.org/index.php/Download). Then follow the installation instructions for OS.
- Establishing a workspace: After installing Netkit, establish a workspace directory in which the user will save configuration files and network topologies.
- Building a network topology: To build a network topology, use the Netkit command-line interface. The devices, connections between them, and network topology are all described in the topology file, which is written in a unique manner.
- Network device configuration: To configure the network devices in the topology, use the configuration files. Standard configuration files, like those for Linux networks or Cisco IOS, are available for usage by users.
- Launching the network: Use the Netkit command to launch the network once the user has set up the topology and network devices. The PC's virtual network will launch as a result.
- Network application testing is now possible on the virtual network for users. To make sure the network is operating as it should and to test device connection, users can use programs like netcat, traceroute, and ping.
- Saving and restoring the network: Once the user has finished testing the network, the user can save the network state and restore it later. This allows the user to start where the user left off and continue testing.

4.2 Cloud Provider with Implication AWS

Large corporations are increasingly using Cloud computing [55]. Among them, Google, Microsoft, Apple, and Amazon are constantly improving their apps and web services via Cloud benefits. The benefits of Cloud computing are reaped by Internet users without their knowledge, and they are unaware they are doing so. Some examples are Gmail, Hotmail, Youtube, Dropbox, Netflix, and Spotify. In this case, AWS is a good reference for Cloud computing. One of the largest online retail markets in the world is Amazon.com, a multinational corporation that operates in the electronic commerce sector [56]. Globally, Amazon has massive data centers (Clouds) capable of running its massive electronic commerce system, which is known for its dependability, availability, and security [57], to meet the high demand for purchases. Since Amazon.com has opened up its servers Clouds and infrastructures to the world, anyone can host a website or service on Amazon's servers, including students and teachers/instructors. Amazon.com launched AWS in 2006 to provide a comprehensive platform for developing Clouds services/applications [58]. As discussed in the previous section (Introduction Section), one of the characteristics of Cloud computing is its ability to provide services quickly and easily. Customers of Amazon web services, for instance, have access to a comprehensive panel from which they can easily locate and use the company's services.

4.2.1. Utilising Netkit and AWS to Establish a Simple Virtual Network

We can utilise Netkit and AWS to establish a simple virtual network by following the steps shown below:

- Set up an AWS account: Go to the AWS website (https://aws.amazon.com/) and sign up for an account if we do not have one already. This will allow us to access the AWS services needed for creating a virtual network.

- Launch EC2 instances: In the AWS Management Console, navigate to the EC2 service. Start the EC2 instances that will function as the nodes of our virtual network. Launch the instances after choosing the proper instance type and configuring the networking settings (security groups, subnets, protocols, hubs, switches, routers, proxies, and firewalls, etc.).
- Set up Netkit locally: We may build virtual network topologies on our PC by using Netkit, an open-source network emulator. Set up the network topology we want, including the required nodes, connections, and IP addresses, by installing Netkit on our local computer.
- Create connection: The right networking configurations must be put up in order to create communication between the AWS EC2 instances and our local Netkit environment. Usually, this entails establishing a Virtual Private Cloud (VPC), a VPN connection, or utilizing alternative connectivity choices like AWS Direct Connect.
- Test and confirm connectivity: After the connection has been made, we can check the connectivity between the Netkit environment and the AWS EC2 instances. Test different network services and exchange network traffic to make sure the virtual network is operating as it should.

4.2.2. Necessity of Choosing AWS

From basic virtual machine rentals to full-service platforms with databases, development environments, and high-performance virtual machines, AWS offers a wide range of services. In addition, the AWS environment offers a number of advanced features, such as autoscaling services, load balancers, and redundant data storage. Amazon's AWS is the most well-known interface. By using web service calls, users can create, launch, and destroy server instances as needed, paying by the hour. AWS is the most widely used interface for getting access to Amazon's Cloud capabilities, despite the fact that it is not a standard. In this regard, most middlewares have their own application programming interfaces (APIs) as well as AWS compatibility [59]. It is substantial to note that other Cloud service providers in the market provide comparable services. AWS was selected to host the application because it meets all of the experience's requirements. Apart from offering a significant portion of free services for a year, users can also perform all tests for free.

4.2.3. AWS Cloud Computing Infrastructure Concepts and Objectives

Across the world, Amazon has a sizable servers infrastructure. Without being aware of how these resources are distributed or how a specific request is being handled, the client routinely accesses AWS Cloud computing resources. New servers, including those from different continents, could be enabled depending on the application's requirements to address a particular demand. This is due to the fact that decentralized, infinite computing is the foundation of Cloud computing [60]. The AWS global Cloud computing infrastructure implements three concepts for the physical location of computing resources. These are regions, availability zones, and points of presence.

- Region: A area, or point with a specific geographic position, that symbolizes a real-world location in the globe (Country, State, City).
- Availability zone: It is a geographically independent data center that is physically isolated and situated in an area with several availability zones. Although each zone functions separately, they are all connected to one another in the same territory.
- Points of presence: These are customized servers that provide material at fast speeds and with little delay. The static material that is sent by these servers, which are dispersed around a region, includes text files, documents (PDF), photos, videos, and HTML websites.

When creating a server or storing a file using AWS, it is necessary to select the region and availability zone where this resource should be created. Using the regions and availability zones approach, it is possible to accomplish two main goals [58]:

- Using this infrastructure, the application can be scaled worldwide, as it can be installed in multiple locations. In Basrah and Thi-Qar, for instance, users in and around Iraq can use servers installed. Users in America would use Texas and Virginia regions. All users may have quick access thanks to its infrastructure, including those who are located internationally.
- In the event of a disaster, ensure that the website is available and functional. Let's say, for instance, that the application is active in the Basrah and Thi-Qar regions. If so, the user can operate servers in both availability zones, and if one fails, the other one keeps processing requests as usual. Although the availability zone seldom

fails, there is talk of a mission-critical systems architecture that cannot be stopped. The goal of this review is not to describe every AWS service. It will only be those that are best known and those that were experienced during the scientific research and project development that will be discussed. EC2, security groups, AMI, simple storage service (S3) and elastic block store (EBS) resources stand out in this regard.

4.3 Virtualisation in Education Labs

Due to significant advances in hardware and software virtualisation technologies, virtualisation plays a significant role in training specialists in information security and sharing data. It enables the paradigm of how education is approached to change. Rather than lecturing in class and having students do "homework", a teacher/instructor could teach the essentials and then have students do practical homework. Likewise, both students and teachers should constantly learn/teach and utilise the latest advances in technology through constant self-study. Specialists in information security are especially susceptible to this [51]. It is not simple to completely virtualise educational missions in a short time. Thus, a crucial issue arises: Should we invest more time, effort, and money in the virtualisation of our regular academic scientific education courses? Such activities will help to prevent such extraordinary and never-before-seen disasters in addition to advancing the global dissemination of high-quality education. Hence, joint efforts are necessary to pool knowledge and resources at the national and international levels in order to reverse this decline in education [61]. If all the conditions and features mentioned in Section 3.1 are met in real-time, the virtual labs will ideally provide sustainable services for teachers and learners. As the virtual labs are not output constant, this depends on the training skills of teachers and learners in using the virtual labs' services and developing skills. According to a number of studies comparing the two types of labs (physical and virtual). Virtual labs are as excellent as, if not better than, physical laboratories at assisting teachers and students in learning science [62].

The virtualisation trend appears to be a significant enabling factor. Almost all suppliers in the information technology (IT) and networking industries embrace the trend of virtualisation. There are more virtualisation tools and new virtual networking equipment that are specifically made to operate in virtual environments (various hypervisors). Just virtualisation, in researchers' opinions [51, 52], offers the chance to get around the drawbacks of "legacy," hardware-based networking labs (cost, power consumption, sustainability, few devices, remote access, etc.), and it creates the possibility for a new type of remotely accessible, natively virtualised networking labs. Generic computer hardware will be used in this virtual lab (more powerful servers or clusters of servers are better). A sufficient number of devices may be operated by each student in virtualised laboratories, even for the simulation of complex networking scenarios. As a result, working with actual equipment is fun for both us and our students. According to the set of researchers [14, 52], virtualisation is presently the only option for deploying future networking laboratories and ensuring their long-term viability. We are actively exploring and utilising some of the virtualisation solutions to prepare for impending changes. By using these solutions, it can simulate complex networking environments and provide the teaching procedure effectively. There are currently some well-known virtualisation tools, but additionally, some that are not so well known, as well as some that are just coming out. Whatever the case may be, the number of solutions is growing, and each offers its own approach and features. Schools and teachers are incorporating these tools into their everyday teaching practices to prove that virtualisation is gaining traction. Figure 5 shows using virtualisation with teaching/learning lab.

As a result of these facts, hardware virtualisation can be defined as creating and running a virtual machine (VM) that acts as a real PC. A host computer is a physical computer on which a virtual machine is installed. Any OS that is supported by the VM may be utilised on the host because the OS of this computer has no bearing on the OS that is really being used. The virtual environment emulates the host computer's hardware while keeping the OS and other applications distinct from it [63]. This viewpoint allows us to divide hardware virtualisation into three sub-groups that are full, partial, and semi-virtualisation [14]. In full virtualisation, it provides an almost perfect emulation of the real hardware, allowing applications dependent on the OS of the VM to run without any alterations. In partial virtualisation, simulating only a part of the target environment is possible. It is necessary to modify some applications before running them on this type of virtual machine. In semi-virtualisation, there is no simulation of hardware at all. The apps, however, are started in distinct, segregated locations as if they were running on a different system.

4.4 Straightforward Network Configuration and Connection

In this section, we will explain the setting up and connection of different types of networks.

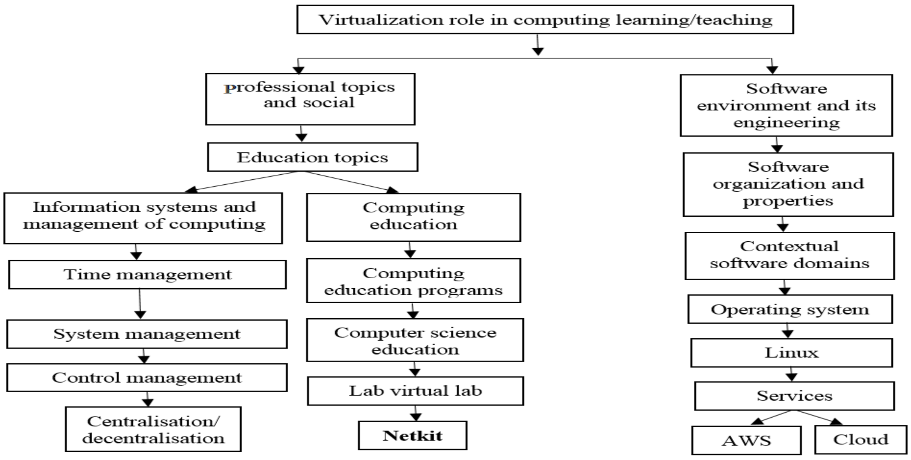

Fig. 5. Using virtualisation with teaching/learning lab

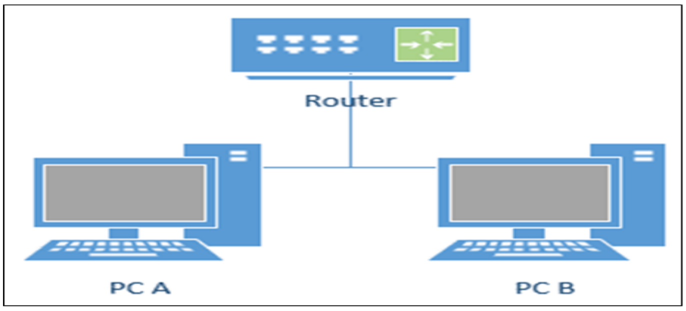

Fig. 6. Lab. 01 - Connecting two computers

4.4.1. Network Configuration with Two PCs

The objective is to connect two computers by configuring two network interfaces. In order to run Netkit labs, the user must download specific configuration files. All the files needed to complete the experiments indicated here will be made available on this website. For better organisation, the user should make a folder and place all the labs inside it. We prefer the term "lab" to describe this folder. The user can use this simple lesson to obtain a sense of the Netkit environment. The user can download the class lab and execute it from the lab's folder. Figure 6 shows connecting two computers.

4.4.2. Network Configuration with Many PCs

Four computers are connected by a switch in order to create a network. Users will need to download particular configuration files for each experiment in order to run the Netkit labs. All the files required to carry out the labs suggested here will be made available here on the website. It is recommended that the user creates a folder and puts all the labs within it for better organisation. In addition, we personally refer to our folder as "lab". Working with several machines will be a skill we develop in this lab. Four PCs, a Switch, and a simulated network environment will be used. Figure 7 shows a network with four computers interconnected by a Switch.

4.4.3. Configuration of Two PC networks Connection

Interconnecting two computer networks requires configuring routers. Users will need to download particular configuration files for each experiment in order to run the Netkit labs. All the files required to carry out the labs suggested here will be made available here on the website. For better organisation, we encourage the user to make a folder and place all of the labs inside it. The term "lab" is preferred for this folder. Students will learn how to set up four computers and two routers in a simulated network environment. A router moves data packets between computer networks to produce a collection of overlay networks. Two or more data lines from various networks are connected by a router. The router analyses the address information from a packet of data after it has arrived on one of the lines to identify its eventual destination. Figure 8 shows connecting two different networks.

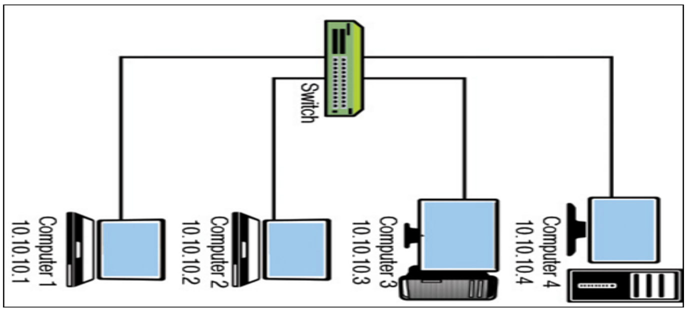

Fig. 7. Lab. 02 - Network with four computers interconnected by a Switch

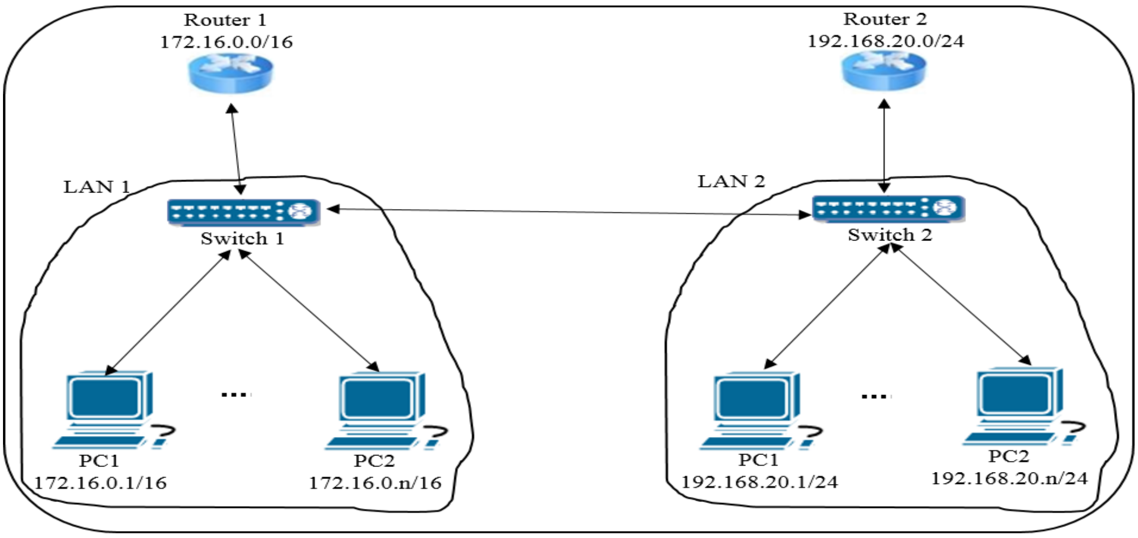

Fig. 8. Lab. 03 - Connecting two different networks

4.5 Service of Elastic Compute Cloud

Elastic compute Cloud (EC2) is a service that works at the Amazon IaaS (Infrastructure as a Service) layer that offers safe and scalable computing capacity in the Cloud. In actuality, it entails building instances, or virtual computers, within the Amazon service. These VMs can then be customized based on the user's requirements or pricing range. While setting the hardware that the virtual machine will utilise, the user will have a range of choices. At this stage, it is possible to choose the type and number of processors, the number of cores for each CPU, the quantity of memory, the storage capacity, and the network performance. Users can increase or decrease the capacity of their instances by changing the settings. This resizing was made feasible by the use of vertical elasticity, a crucial element of Cloud computing. In addition to hardware choices, Amazon provides a variety of virtual machines running Linux and Windows with 32-bit or 64-bit architectures [64]. The instances in the infrastructure as a service layer only contain the basic OS; the user may then customize anything from system resources to the installation of specific applications to suit their needs.

To connect to the instances over the Internet, one must utilise the secure shell (SSH) protocol. In order to connect to the VM, a user must have an authentication key generated [65] during the VM creation process and provided by Amazon. Once logged in, the user can use the virtual machine as if it were a genuine remote Linux virtual machine. The virtualisation problem is absolutely unknown to the Cloud user. After choosing the hardware and OS that the VM will run on, it is important to build a security group and check runtime properties where all of the access rules [66] for that instance will be configured. This step only entails configuring Amazon's internal Firewall so that users may define which ports and services can be accessed through that virtual machine.

4.5.1. Importance of Security Groups

An authentication key [67, 68] issued and given by Amazon is required to access each new EC2 instance. In addition, Amazon has established a security system based on security groups, which are really merged into a graphical interface from which the Cloud administrator may configure the firewall settings for the network. With EC2 instances, only SSH [70] connections are allowed by default; however, additional firewall rules can be applied to enable or restrict other ports as needed.

With the firewall settings, the administrator can set up numerous security groups, each with a distinct level of privilege. There must be a group for each instance, which defines the access rights this machine can grant [69]. For instance, a server running the MySQL database may only have opened port 3306, which is the default port for the database, or port 22 for SSH access, or port 80 for HTTP queries. Access filtering by IP address and port settings is also made possible by security groups. By default, the Cloud is accessible from any IP address (from anywhere), but the Cloud administrator can provide a list of allowed IP addresses. Moreover, the interface provides a choice for automated address generation. The Cloud platform now produces a fixed address associated with the instance in order to guarantee that only the machine that performed the process may access it.

4.5.2. Importance of Runtime Properties

Monitoring data should be divided into three categories: cost, quality, and resource in order to facilitate a multidimensional study of elastic service behavior. There are measurements for every dimension. These categorisations are adequate for gathering low-level information about any monitored component of a Cloud service that may be used to comprehend the elastic behavior of that service. The monitoring data should be conceptually defined in order to be captured for a monitored element at a specified time. It should thus reflect metric limits retrieved from user-defined elasticity criteria as well as boundaries detected/evaluated via monitoring techniques employing the elasticity boundary in order to analyse the elastic behavior of monitored data [71].

4.6 Identical Instances by Amazon Machine Image

Amazon allows users to create virtual images of EC2 instances, called Amazon machine images (AMI), so that new identical instances can be created from these images. As a result, the process of horizontal elasticity is facilitated and sped up since only one round of virtual machine preparation is required. Essentially, the AWS user chooses which OS to use, installs all the software needed for his or her tasks, and creates an image of the instance. AWS can provide new instances mirrored in this image if the user needs, for example, ten more machines. The Amazon services website may be used to perform all of these instance configuration tasks, whether they involve hardware or software [72].
The user has the option of using images made and altered by the Amazon professional community when establishing an instance. There are both free and paid images available with the widest range of options, including applications and

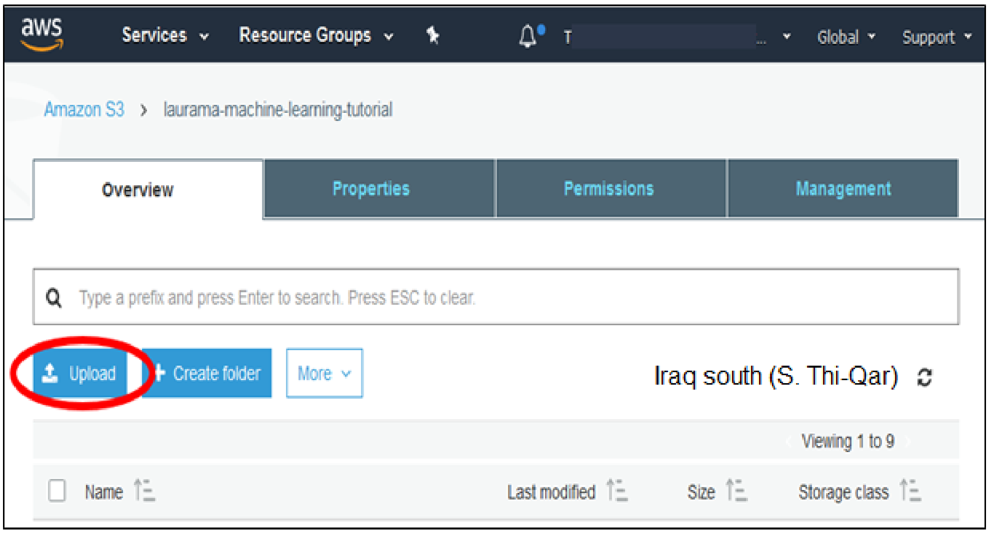

Fig. 9. Bucket creation screen in Amazon S3

solutions for various purposes. This study found that there are 48,596 distinct kinds of AMIs accessible through the Amazon portal. For individuals who need to deal with databases, web servers, cluster systems, and high performance, there are particular images. By employing this kind of image, the user abstracts away technical considerations and utilises a setting that is ready and waiting for a certain activity. It is considered to be operating in the platform as a service (PaaS) layer in the latter scenario.

4.7 Data Storage Service

One of the most popular aspects of AWS is the simple storage service (S3), a Cloud data storage service that is known for being quick, easy, high performance, scalable, redundant, and secure. Users may build buckets and upload any desired things to the Cloud using the Amazon website. In actuality, objects are the items that the user wishes to store and buckets are folders. Users of the AWS interface may quickly create folders and upload files using the administrative panel that is available. Figure 9 depicts the screen for creating buckets in Amazon S3. AWS offers an API via which users or businesses may design their own interfaces to access Amazon S3 in addition to the administrator panel. S3 is a commonly utilised storage facility, and even well-known products like DropBox store all of their data there in a protected form [73]. DropBox developed a user-friendly online interface to incorporate access and integration with file managers of the most diverse OSs, enabling users to use the Cloud-based file repository as a simple folder that is accessible on their PC or mobile device. Only the API's ability to add and remove files programmatically made this possible [74].
Whether they are text files, PDFs, photos, videos, or any other kind of file, S3 gives each folder and file a URL from which it can be accessed directly in the browser with a simple GET request. Public or private access levels can be assigned to each stored object. The first will be publicly available to anybody who knows the URL, while the second will be hidden from everyone save the administrator of the Amazon account to which the file is attached. The Amazon S3 admin panel or the Dropbox online interface both allow you to modify an object's visibility status. Together with the previously listed file formats, HTML pages, JavaScript scripts, and CSS style sheets are also accessible using S3. This will enable the user to publish a fully static website and make it accessible online without the need to pay for hosting. A redundancy control distributes newly contributed data to S3 among many instances in the area. An asset kept in an S3 bucket has 99.99% durability, according to Amazon [75].

4.8 Data Storage Volume

When constructing an EC2 virtual machine, the user must select the storage capacity that will be used by this instance; this size is fixed and once set, it cannot be modified. It is possible to assume that this will be the computer's default storage drive and that it will be its hard drive of choice. The OS and all other VM applications will be set to be installed on the default volume. Users may also use it to write files, create folders, and backup data, however in this case, if the volume is removed after it has been created, all previously stored data would be lost. Elastic Block Store (EBS) from Amazon is available for the long-term archival of instance data. EBS is a data storage volume that, as its name indicates, leverages

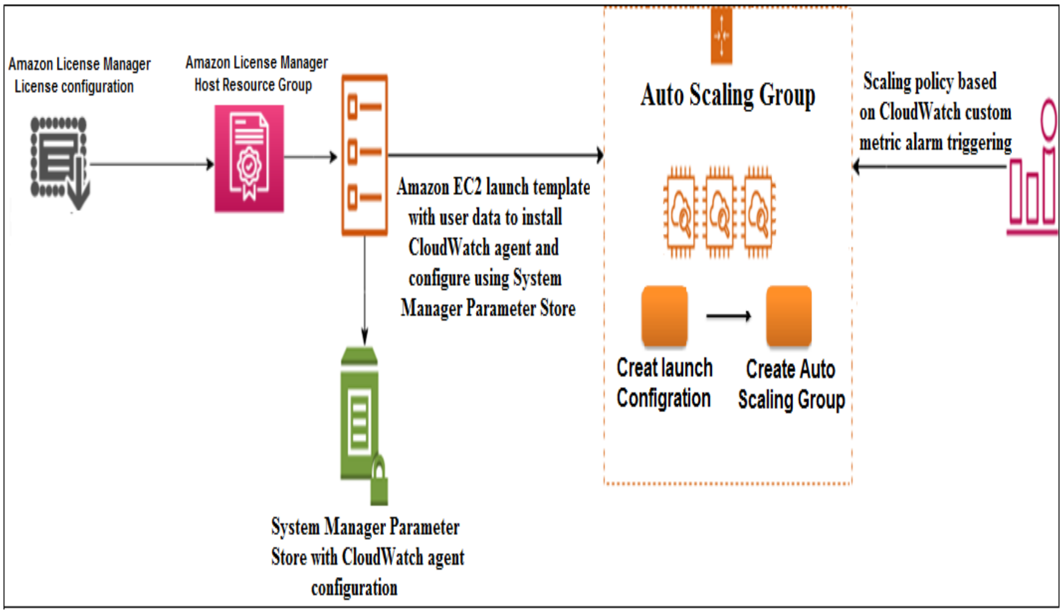

Fig. 10. Auto scaling configuration screen

the idea of elasticity and may hence increase its capacity as necessary. In this case, the EBS functions as a secondary hard drive (HD), or to put it another way, the volume functions as an external HD. These volumes have the benefit of being able to persist independently of the instances and may be created and connected to an EC2 instance like an additional hard disk. This indicates that if required, it is feasible to remove an instance without losing its data [58].

4.9 Cloud/AWS Horizontal Elasticity

As previously indicated, users have the option to request more instances in addition to raising the instances' capacity. Using horizontal elasticity is another remarkable aspect of Cloud computing [76]. The user can ask for the shutdown or even the eradication of this virtual machine whenever a bigger number of computers are no longer required. Hence, the contractor only pays for the services rendered. One of the most important and often utilised aspects of Cloud computing is the concept of elasticity. The idea of infinite computation is intended to be made available via its realization. At Amazon, managing instances is done through an administrator portal, where users may easily create or modify instances remotely. Figure 10 depicts auto-scaling configuration screen. The user can manually create, terminate, or destroy instances as necessary using the admin section of the Amazon services website. Moreover, Amazon offers a feature called auto scaling that allows the system administrator to set up metrics. From that point forward, the tool will keep track of how instances and applications behave and decide which elasticity action should be used in each situation. Automating the procedure and making sure service is provided. The primary functions and tools of AWS were covered in this part, along with the attributes that have made Amazon a leader in the computing Cloud business. The teaching environment used by NetEnsina and the specifics of how it was implemented by that provider is described in the next section.

4.10 Lab Services Security

Users can assemble and test secure service-based applications using lab services security in the Cloud. Our proposed review methodology, which was discussed in the preceding sections, is used to generate these composite apps. Our approach is made up of three primary parts that enable the dynamic instantiation of assembled applications, the design and distribution of security settings, as well as the tracking and evaluation of implemented security methods. There are some important security measures such as lab management, policy administration, regulations for competition and security evaluation that can mitigate security threats.

Lab Management: Users may visually design the system structure using the scenario management component [77]. The services modeled in the system diagram can be mapped to the services offered by a repository (service pool). This component is also in charge of setting up and setting up a composed application in a virtual machine in line with a model. A virtual machine image containing a base system, an application server, and a management web service is copied by the management service.

Policy administration: The visual designer may be used to convey security intents and establish security criteria in addition to the system structure. Based on the modeled security requirements, the security management component creates system settings through a transformation process. The first transformation stage resolves a platform-independent system model and security restrictions using our security configuration pattern framework. The policy generator component produces actual system settings (like WS-SecurityPolicy) in the second transformation stage. The scenario management component configures the constructed application using the created policies and configuration files.

Regulations for competition: This competition requires rules, just like any good game, but those rules should not be overly restrictive or allow for actions that significantly undermine the competition's educational objectives. The first rule states that no team may launch a denial of service (DoS) assault on the network, the services on another team's boxes, or a team's ability to utilise their own computer (i.e., locking them out of their accounts). It is just outside the field of the exercise, difficult to grade, and extremely stressful for students to defend against packet floods, service exhaustion, and malicious operating system annihilation [78].
Security evaluation: A user can examine security modules and analyse the exchanged messages after running a use case. The security analysis component performs this, and it is based on monitoring agents that have been installed in the virtual machine. Messages are intercepted by these agents and forwarded to the security analysis component's message monitor. By aligning monitored messages with modelled entities, the message visualiser allows users to track communication and security module behavior [79].

5. DISCUSSION

This section includes NetEnsina environment, NetEnsina Cloud and cost estimation.

5.1 NetEnsina Networks

The teaching environment of the NetEnsina computer networks will be shown in this section. This environment is built on the usage of Netkit software to simulate virtual labs for practice in the network disciplines classes. The NetEnsina Cloud, a development of the original project made accessible on the AWSs Cloud service, will also be demonstrated, hence extending access to the educational resource. Almost all areas of informatics study require practical exercises to solidify information, but in courses on computer networks, these exercises become more difficult since these training modules call for a computational infrastructure that goes beyond ordinary PCs. Each networking course requires resources like switches, routers, cables, and repeaters, which places a heavy load on these qualifications.

5.1.1. NetEnsina and Education Support

A helpful tool for teaching computer networks is NetEnsina. This tool proposes using Netkit software in network course practices and a website to assist teachers in developing a suitable didactic sequence to be used during laboratory practices. NetEnsina promises to offer a digital Cloud environment of computers with pre-built virtual machines set with the required capacity to utilise the Netkit software in addition to the online website. The computers may be accessible through the Internet from any location, allowing students to practice the virtual laboratories without having to install all the required software on their own computers.

5.1.2. Using Netkit on NetEnsina Cloud

The following actions are taken in order to install Netkit on NetEnsina:

- Check for compatibility: Make sure the NetEnsina Cloud environment can fulfill the requirements needed to execute Netkit. Verify the availability of UML and the installation of the necessary kernel modules and dependencies.

- VM setup: In the NetEnsina Cloud environment, create virtual machines (VMs). In our network simulation, each VM will stand in for a Netkit node. To allow connectivity, configure the virtual machines (VMs) with the proper networking settings.

- Install Netkit: Within the NetEnsina Cloud environment, install Netkit on every virtual machine. Depending on the particular cloud environment, we might need to assemble and setup the Netkit components, including UML and the required network virtualization tools.

- Establish Netkit topology: Use Netkit configuration files to plan and specify our network topology. For every Netkit node in our simulation, provide its virtual network interfaces, IP addresses, routing tables, and other network properties.

- Launch the simulation: Start the Netkit simulation by launching the Netkit virtual machines within the NetEnsina Cloud environment. Ensure that the networking is properly configured and that the VMs can communicate with each other.

- Test and validate: Once the Netkit simulation is running, we can test and validate our network configurations and experiment with various network scenarios. Use standard networking tools and protocols within the Netkit environment to analyse network behaviour and performance.

- To configure network, users will need to download particular configuration files for each experiment in order to run the Netkit labs (see Section 4.4).

5.1.3. Netkit employment Inside NetEnsina Framework

Netkit is a program that mimics whole computer network topologies, enabling the virtualisation of the widest range of network components using virtual labs, as was previously discussed in this review. These laboratories are operated by reading text files that have already been setup, from which Netkit generates the necessary virtual components. The teacher requires a didactic script that students must follow in order to teach computer networks utilising Netkit and virtual labs. A text file including detailed instructions for each activity that will be produced throughout the semester. For example, a file with the series of instructions the learner has to enter into the virtual machine to set the IP address and netmask.

Users of Netkit are free to customize the text files anyway they see fit, depending on the laboratory that will be using them. The instructor must next design the step-by-step instructions for practical sessions based on the experiences they want their students to have in the already set up virtual machines. In summation, in order to conduct a practical class using Netkit, the instructor must make the virtual machines' configuration files, or the laboratory itself, available to the students, as well as a text file containing the script that will be used to create the laboratory activity.

Although Netkit is a helpful tool for teaching computer networks, setting it up and configuring it can be difficult and time-consuming for users with limited computer expertise, especially for those unfamiliar with the Linux operating system because Netkit only runs on this platform. New users are frequently discouraged from using the program due to certain challenges and the requirement to utilise a certain OS. The teaching environment in NetEnsina is a computer network where the instructor may sign in and make all the materials available to the students. Also, there are labs, tutorials, didactic scripts, and particularly virtual computers that have Netkit installed and configured and are ready for use. As a result, this procedure is clear to the user, in this case, the students, and the instructor is able to provide the class with a full-fledged laboratory environment for the practice of network disciplines.

5.2 NetEnsina Cloud

This section includes Cloud architecture, Netkit servers on AWS and NetEnsina web portal.

5.2.1. Architecture of Cloud

A prevalent issue that affects institutes, schools, universities, and other educational institutions is the variance in the number of students for each course or academic session. Practical classes are unavoidably impacted by this fluctuation in enrollment. It applies equally to computer network disciplines. In order to be successful, computer courses must include laboratory work. This, in turn, necessitates the bare minimum of technical equipment required for the course to function, which results in expenditures, especially in network disciplines that demand numerous computational resources. The volatility in student enrollment makes it challenging to estimate how many resources will be needed during the school year, which can lead to excesses or reductions in their acquisition and have a detrimental impact on both the economic and academic elements.

Simulators are a useful tool for computer network courses because they provide laboratory practice without requiring the purchase of computer components, which lowers the cost. In accordance with this work, NetEnsina will offer a virtual setting for this laboratory exercise. Using of Cloud computing, NetEnsina Cloud seeks to expand on this idea somewhat. Elasticity is one of the features of Cloud computing, which enables handling continuously changing demand at a cost that also fluctuates depending on the need and what is used. To benefit from this provider's horizontal flexibility, NetEnsina Cloud was created wholly within the Amazon Cloud environment. The NetEnsina Cloud architecture is split into two parts: the back end, made up of Netkit servers, which will be used as a foundation for building new instances with similar

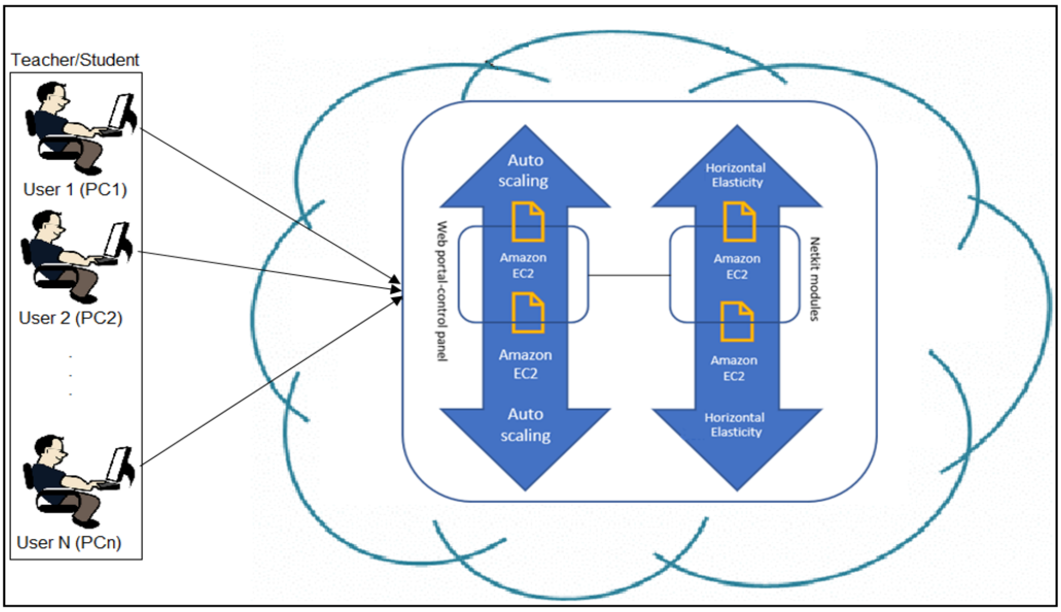

Fig. 11. Architecture of NetEnsina Cloud

properties and configurations, and the front end, made up of the web servers in charge of the web portal. Figure 11 depicts NetEnsina Cloud Architecture.

5.2.2. Netkit Servers

When we think about servers, we typically picture machines with incredibly powerful hardware and software that have been set up to handle heavy workloads. This thought cannot be based on that concept. With a text-based interface and minimal computing requirements, Netkit is a lightweight program that performs satisfactorily. With only 32 memory of RAM, each virtual computer that Netkit emulates runs a Debian operating system. This will enable many Netkit machines to operate simultaneously on a single computer with limited physical memory, opening up entire laboratories with additional network components. As a result, in this work, the phrase "Netkit server" exclusively refers to a virtual machine—more specifically, an EC2 instance—that has Netkit installed, configured, and ready for use. This instance will then be used as an AMI, a template for building new instances based on the number of virtual machines required to meet a certain lab demand. This is one benefit of applying Cloud computing to this project.

In a typical networking class, the instructor or technical manager has to have advanced access to the physical lab to assess how each system is being used and carry out any required maintenance, such as formatting or installing particular software. Each computer must go through this procedure separately, which takes a long time. Also, depending on the issue, this step needs to be repeated if there is a problem during the course or if the equipment is misused. As it is sufficient to setup a single machine, i.e., the EC2 instance named Netkit server, and from there build new equal instances through the AMI, the adoption of the Cloud-based Netkit helped to minimize this issue. Using the Internet, these may be accessible from anywhere. This makes it quite easy to set up new virtual courses in practice. Consider a scenario in which an instructor begins a course with a group of 50 students and mandates that all of them use Netkit to practice the material. The instructor only needs to enter the Amazon interface to generate 50 virtual computers that are already set up with Netkit and all the other components required for the virtual lab. With just an Internet connection, the students may use these devices independently from any computer, anywhere, and follow the instructions that the instructor supplied for the lab practice. All of this was accomplished in a transparent manner without the students even being aware of the location of the virtual machines or the installation and setup procedures required to use Netkit.

The instructor may easily erase these virtual computers at the conclusion of the course to avoid paying for their use and make use of the pay-per-use Cloud computing functionality. In other words, leveraging the advantages of horizontal elasticity, the teacher or the person in charge of Cloud management will be able to manually generate or remove EC2 instances. Another issue with portability is solved by using Netkit on the Cloud. As Linux environments are the only ones where Netkit functions, users are frequently deterred from using other systems. Once the program is in the Cloud, it may be accessed from any computer, regardless of operating system, as long as it is linked to the Internet.

A framework of options for laboratory practice is created by the user, teacher, or student installing and configuring additional applications to be utilised throughout the courses in addition to Netkit.

5.2.3. Web Portal of NetEnsina

All folders and text files that will be read by the platform must be made available for the practical laboratory class using Netkit, as was specified at the beginning of this section, in order for virtual machines to be generated that match the standards outlined therein. Students must also use virtual machines to create a file that contains step-by-step instructions. A didactic script demonstrating the instructions to set up packet forwarding routes on a router serves as an example. According to the experiences users wish to emulate in Netkit, they are able to create their own labs and teaching materials. Users can search the Internet for various ready-to-download laboratories and utilise them if they do not want to create the labs themselves. Teachers may organise their Netkit virtual laboratories using the NetEnsina web portal. The platform enables the instructor to put into practice lesson plans that follow a didactic order determined by the knowledge that has to be taught to the students.

Consider a situation where a teacher wishes to have his or her students experience setting up and configuring a computer network using Netkit. This instructor will be able to design virtual laboratories using the NetEnsina application and make them accessible to their students in the order they choose is best for the consolidation of information. For instance, in a basic course, the instructor may begin with a straightforward lab with only two machines, then go on to laboratories with switches, labs with routers, etc. Using an AMI that was made available on the AWS platform, the NetEnsina portal was created. With the installation and configuration of the Apache web server, PHP, MySql, and WordPress modules, this AMI offers an EC2 instance prepared for use as a web server. The Cloud service makes it easier to create dynamic websites since, upon selecting an image that meets these specifications, all of these components are instantly available without the need for human configuration. The developer just has to focus on constructing the web gateway because all these procedures are transparent.

5.3 Estimation of Cost

Services provided by Amazon are charged by the hour and by the type of resource hired. For example, storage services charge per gigabyte consumed. Amazon offers 750 hours of utilisation of t2.micro EC2 instances every month for a whole year as part of its free offerings. T2.micro instances now provide a 1.2 GHz Intel Xeon vCPU, 1 Gigabyte of Memory, and 8 Gigabytes of storage (June/July 2021). Enough computing capability to operate Netkit efficiently, as it requires few computing resources to do so. In this way, the portion of unrestricted services adequately supported the tests at this time. After the trial period, a t2.micro instance costs about US $9.05 per month as of the time of this study. For machines employed in the USA, in the Texas and Virginia availability zones, this is assuming the VM is on for 24 hours, every day of the week. No sums will be charged for the resource's inactivity once the VM is switched off. An EC2 instance of type t2. medium was hired for the web server. It comes with two 1.2 GHz Intel Xeon vCPUs and 4 GB of memory and is not included in the free AWS services. Its monthly cost is approximately US$36.00 for machines hired in the USA, in the Texas and Virginia availability zone, for 24-hour use every day of the week. AWS offers an online calculator where the expenses may be estimated prior to contracting the service in order to make it simpler for the customer while contracting the resource. See Figure 12, which shows the AWS calculator. Users select the service, set the time and dates for payment, and record the amounts due. These values vary according to the geographic area and length of the contract where the services are provided. The value of the identical cases in the Virginia area of the United States is shown in Figure 12. Instances that are farther apart have a higher chance of experiencing service delay; as a result, the value should not be the only factor to be considered. Each situation requires an examination to be done individually. AWS was selected for this study because it is regarded as a standard in the field of Cloud computing and because it meets all criteria for carrying out the tests that served as the foundation for the entire study. It is substantial to note, however, that there are other additional Cloud service providers on the market, each with unique features, offerings, and prices.

5.3.1. Solutions and Software of Open-Source

The opportunity to learn from mistakes is a crucial feature of these tools, from the straightforward multiple-choice questions that provide students immediate feedback to the interoperability tests and peer evaluations that motivate the users to offer helpful criticism. The open educational resources can be forked, adapted, and contributed to by other networking educators [44]. A provider's selection and the finest network design tool both demand careful consideration. There are free, open-source alternatives to for-profit Cloud services like Amazon, Azure, and Google that allow businesses to set up private Clouds with their own rules. The Eucalyptus project stands out in this context because of its collection of web services, IaaS service models, and Amazon compatibility. Open-source software called Eucalyptus makes advantage of workstation farms and clusters. In order to verify security, scalability, stability, and interface implementation,

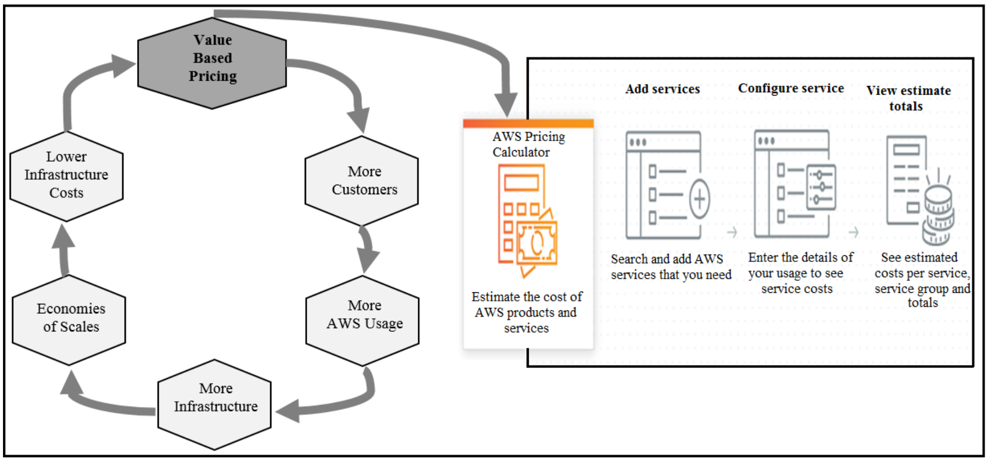

Fig. 12. AWS services calculator

Eucalyptus was created to be totally modular [80].

Eucalyptus shares infrastructure-related qualities to execute the IaaS service model, such as a single management interface, APIs for interfacing with other hosts, switches, and routers, and a clear and straightforward approach to install new equipment [81]. Computing network service models can be migrated to Cloud computing using open-source Cloud infrastructures. The user must research their options and select the best one for them. Studies that compare Cloud services exist to assist users in selecting the most complete service. Neither this review compares nor endorses any particular Cloud service providers. Distributed systems and resource sharing are addressed by Cloud computing.

6. PERSPECTIVES OF TOPICS

NetEnsina can be used as a didactic aid in courses on computer networks to assist instructors with lab work. A teacher can build up a didactic approach to aid in the consolidation of previously explained theoretical knowledge using NetEnsina to generate teaching modules, construct a sequence of practical lessons to be carried out with his or her students, and create teaching modules. Classes are more dynamic and productive because of NetEnsina's Cloud implementation and the presence of Netkit on this platform. Instead of needing many computers, students may use each one as a possible lab, imitating virtual machines and associated devices to test the information taught in network disciplines. Students are not restricted to physical labs or set class periods once the tool and its laboratories are on the Cloud. On any computer with an Internet connection, students may utilise NetEnsina to practice their knowledge. Three straightforward examples are provided in this study to enable individuals who are not familiar with Netkit labs to comprehend. The setup of two computers, including their IP addresses and network masks, is taken into account in the first text file. In the second, four PCs are joined by a switch to imitate a network. The third shows how to manually set up static routes on two routers to join two networks.

7. OBSTACLES OF RESEARCH STUDY

The needs of the experimenter cannot be met by conventional laboratories. Virtual Laboratory is a novel study approach for experimental science that has been made possible by the ongoing development of Internet, simulation, and virtual reality technologies [82]. The following stand out among the barriers and challenges that were overcome and/or reduced throughout the research:

- Picking a virtual lab simulation tool: There are many tools (such as Netkit, VNUML, MLN, Xen . . . etc.) used in existing studies for the purposes of virtual laboratories. The selection of Netkit for this study was based on an in-depth study in considering it the most appropriate for this study (see Section 2.4).
- Deciding on the Cloud service provider to employ for the tests: Deploying or migrating a system to the Cloud presents this challenge to everyone. The system administrator must select the supplier that best meets their demands from among a variety of providers offering the widest range of services. Because it has all the requirements for the testing and a selection of free services that satisfied the need, AWS was selected for this assignment.

- Cloud configuration of Netkit VMs: Virtual machines are available from Amazon in a variety of configurations, with varied prices based on computing power. Finding the right equipment at this time was the issue; otherwise, money would be wasted on unneeded hiring and resources would go unused. It was chosen to utilise t2.micro VMs after conducting a number of experiments since Netkit emulates virtual terminals in text mode, which necessitates less computing power from the computer.
- Tool deployment using elasticity: As long as the server machine has sufficient computational capacity, several client machines can connect to VMs simultaneously via SSH protocol.
- Compatibility of different technologies to work in the educational environment: The use of several technologies (such as AWS, Cloud computing, Netkit, NetEnsina . . . etc.) raises some concerns about their applicability to work in a single approach. Although these technologies are appropriately suited to the application of virtual laboratory tasks and to meet the teaching of students in educational institutions, there is still a lot of work to improve this approach as described in the next section.

This highlighted concerns about the appropriate level of flexibility to implement in Netkit servers, where it would be feasible to rent a less powerful computer and upgrade its processing capacity as necessary. Testing revealed that this strategy would not be effective for the proposed project since Netkit opens a virtual laboratory by creating a distinct OS process that enables the lab to run on numerous client PCs. Hence, to operate Netkit with adequate performance, modest virtual machines were hired.

8. EDUCATORS AND INSTITUTIONS' RECOMMENDATIONS FOR ADOPTING NETKIT VIRTUAL LABS

There is a set of recommendations for educators and institutions that should be adopted when using virtual labs such as NetKit for teaching/learning computer networking.

- Determine teaching necessities and learning objectives: Educators should pay close attention to the particular skills educators want students to acquire as well as the course curriculum and learning objectives. Ascertain is the most effective way for virtual laboratories to assist these objectives and improve the learning process as a whole.
- Analyze platform options: Educators and institutions should look into and contrast several virtual lab platforms, such as NetKit, Xen, and Kathara. Educators should focus on features like pricing, simplicity, flexibility, security of usage, usefulness, and degree of support offered.
- Assure technical readiness: Confirm that your institution/school has the IT and ICT support, computer power, and dependable Internet access needed to set up and manage the virtual lab environment such as Netkit.
- Institution/school curriculum integration: It should be recommended to easily incorporate the online lab exercises into the syllabus for the institution course. Create lab activities, homework assignments, and evaluations that support the theoretical ideas covered in the classroom and are in line with the institution's learning/teaching goals.
- Educate teachers/students continuously: Educating teachers and students throughout on how to use the virtual lab platform is recommended. This covers instructions for configuring accounts, using the interface, and resolving frequent problems.
- Applying practical experiences: Design the online lab exercises so that students have lots of chances to practice using networking principles in real-world settings, solve problems, and conduct hands-on experiments.
- Collect input and keep Enhancing: To find areas for development, handle any difficulties, and keep improving the virtual lab implementation, gather input from educators and students on a regular basis.

9. OPEN ISSUES AND FUTURE ASPIRATIONS

There are several important issues that require attention and addressed, which could be open issues and important in this field.

- Verifying the NetEnsina Cloud environment's usability and educational value in a classroom setting.
- Evaluating the feasibility of moving NetEnsina from Amazon web services to open-source, hence lowering installation costs.

- The use of deep learning can support virtual labs by predicting and determining the best choice for students and teachers. This method can enable students and teachers to enter some information into virtual laboratory tools (such as Netkit) to select appropriate topics for either teaching or learning.

- To further simplify the configuration of virtual networks, user interface enhancements, lab self-testing, more options, and support for unintended mistake checks should be included in the future.

- Building up a mixed platform with a lab that has both actual and virtual equipment that is "co-present" at the same time. Using virtual reality and mixed reality, some students will be virtually present in the lab while others will be physically present.

- The creation of control tools (hardware and software) enabling collaborative work between a remote Netkit lab and a physical design for process control education.

- Further educational datasets, maybe additional teaching information distribution models, training models, and post-modeling analysis tools will all be highlighted in future Netkit development.

- Some of the research efforts should be focused on the compatibility of the OSs platform for the VMs and the integration of many VMs in order to provide a more efficient and user-friendly virtual environment for emulating Netkit networks.

- Also, one of our future inclinations will be a focus on cybersecurity education material. Where collaborative learning, gamification, and social interaction are among the engagement and learning tactics.

- One of the important topics in virtual e-learning is protecting the information of students and teachers when it is transmitted in unsecured channels (the Internet) and securing their privacy. We aim to protect personal information and education data entered into Netkit lab with secure encryption and signature mechanisms.

- We plan to provide practical details/data of experiments about a sample-specific application using Netkit and AWS-Clouds as technical tool to establish a simple virtual network i.e. setting protocols, hubs, switches, routers, proxy and firewalls for teaching-learning purposes.

10. CONCLUSION

In education institutions, teaching/learning continues to adapt and develop, incorporating new methods, resources, and pedagogical tools to make it more appealing, interesting, and effective. Technologies have been added to education that make it easier for teachers and students to share knowledge. Tablets, laptops, and data displays are everyday familiar items. Virtual learning environments, which imitate classrooms and laboratories in their interfaces, might be added to the list of resources above. Virtual environments do not need a physical framework, making them portable and affordable. This review introduces a Cloud-based, Netkit-based virtual learning environment for computer networks courses and disciplines. Physical computer network laboratories are impractical due to the high setup and maintenance costs. Instead, this subject is taught through learning units, primarily on public networks. As a result of Netkit, we are able to emulate real-world network devices and topologies with a variety of configurations and details close to those of a real network. Using simply a computer, students may practice classroom concepts. Since it expands the pool of people who can access and utilise the free software, which can only be used with Linux, this study covers leveraging the Cloud to install and use Netkit. We made Netkit portable by storing it in the Cloud, making it accessible from any Internet-connected device, independent of OS. On Amazon's AWS Cloud, instructors and students may create NetKit virtual computers. As a result, computer networking lessons may be done from any computer with Internet connectivity, without requiring any additional configuration. The use of Cloud is encouraged by scalability and on-demand costs. However, since the system may be duplicated to accommodate a much higher demand from users utilising the Cloud service's horizontal elasticity feature, we need not be concerned with the physical structure where the system will be configured. Inactivity fees will not be applied to this resource. Moreover, a website with instructional scripts was made. Lab practice may be organised by instructors/teachers using the website to write scripts and make their Netkit laboratories available to students.

Conflicts Of Interest

The authors declare that they have no conflict of interest.

Funding

This review paper received no external funding.

REFERENCES

[1] A. Kundu and K. Dey, “Barriers to utilizing ICT in education in India with a special focus on rural areas,” *International Journal of Scientific Research and Reviews*, vol. 7, no. 2, pp. 341–359, 2018.
[2] A. Kundu, T. Bej, and K. N. Dey, “An empirical study on the correlation between teacher efficacy and ICT infrastructure,” *The International Journal of Information and Learning Technology*, vol. 37, no. 4, pp. 213–238, 2020.
[3] V. Arkorful, K. A. Barfi, and I. K. Aboagye, “Integration of information and communication technology in teaching: Initial perspectives of senior high school teachers in Ghana,” *Education and Information Technologies*, vol. 26, pp. 3771–3787, 2021.
[4] E. E. Abel and M. S. A. Latiff, “The utilization of algorithms for cloud Internet of things application domains: A review,” *Frontiers of Computer Science*, vol. 15, pp. 1–27, 2021.
[5] M. Scazzariello, L. Ariemma, and T. Caiazzi, “Kathará: A lightweight network emulation system,” in *NOMS 2020-2020 IEEE/IFIP Network Operations and Management Symposium*. IEEE, 2020, pp. 1–2.
[6] S. Chapman, R. Smith, L. Maglaras, and H. Janicke, “Can a network attack be simulated in an emulated environment for network security training?” *Journal of Sensor and Actuator Networks*, vol. 6, no. 3, p. 16, 2017.
[7] Z. Wang, “Foreign language teaching and intercultural communicative based on network environment and cloud computing platform,” in *Data Processing Techniques and Applications for Cyber-Physical Systems (DPTA 2019)*. Springer, 2020, pp. 1773–1780.
[8] M. Rimondini, “Emulation of computer networks with Netkit,” 2007.
[9] M. Prvan and J. Ožegović, “Methods in teaching computer networks: A literature review,” *ACM Transactions on Computing Education (TOCE)*, vol. 20, no. 3, pp. 1–35, 2020.
[10] J. Haag, H. Vranken, and M. van Eekelen, “A virtual classroom for cybersecurity education,” *Transactions on Edutainment XV*, pp. 173–208, 2019.
[11] L. Mishra, T. Gupta, and A. Shree, “Online teaching-learning in higher education during lockdown period of COVID-19 pandemic,” *International Journal of Educational Research Open*, vol. 1, p. 100012, 2020.
[12] K. A. Gamage, D. I. Wijesuriya, S. Y. Ekanayake, A. E. Rennie, C. G. Lambert, and N. Gunawardhana, “Online delivery of teaching and laboratory practices: Continuity of university programmes during COVID-19 pandemic,” *Education Sciences*, vol. 10, no. 10, p. 291, 2020.
[13] S. M. Sepasgozar, “Digital twin and web-based virtual gaming technologies for online education: A case of construction management and engineering,” *Applied Sciences*, vol. 10, no. 13, p. 4678, 2020.
[14] M. Klement, “Models of integration of virtualization in education: Virtualization technology and possibilities of its use in education,” *Computers & Education*, vol. 105, pp. 31–43, 2017.
[15] F. K. Parast, C. Sindhav, S. Nikam, H. I. Yekta, K. B. Kent, and S. Hakak, “Cloud computing security: A survey of service-based models,” *Computers & Security*, vol. 114, p. 102580, 2022.
[16] J. Alonso, L. Orue-Echevarria, and M. Huarte, “CloudOps: Towards the operationalization of the cloud continuum: Concepts, challenges and a reference framework,” *Applied Sciences*, vol. 12, no. 9, p. 4347, 2022.
[17] M. Brantner, D. Florescu, D. Graf, D. Kossmann, and T. Kraska, “Building a database on S3,” in *Proceedings of the 2008 ACM SIGMOD international conference on Management of data*, 2008, pp. 251–264.
[18] E. F. Coutinho, F. R. de Carvalho Sousa, P. A. L. Rego, D. G. Gomes, and J. N. de Souza, “Elasticity in cloud computing: A survey,” *annals of telecommunications-annales des télécommunications*, vol. 70, pp. 289–309, 2015.
[19] I. M. Gómez-Trigueros, M. Ruiz-Bañuls, and D. Ortega-Sánchez, “Digital literacy of teachers in training: Moving from ICTs (information and communication technologies) to LKTs (learning and knowledge technologies),” *Education Sciences*, vol. 9, no. 4, p. 274, 2019.
[20] P. H. Gurgel, L. H. Branco, E. F. Barbosa, and K. R. Branco, “Development of a practical computer network course through netkit virtualization tool,” *Procedia Computer Science*, vol. 18, pp. 2583–2586, 2013.
[21] Y. Ariyanto, Y. W. Syaifudin, and B. Harijanto, “Performance analysis of network emulator based on the use of resources in virtual laboratory,” in *2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*. IEEE, 2017, pp. 1–6.
[22] J. Haag, “DVCL: A distributed virtual computer lab for security and network education,” Ph.D. dissertation, The Open University, 2018.
[23] M. Pizzonia and M. Rimondini, “Netkit: Easy emulation of complex networks on inexpensive hardware,” in *4th International ICST Conference on Testbeds and Research Infrastructures for the Development of Networks & Communities*, 2010.
[24] F. G. Márquez and D. F. Cambronero, “Distributed virtualization scenarios using VNUML,” in *1st International DMTF Academic Alliance Workshop on Systems and Virtualization Management: Standards and New Technologies*, vol. 2007, 2007.
[25] A. Ruiz-Martínez, R. Marín López, F. Pereñíguez-García, P. M. Ruiz Martínez, and A. F. Gómez Skarmeta, “Experience with the VNUML virtualization tool for teaching computer networks,” 2010.
[26] F. Galán, D. Fernández, W. Fuertes, M. Gómez, and J. E. López de Vergara, “Scenario-based virtual network infrastructure management in research and educational testbeds with VNUML: Application cases and current challenges,” *Annals of telecommunications-annales des télécommunications*, vol. 64, pp. 305–323, 2009.
[27] J. Á. González and F. López Pires, “Evaluación de convergencia del protocolo ospf en redes definidas por software,” in *XXV Congreso Argentino de Ciencias de la Computación (CACIC)(Universidad Nacional de Río Cuarto, Córdoba, 14 al 18 de octubre de 2019)*, 2019.
[28] A. Gaspar, S. Langevin, W. Armitage, and M. Rideout, “Enabling new pedagogies in operating systems and networking courses with state of the art open source kernel and virtualization technologies,” *Journal of Computing Sciences in Colleges*, vol. 23, no. 5, pp. 189–198, 2008.
[29] A. Gaspar, S. Langevin, W. D. Armitage, and M. Rideout, “March of the (virtual) machines: Past, present, and future milestones in the adoption of virtualization in computing education,” *Journal of Computing Sciences in Colleges*, vol. 23, no. 5, pp. 123–132, 2008.
[30] W. D. Armitage, A. Gaspar, and M. Rideout, “Remotely accessible sandboxed environment with application to a laboratory course in networking,” in *Proceedings of the 8th ACM SIGITE conference on Information technology education*, 2007, pp. 83–90.
[31] A. Ruiz-Martínez, F. Pereñíguez-García, R. Marín-López, P. M. Ruiz-Martínez, and A. F. Skarmeta-Gomez, “Teaching advanced concepts in computer networks: Vnuml-um virtualization tool,” *IEEE Transactions on Learning Technologies*, vol. 6, no. 1, pp. 85–96, 2013.
[32] W. M. Fuertes and J. E. L. de Vergara, “A quantitative comparison of virtual network environments based on performance measurements,” in *Proceedings of the 14th HP Software University Association Workshop, Garching, Munich, Germany*, 2007, pp. 8–11.
[33] F. Flammini, A. Gaglione, D. Tokody, and D. Dobrilović, “Virtualization technology for LoRaWAN roaming simulation in smart cities,” in *Machine Intelligence and Data Analytics for Sustainable Future Smart Cities*. Springer, 2021, pp. 251–265.

[34] M. Scazzariello, L. Ariemma, and T. Caiazzi, “Kathará: A lightweight network emulation system,” in *NOMS 2020-2020 IEEE/IFIP Network Operations and Management Symposium*. IEEE, 2020, pp. 1–2.
[35] F. Flammini, A. Gaglione, D. Tokody, and D. Dobrilović, “Virtualization technology for lorawan roaming simulation in smart cities,” in *Machine Intelligence and Data Analytics for Sustainable Future Smart Cities*. Springer, 2021, pp. 251–265.
[36] K. Cabaj, L. Caviglione, P. Georgi, J. Keller, W. Mazurczyk, and A. Schaffhauser, “Teaching cyber security through distance learning with international students,” *Innovations in Cybersecurity Education*, pp. 303–324, 2020.
[37] M. Scazzariello, L. Ariemma, and T. Caiazzi, “Kathará: A lightweight network emulation system,” in *NOMS 2020-2020 IEEE/IFIP Network Operations and Management Symposium*. IEEE, 2020, pp. 1–2.
[38] Á. Salinas, M. Nussbaum, O. Herrera, M. Solarte, and R. Aldunate, “Factors affecting the adoption of information and communication technologies in teaching,” *Education and Information Technologies*, vol. 22, pp. 2175–2196, 2017.
[39] A. Borchert, N. E. Díaz Ferreyra, and M. Heisel, “Building trustworthiness in computer-mediated introduction: A facet-oriented framework,” in *International Conference on Social Media and Society*, 2020, pp. 39–46.
[40] W. Yin, “An artificial intelligent virtual reality interactive model for distance education,” *Journal of Mathematics*, vol. 2022, pp. 1–7, 2022.
[41] A. Alam, “Cloud-based e-learning: Scaffolding the environment for adaptive e-learning ecosystem based on cloud computing infrastructure,” in *Computer Communication, Networking and IoT: Proceedings of 5th ICICC 2021, Volume 2*. Springer, 2022, pp. 1–9.
[42] I. A. Buckley, J. Zalewski, and P. J. Clarke, “Introducing a cybersecurity mindset into software engineering undergraduate courses,” *International Journal of Advanced Computer Science And Applications*, vol. 9, no. 6, 2018.
[43] J. Haag, H. Vranken, and M. van Eekelen, “A virtual classroom for cybersecurity education,” *Transactions on Edutainment XV*, pp. 173–208, 2019.
[44] O. Bonaventure, Q. De Coninck, F. Duchêne, A. Gego, M. Jadin, F. Michel, M. Piraux, C. Poncin, and O. Tilmans, “Open educational resources for computer networking,” *ACM SIGCOMM Computer Communication Review*, vol. 50, no. 3, pp. 38–45, 2020.
[45] B. Letowski, C. Lavayssière, B. Larroque, M. Schröder, and F. Luthon, “A fully open source remote laboratory for practical learning,” *Electronics*, vol. 9, no. 11, p. 1832, 2020.
[46] F. Rahman, M. S. Mim, F. B. Baishakhi, M. Hasan, and M. K. Morol, “A systematic review on interactive virtual reality laboratory,” in *Proceedings of the 2nd International Conference on Computing Advancements*, 2022, pp. 491–500.
[47] L. Baumann-Birkbeck, S. Anoopkumar-Dukie, S. A. Khan, M. O’Donoghue, and G. D. Grant, “Learner attitudes towards a virtual microbiology simulation for pharmacy student education,” *Currents in Pharmacy Teaching and Learning*, vol. 14, no. 1, pp. 13–22, 2022.
[48] A. Ishak, M. M. AlRawashdeh, M. Meletiou-Mavrotheris, and I. P. Nikas, “Virtual pathology education in medical schools worldwide during the COVID-19 pandemic: Advantages, challenges faced, and perspectives,” *Diagnostics*, vol. 12, no. 7, p. 1578, 2022.
[49] J. Hassan, A. Devi, and B. Ray, “Virtual laboratories in tertiary education: Case study analysis by learning theories,” *Education Sciences*, vol. 12, no. 8, p. 554, 2022.
[50] M. Hussain Al-Qahtani, “Teachersâ€™ and studentsâ€™ perceptions of virtual classes and the effectiveness of virtual classes in enhancing communication skills,” *Arab World English Journal (AWEJ) Special Issue: The Dynamics of EFL in Saudi Arabia*, pp. 223 –240, 2019.
[51] A. Karlov, “Virtualization in education: Information security lab in your hands,” *Physics of Particles and Nuclei Letters*, vol. 13, pp. 640–643, 2016.
[52] P. Segeč, M. Moravčík, M. Kontšek, J. Papán, J. Uramová, and O. Yeremenko, “Network virtualization tools–analysis and application in higher education,” in *2019 17th International Conference on Emerging eLearning Technologies and Applications (ICETA)*. IEEE, 2019, pp. 699–708.
[53] A. D. Dumford and A. L. Miller, “Online learning in higher education: exploring advantages and disadvantages for engagement,” *Journal of computing in higher education*, vol. 30, pp. 452–465, 2018.
[54] D. T. H. Dung, “The advantages and disadvantages of virtual learning,” *IOSR Journal of Research & Method in Education*, vol. 10, no. 3, pp. 45–48, 2020.
[55] C. Stergiou and K. E. Psannis, “Recent advances delivered by mobile cloud computing and Internet of things for big data applications: A survey,” *International Journal of Network Management*, vol. 27, no. 3, p. e1930, 2017.
[56] V. Sandeep and B. Pohutezhini, “The e-commerce revolution of amazon. com,” *Splint International Journal of Professionals*, vol. 6, no. 4, pp. 33–39, 2019.
[57] W. A. Jebbar and M. Al-Zubaidie, “Transaction-based blockchain systems security improvement employing micro-segmentation controlled by smart contracts and detection of saddle Goatfish,” *SN Computer Science*, vol. 5, no. 7, 2024.
[58] N. Hota and B. K. Pattanayak, “Cloud computing load balancing using Amazon web service technology,” in *Progress in Advanced Computing and Intelligent Engineering: Proceedings of ICACIE 2020*. Springer, 2021, pp. 661–669.
[59] N. Joshi and S. Shah, “A comprehensive survey of services provided by prevalent cloud computing environments,” in *Smart Intelligent Computing and Applications: Proceedings of the Second International Conference on SCI 2018, Volume 1*. Springer, 2019, pp. 413–424.
[60] N. Krishnaraj, K. Bellam, B. Sivakumar, and A. Daniel, “The future of cloud computing: Blockchain-based decentralized cloud/fog solutions–challenges, opportunities, and standards,” *Blockchain Security in Cloud Computing*, pp. 207–226, 2022.
[61] S. Ray and S. Srivastava, “Virtualization of science education: A lesson from the COVID-19 pandemic,” *Journal of proteins and proteomics*, vol. 11, pp. 77–80, 2020.
[62] S. Puntambekar, D. Gnesdilow, C. Dornfeld Tissenbaum, N. H. Narayanan, and N. S. Rebello, “Supporting middle school studentsâ€™ science talk: A comparison of physical and virtual labs,” *Journal of Research in Science Teaching*, vol. 58, no. 3, pp. 392–419, 2021.
[63] N. M. Tyj, “Adaptive deduplication of virtual machine images using AKKA stream to accelerate live migration process in cloud environment,” *Journal of Cloud Computing*, vol. 8, no. 1, p. 3, 2019.
[64] S. Kaiser, M. S. Haq, A. Ş. Tosun, and T. Korkmaz, “Container technologies for ARM architecture: A comprehensive survey of the state-of-the-art,” *IEEE Access*, 2022.
[65] M. Al-Zubaidie, “Implication of lightweight and robust hash function to support key exchange in health sensor networks,” *Symmetry*, vol. 15, no. 1, p. 152, 2023.
[66] D. H. Tahayur, and M. Al-Zubaidie, “Enhancing electronic agriculture data security with a blockchain-based search method and e-signatures,” *Mesopotamian Journal of CyberSecurity*, vol. 4, no. 3, p. 129–149, 2024.
[67] M. Al-Zubaidie and W. A. Jebbar, “Providing security for flash loan system using cryptocurrency wallets supported by XSALSA20 in a blockchain environment,” *Applied Sciences*, vol. 14, no. 14, p. 6361, 2024.
[68] R. A. Muhajjar, N. A. Flayh, and M. Al-Zubaidie, “A perfect security key management method for hierarchical wireless sensor networks in medical environments,” *Electronics*, vol. 12, no. 4, p. 1011, 2023.
[69] R. H. Razzaq and M. Al-Zubaidie, “Maintaining security of patient data by employing private blockchain and fog computing technologies based on Internet of medical things,” *Informatica*, vol. 48, no. 12, 2024.

[70] R. H. Razzaq and M. Al-Zubaidie, "Formulating an advanced security protocol for Internet of medical things based on blockchain and fog computing technologies," *Iraqi Journal for Computer Science and Mathematics*, vol. 5, no. 3, pp. 723–734, 2024.

[71] D. Moldovan, G. Copil, H.-L. Truong, and S. Dustdar, "Mela: Monitoring and analyzing elasticity of cloud services," in *2013 IEEE 5th International Conference on Cloud Computing Technology and Science*, vol. 1. IEEE, 2013, pp. 80–87.

[72] B. S. d. SANTOS *et al.*, "Cloud-based computer networking teaching environment," 2017.

[73] M. Zhao, Z. Li, W. Liu, J. Chen, and X. Li, "UFC2: User-friendly collaborative cloud," *IEEE Transactions on Parallel and Distributed Systems*, vol. 33, no. 9, pp. 2163–2182, 2021.

[74] N. Krumm and N. Hoffman, "Practical estimation of cloud storage costs for clinical genomic data," *Practical Laboratory Medicine*, vol. 21, p. e00168, 2020.

[75] D. Guide, "Amazon simple storage service," 2008, https://docs.aws.amazon.com/pdfs/AmazonS3/latest/userguide/s3\protect\discretionary{\char\hyphenchar\font}{}{}userguide.pdf#DataDurability.

[76] C. G. Ralha, A. H. Mendes, L. A. Laranjeira, A. P. Araújo, and A. C. Melo, "Multiagent system for dynamic resource provisioning in cloud computing platforms," *Future Generation Computer Systems*, vol. 94, pp. 80–96, 2019.

[77] S. Mayoof, H. Alaswad, S. Aljeshi, A. Tarafa, and W. Elmedany, "A hybrid circuits-cloud: Development of a low-cost secure cloud-based collaborative platform for A/D circuits in virtual hardware E-lab," *Ain Shams Engineering Journal*, vol. 12, no. 2, pp. 1197–1209, 2021.

[78] C. P. Lee, A. S. Uluagac, K. D. Fairbanks, and J. A. Copeland, "The design of NetSecLab: A small competition-based network security lab," *IEEE Transactions on Education*, vol. 54, no. 1, pp. 149–155, 2010.

[79] M. Menzel, R. Warschofsky, I. Thomas, C. Willems, and C. Meinel, "The service security lab: A model-driven platform to compose and explore service security in the cloud," in *2010 6th World Congress on Services*. IEEE, 2010, pp. 115–122.

[80] A. Alqahtani and H. Gull, "Cloud computing and security issues-a review of amazon web services," *Int J Appl Eng Res*, vol. 13, no. 22, pp. 16 077–16 084, 2018.

[81] S. Saisree and S. Shitharth, "A comprehensive study on Eucalyptus, open stack and cloud stack," in *Artificial Intelligence and Data Science: First International Conference, ICAIDS 2021, Hyderabad, India, December 17–18, 2021, Revised Selected Papers*. Springer, 2022, pp. 404–418.

[82] H. Chen, "Research and realization of network virtual optical laboratory," in *2016 2nd Workshop on Advanced Research and Technology in Industry Applications (WARTIA-16)*. Atlantis Press, 2016, pp. 223–226.