Automated Dynamic Topology Configuration

An Innovative Approach to Online Rack Renting

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***Abstract*— The facility to rent access-time to computer network hardware on the Internet has been available for a number of years. Provided as a service targeted at academics engaging in the study of Computer Networks, it has been a viable solution successfully filling the void created by numerous obstacles encountered in procuring physical equipment due to various factors. However, current business models offer limited flexibility to end users because the online labs are offered as a predetermined selection of devices prewired to a topology deemed suitable by the service provider; consequently the end user, although paying for this service, has no control over the composition or topology of the labs they hire. This paper introduces a new improved model and the underlying technological implementation, which features a paradigm shift in the way online labs are defined, configured and ultimately offered to the end user. It aspires to eliminate the above limitations through automated and dynamic configuration of the network topology, allowing the end user to select the composition and topology of the labs they hire, thus unleashing their true potential.**

Keywords-online rack rental; dynamic topology configuration; Layer 2 Protocol Tunneling; VLAN

I. INTRODUCTION

The facility to rent access-time to computer network hardware on the Internet (also called online rack rental) has been available for a number of years. Provided as a service targeted mainly at students, academics and professionals engaging in the study of Computer Networks, it has been a viable solution successfully filling the void created by various impracticalities in economics and logistics of procuring physical networks equipment.

The demand on modern education systems to provision around-the-clock access to IT resources is conspicuous and the ability to meet that demand is no more a nicety but a necessity. Online rack rental systems are therefore an ideal platform to provide students with the means to configure and test network configurations without having to worry about economical or logistical confines. However, existing online rack rental systems suffer from some restrictions which limit the flexibility they offer to end users. Service providers offer a predetermined selection of devices prewired to a specific topology that they deem suitable. Therefore when renting a lab, the user would not only hire access-time to the devices but also the topology that comes with it.

Generally, a prospective client would browse the available labs and select one or more that best fits their requirements. Consequently, a lab may not be an exact match of the user's requirements; it may be comprised of too few or too many devices, and/or may not offer the topology they require. In the former case, the user could be paying for redundant devices, which could otherwise have been rented out to other users or shutdown providing a reduced environmental footprint. Most service providers offer a full or partial mesh topology on their labs where possible, to work around the latter [1].

Root cause analysis conducted to find the underlying cause(s) for the above limitations have yielded some interesting results, as shown in Figure 1. It is evident that the limitations discussed above stem from the presence of a prewired topology. Therefore, if it is possible to eliminate the presence of a prewired topology, such a solution would minimize, if not eradicate, the above limitations and provide a better experience to both end users and the service provider. The authors have not come across any previous work which has identified these limitations with an online rack rental system. Therefore, this research is characteristically novel in its field. As a result, implementation of the fundamental technical concepts has been empirical in nature.

This research paper introduces a new approach to online rack renting by moving the definition of a lab from one which is static and predetermined by the service provider, to dynamic composition of network devices selected by the end user where they only pay for what they use and are able to dynamically configure a topology of their choice. Users who hire labs from the same service provider are able to collaborate notwithstanding geographical boundaries, by networking their individual labs, provided the labs are on the same platform. By adapting their business model to accommodate an automatic, dynamically configurable lab platform for the provision of online rack rental systems, the service provider makes substantial gains as a result of increased revenue opportunities by retaining a more satisfied client base, optimum utilisation of merchandise, reduced electricity costs and promoting a greener business ethos. These lab models could be sold as service packages by

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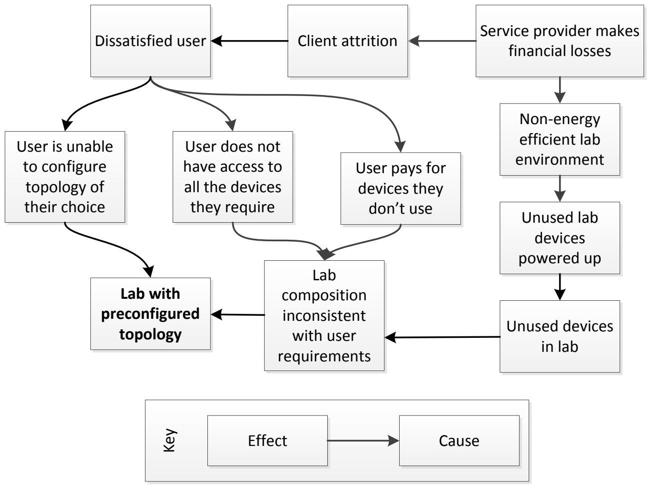

Figure 1. Root cause analysis

service providers to academic institutions through cloud hosting, helping institutions save on initial capital expenditure and recurring expenses on maintenance contracts.

A. *Problem Domain*

Normally, a service provider would have an assortment of devices similar to that given in Figure 2 (usually, although not essentially, on a larger scale). Consider two users X and Y (see Table 1) who have different device requirements. User X may hire either lab, but will be unable to source both the routers required, unless he/she hires both labs. However, by doing so they would also be paying for a redundant switch, and as each lab is intended to be rented out separately, they are self-contained and do not offer networking between them.

Either lab would address User Y's requirements; however they would also inevitably be paying for a redundant router. Ultimately neither user's requirements are fully met despite the service provider being in possession of an adequate number of devices to be able to do so.

TABLE 1. EXAMPLE USER REQUIREMENTS

User	Device requirement	
	Routers	*Switches*
X	2	1
Y	0	1

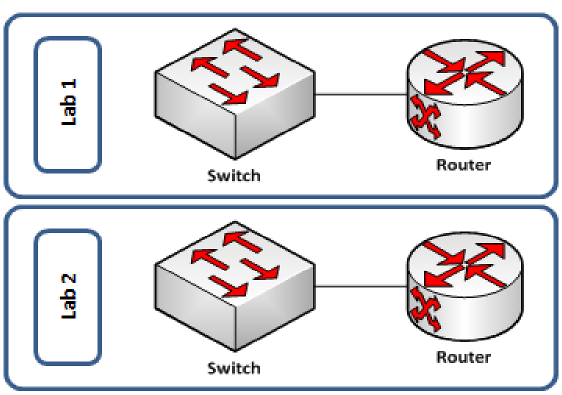

Figure 2. Example setup of current online rack rental system

B. *The Proposition*

Having identified the root cause of the problem, the principal research focus of this paper was on developing a mechanism which would enable service providers to offer labs independent of a prewired topology, where the end user would be able to dynamically configure a topology as they wish. A prospective solution must satisfy some fundamental requirements to qualify as a successful solution. It should (a) remain transparent to the end user; (b) not interfere with the devices being offered in a way which impedes their normal operation; (c) allow users to determine the composition of and dynamically alter their lab both in terms of its constituent devices and topology; and (d) require minimal involvement from the end user to setup and manage.

As we seek a solution where the devices being offered to users (hereinafter referred to as user devices) are not prewired to each other in the normal fashion, naturally this prompted us to explore various network devices which would be configurable by the service provider, thereby connecting user devices as and when required and severing those connections when they are not required. Our device of choice should meet the requirements identified above. Further, the authors were primarily interested in developing a solution which would benefit an academic audience. Therefore, in addition to the primary requirements, our solution should enable this facility to be provisioned as a service package to academic institutions and, where such institutions choose to offer online racks to its students, our solution should facilitate the option to provide the online labs as collaborative networking platforms to their students.

In the Methodology section we will explore several approaches which were considered when selecting a viable solution, the chosen method and justification to the same. The Implementation section contains a detailed description of the technical application of the new model along with a comprehensive example. In this section we will also discuss how a new business model could evolve around the new technical capabilities the new model offers and its relevance to an academic audience. In the discussion section, we will evaluate our solution's fit-for-purpose and acknowledge its limitations offering workarounds where possible. This paper concludes by identifying avenues which may lead to future work.

II. METHODOLOGY

The fundamental concept proposed by this paper is to eliminate inter-device connections by connecting all user devices to a Central Device (CD). The service provider would then configure the CD to restrict communication between user devices connected to its ports by setting up and severing connections between them. Figure 3 helps visualise this concept. Two user devices would be able to communicate with each other only if the CD permits. By altering the configuration, permission can be granted or denied, therefore dynamic. By delegating a bespoke application to monitor user requirements, script and forward the appropriate configuration commands to the CD, the above process can be automated. Therefore, the end result

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would be a system capable of automated dynamic topology configuration on an online rack rental platform.

A. Physical segmentation

Several candidates were considered for the role of CD. Network segmentation devices (see [2]) considered were bridges, hubs, switches and routers. A bridge normally has two ports. This makes it an ideal medium to interconnect two Local Area Networks, but not so much to interconnect more than two devices. A hub, on the other hand, has several ports, but by nature they forward traffic out on all ports bar the ingress port; this would not be suitable as we need to be able to restrict traffic between devices. A router is characteristically a device used to segment networks. It sections broadcast domains. Each network segment connected to a router would be a subnet on its own and would normally have its own IP addressing scheme. Each port will need to be addressed with an address from their respective subnet address pools. This is not merely a feature of a router, but also a requirement. Two interfaces on a router cannot have addresses on the same subnet. Therefore a routing protocol would need to be employed to facilitate inter-device communication. Invariably this would introduce routing table lookup delays on traffic traversing the CD.

OSI Layer 1, 2 and 3 switches were considered. Physical Layer switches have been used for network testing purposes for a number of years. Commonly referred to as "wire-once infrastructure", they replace the manual patch panel and allows users to program a connection from any port to any other port within the system using a non-blocking switching matrix [3]. Justification for both initial and recurring investment is the return on investment the device provides. In an industrial test environment physical layer switches offer an array of advanced features conducive to test lab automation [4], which are far beyond the requirements of an online rack rental system designed for students of Computer Networks. For a fraction of the cost, a Layer 2 or Layer 3 switch can be obtained and maintained. On the basis that a switch (a) can offer complete Link layer segregation to (b) a relatively large number (dependent on number of available ports) of connected devices; (c) does not require assignment of an IP addressing scheme and thus (d) offers up to wire-speed data transfer rates through its ASICs without routing table lookup delays, a switch was deemed the most suitable candidate for the role of a CD.

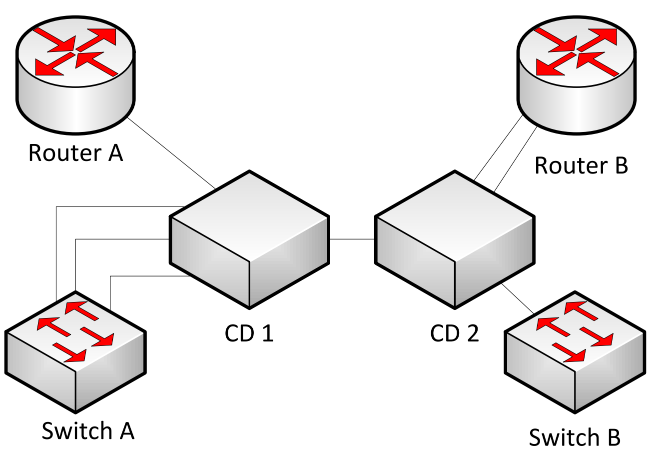

Figure 3. Example setup of proposed solution

User devices are added to the platform by connecting them to the CD. A user device can have multiple connections to the CD. The number of user device – CD connections is only limited by the number of available ports on the CD switch and on a particular user device. However, it is possible to hook up additional switches to the original CD-switch by daisy-chaining them, as shown in Figure 3, to which more user devices could then be connected.

B. Logical segmentation

Having physically segmented the network rack, the next step was to evaluate logical segmentation technologies. Virtual Local Area Network (VLAN)s are a commonly used technology in contemporary networks, which allows isolation of ports at Layer 2 and above on the device this technology is configured [5]. Inter-VLAN communication is denied by default. By configuring two ports on a network device to be on the same VLAN, we allow exclusive communication between them.

Layer 2 Protocol Tunneling (L2PT) (not to be confused with Layer 2 Tunneling Protocol) allows Internet Service Providers to carry traffic from multiple customers across their core network while preserving VLAN and other Layer 2 protocol information without impacting other customers; enabling customers to operate a consistent VLAN implementation across a Wide Area Network. L2PT tunnels Layer 2 Protocol Data Units by encapsulating them. Numerous, but not all, Layer 2 protocols can be tunneled. For instance protocols supported by Cisco Systems Inc. and Juniper Networks Inc. are given in [6] and [7], respectively. VLANs are available on both Layer 2 and 3 switches. However, L2PT is not available on Layer 2 switches. Therefore a Layer 3 switch was selected as the most suitable candidate for the role of CD.

The CD should be configured by the service provider so that when for instance, a user requests a specific port on a user device connected to a specific port on the same or another user device, the CD allows communication exclusively between the two ports on the CD(s) to which the respective ports on the user device(s) are connected, while remaining transparent. To remain transparent, the CD must preserve and relay information at Layer 2 and above between the device(s). Our solution will employ L2PT to communicate Layer 2 protocol information between any two ports on the same VLAN. Each port on the CD connected to a user device will have L2TP configured. A unique VLAN ID will be assigned to each pair of ports on the CD to which the user device ports are connected, when communication should be allowed between them. By functioning in unison, VLAN and L2PT protocols render the CD completely transparent to the end user while allowing exclusive communication between the two devices.

III. IMPLEMENTATION

The new model will consist of bespoke front-end and back-end applications to support its delivery. Patrons of

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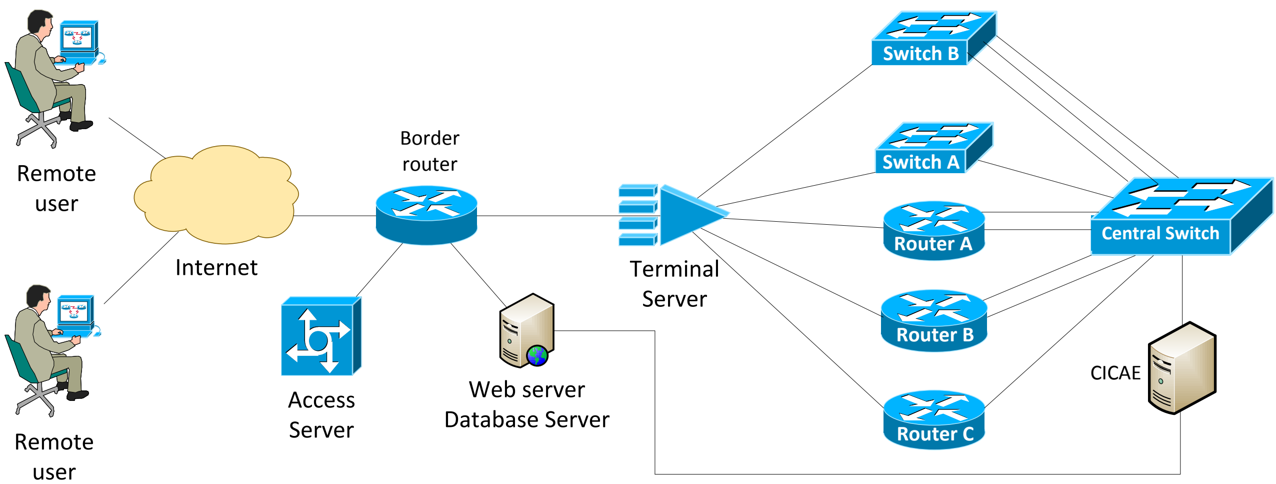

Figure 4. Graphical representation of new online rack rental model

online rack rental systems are familiar with using a web interface to make and manage reservations for rack-time. Therefore, in the interest of user familiarity, we will retain a web portal as the front-end, which will feature the ability to select devices and the topology to be used, allowing end users to build a customized lab of their choice, in addition to making and managing reservations.

To be a scalable model, the back-end is required to have some form of automation for the underlying processes. An application server (identified in Figure 4 as CICAE (Cisco IOS Command Automation Engine)) will be responsible for managing (a) a collection of CDs; (b) a collection of user devices; (c) mappings of user device port to CD port connections; (d) CD port VLAN pairs. The CICAE is not an off-the-shelf application, and was designed and developed by the authors on the Microsoft .NET platform, using the C# programming language. This application interfaces with the database server and web server to keep track of user requests and provide users access to specific devices at specific times, by scripting and issuing commands to the CD. The database server will serve as the repository for user registration/login details and lab reservation information. The terminal server provides console access to remote users. The access server is used to authenticate and authorise remotely connecting users. The border router is the gateway to and from the Internet. Figure 4 is a graphical representation of the complete solution.

The following example gives a detailed illustration of how the new model may be deployed by a service provider. This particular implementation was successfully exhibited by the author for the University dissertation presentation and thus has been practically tested and verified to be a working model. Assume ACME Online Rack Rentals Limited (a fictitious organisation) is a provider of online rack rental solutions who have implemented the new model as shown in Figure 4. After the network rack is setup and the devices connected as shown, details of the user device-CD connections are entered on to the CICAE. Each port on the CD in a connection with a user device is assigned a unique VLAN ID. It should be unique across multiple CDs. The CICAE has been programmed to assign VLAN IDs according to the following algorithm to ensure this.

- VLANs 1 – 9 reserved for administration purposes
- Add 100 for CD 1, 200 for CD 2 and so on
- Add 10 for port Fa0/1, 20 for port Fa0/2 and so on

For instance, a connection on port Fa0/16 on CD 2 would be assigned to VLAN 200 + 160 = 360.

When two ports are to be mapped to each other, the lower of the two VLAN IDs is assigned to the other port, thereby allowing traffic exclusively between the interfaces connected to that pair of ports. When the mapping is no longer required, the VLAN assignment is reset according to the above algorithm.

Two users based geographically distant from each other would like to collaborate to work on a project which involves configuring a networked system. Assume the users (User X and User Y) and their requirements are identical to those in Table 1. Both users would visit ACME's web portal where they would register their details and make a reservation each for the devices they would be working on, specifying the date/time they wish to have access to their labs depending on availability. They have agreed to work on the devices as shown in Figure 5.

The request would be stored on the database. At the

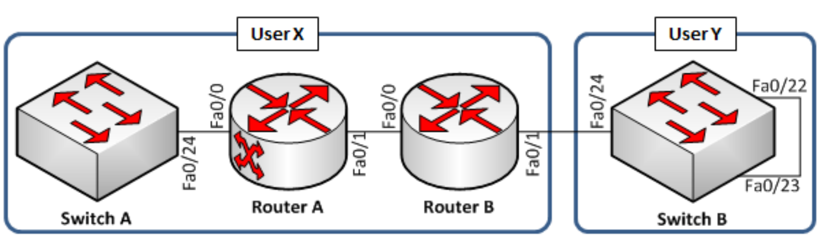

Figure 5. Example setup for collaborative working

date/time the users had requested access, the CICAE application would issue commands to the CD to setup the topology requested. Note that the date/time for each user may or may not be the same if they are working on them separately. However, if they wish to work collaboratively, they would need to agree on a mutually convenient time when reserving the devices.

The CD would be configured so that the ports connecting Switch A to Router A would be in a different VLAN to the ports connecting Router A to Router B and so on. User Y has not requested Switch B to be connected to any other device at this stage; however they have requested a link between two ports on the switch. Unique VLAN IDs would be worked out by the application before the commands are pushed through. Assume the devices are connected to the CD as shown in Table 2 and the given VLAN IDs have been worked out by the application. The following commands configured on a Cisco 3560 switch (used as the CD) would be for the connection between Router A and Router B, and exemplify the commands sent to the CD for all the other connections.

TABLE II
EXAMPLE SETUP OF SERVICE PROVIDER NETWORK RACK

CD port	User device	User device port	VLAN ID
Fa0/1	Switch A	Fa0/24	10
Fa0/2	Router A	Fa0/0	10
Fa0/3	Router A	Fa0/1	30
Fa0/4	Router B	Fa0/0	30
Fa0/5	Router B	Fa0/1	50
Fa0/6	Switch B	Fa0/24	60
Fa0/7	Switch B	Fa0/23	70
Fa0/8	Switch B	Fa0/22	70

```
interface FastEthernet0/3
description CONNECTION TO ROUTER A FA0/1
interface FastEthernet0/4
description CONNECTION TO ROUTER B FA0/0

interface range FastEthernet0/3-0/4

!Assign ports to VLAN 30
switchport access vlan 30
!Establish a tunnel between the ports
switchport mode dot1q-tunnel

!Specify the Layer 2 protocols to be
tunneled
l2protocol-tunnel cdp
l2protocol-tunnel stp
l2protocol-tunnel vtp
```

User X would be granted console access to Switch A, Router A and Router B, while User Y would be granted console access to Switch B once they have been successfully authenticated. Once the users have completed their individual tasks and wish to conjoin their individual labs they indicate their intention to do so to the service provider. Once ACME has received corresponding requests from both users who also indicate, which device and port (note that a single device may be connected to CD via multiple ports) they wish to use to connect to the other user's lab, the ports on the CD to which the two devices are connected are configured with the same VLAN IDs. In this example, port Fa0/6 on the CD would be assigned to VLAN 50, thereby configuring it to be in the same VLAN as Fa0/5 on the CD; thus allowing communication between the two labs. Now User X and User Y are able to network between their individual labs, allowing them to collaborate to complete the project.

C. Adapting an existing environment on to the new model

The proposed model fundamentally suggests how current rack rental systems can be improved to offer a more flexible and cost effective service to end users. We have also looked at how adopting the new model may be in the interest of the service provider. Service providers are able to re-configure labs which they currently offer on to the new model as follows.

Primarily the network rack would need to be rewired to a hub-spoke topology as shown in Figure 4 with any CDs as hubs and user devices as spokes. Depending on the number of user devices available and how many CD-user device connections they wish to offer, additional CD-switches may need to be procured to connect all user devices. Details of the CDs, user devices and how they are connected to the CDs would then need to be added to the CICAE server via a graphical user interface. Most rack rental systems employ a webserver, database server and an AAA server of some flavor, all of which can be retained and reconfigured. The web application required for the new model offers users the ability to select the composition and topology of the lab. The same or a similar interface should be served off the webserver. The database would need to be restructured to represent the various entities such as CD, user device, CD-user device connection, VLAN mapping etc. in addition to user details. The AAA server would require no additional configuration. Existing network configurations such as NAT,

TABLE III.
COST OF HIRING FIXED LABS VS. INDIVIDUAL DEVICES

Service Provider	Avg. cost per session per lab (USD)	No. of devices offered in lab	Avg. cost per device in lab (USD)	Avg. cost for 3 devices (USD)
A	15	16	0.9	2.8
B	17.50	23	0.8	2.4
C	16	13	1.2	3.6

load-balancing, Layer 2 and Layer 3 redundancy, network management and firewalls will require either little or no changes to accommodate the new model.

D. The New Business Model

Current business models are built around a fixed topology lab model, which primarily cater to the likes of CCIE (Cisco Certified Internetwork Expert) aspirants. Therefore, both the caliber and number of devices they offer, as well as the topologies they feature, are aimed at satisfying the requirements of advanced Cisco certification tracks. Naturally, the costs associated with hiring these labs are representative of this. Table 3 gives an indication of prices charged by 3 service providers in the present rack rental market. The pricing model is per session per lab. Sessions typically last from between 4 to 8 hours. The table identifies the cost per session per lab; the total number of devices offered in their CCIE Routing & Switching certification track labs; the average cost per device; and the cost to a user if the service provider were to offer individual devices and the user hired 3 devices. The average costs are rough estimates and does not take into account economics of scale etc., but gives a good indication of how offering the end user the ability to determine the composition of their lab is cost-effective from the user's perspective.

By re-configuring their labs according to the new lab model, a service provider can reengineer their business model around this to offer a more customized solution to a much larger client base. They will be able to offer an array of devices to an advanced user and a single device to a client who requests a standalone device. The service provider may then adapt their pricing model to reflect this, making their offering more attractive to prospective clients. Moreover, they can boast the ability for users to collaborate as part of their service offering. This encourages peer recommendation.

From the perspective of an academic institution, despite the increasing demand on education systems to provide ubiquitous learning resources to support evolving delivery models which cater for internationalisation and distant learning, it may not be feasible to offer separate conventional labs to students individually in the face of increasing budget constraints. However, where an institution wishes to provide its students this facility, by implementing the proposed solution, a tutor is not only able to allocate specific devices between their students to work on remotely from a single lab platform, but can also encourage students to collaboratively work on completing lab assignments. Figure 6 is a visual representation of the proposed business model; a flow diagram showing the various interactions between user, back-end (CICAE, database server, access server and terminal server) and the network rack (CD and user devices).

IV. DISCUSSION & FUTURE WORK

From the outset, we established that an improved solution to online rack renting should meet the following requirements to be considered successful. (a) It was important that intermediate devices should remain transparent to the end user; we have been able to achieve this through the use of L2PT technology. (b) It must not interfere with the normal operation of the user devices; all configurations are done on the CD, and its role is merely restricting traffic through the use of VLANs and relaying traffic between devices intra-VLAN, thus remaining indifferent to the state of the user device or the nature of traffic. (c) The new system needs to be flexible and highly customisable by the end user to suit their individual requirements; this has been achieved by eliminating inter-

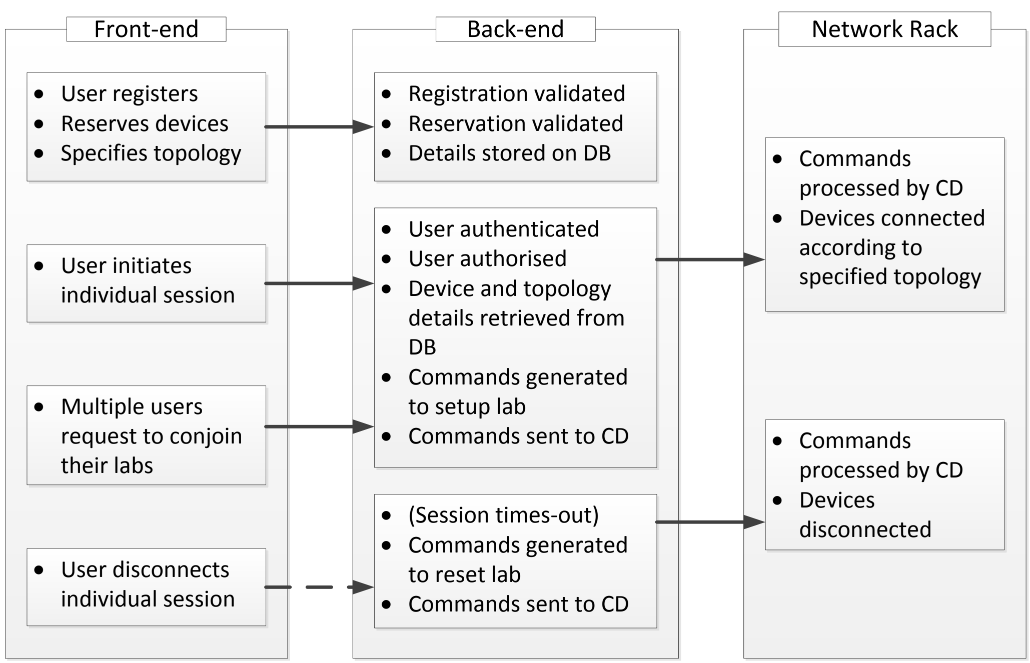

Figure 6. New business model. Dashed arrow indicates optionality; a lab is reset when the user's allocated time comes to an end (session times-out), or when the user initiates a request to terminate their session, whichever precedes.

device connections and introducing a CD in its stead. End users are able to select the composition of their labs and determine its topology as they wish. (d) It should require minimal involvement from the end user to setup and manage; this model retains the web interface users are accustomed with to make and manage reservations for devices and specify the lab topology of their choice. Finally, as we are interested in the academic relevance of this solution, we resolved that (e) it must be able to serve as a collaborative learning tool; using an elaborate example we have looked at how this model achieves this objective. The proposed solution meets all the above requirements.

This model is however not without some limitations. Firstly, the system has at present only been tested on Ethernet, Fast Ethernet, Gigabit Ethernet and Fibre Optic interfaces. Technical limitations dictate that VLANs cannot be configured on serial interfaces. However, it is possible to incorporate serial connections as prewired connections on a hybrid setup. Alternatively, future work could research the possibility of incorporating frame relay switches to which serial links from devices with serial ports could be connected and, by enabling the system to automatically configure frame relay circuits this limitation could potentially be overcome.

Secondly, the CD will normally transition its ports into a “disabled” state in case certain errors are detected on them. Although they can be configured to return to their functional state automatically, this may not eliminate the reason the ports were disabled in the first place.

Thirdly, shutting down an interface on a device which has been mapped to another device does not automatically shut down the interface on the other end of that mapping as the device interface status reflects the status of the port on the CD it is connected to. Physical layer switches we discussed in the Physical Segmentation section overcome this limitation by shutting down the corresponding interface through software intervention. Therefore, it is a capability which could potentially be introduced on to the CICAE, but has not been tested.

A further limitation is that in a solution such as this where a single central device has all peripheral devices connected to it is implemented, a single point of failure is introduced. If the central device fails or becomes compromised, although users will still have remote access to the peripheral devices via the terminal server, they will no longer have connectivity between them.

One of the opportunities we discussed, offered by introducing this model, was the ability for the service provider to have knowledge of which devices on their lab platform will not be used in upcoming sessions. The advantage here is that these devices can be identified and shutdown, saving on operating costs. Technology enabling remotely power-cycling devices has been available for a number of years. Remote Power Management (RPM) solutions offer just that [8]. They are deployed in industry primarily to enable network administrators to recover locked-up devices. There a number of vendors who offer RPM solutions and a majority of them offer the ability to configure via command-line. Therefore, future work could explore the integration of an RPM device on to the current model. The CICAE could be enhanced to script the necessary commands to power-cycle unused devices on the lab platform thus reducing power consumption.

V. CONCLUSIONS

This paper introduced a new approach to online rack renting. The improvements suggested in this paper build on the success of prevalent online rack rental systems, which have been rendering an indispensable service to academics engaging in the study of Computer Networks across the globe. By reengineering the way labs are defined and offered, we identified a number of opportunities to add value to both end users and service providers. We discussed how current business models could adapt to accommodate the proposed improvements and the potential opportunities the new model offers to academic institutions by enabling collaborative learning.

Finally, we reflected on some limitations and investigated ways of overcoming these limitations. The authors have identified a number of avenues for future work and encourage and invite interested parties to engage.

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