Legacy Network Infrastructure Management Model for Green Cloud Validated Through Simulations

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***Abstract* — The concepts proposed by Green IT have changed the priorities in the design of information systems and infrastructure, adding to traditional performance and cost requirements, the need for efficiency in energy consumption. The approach of Green Cloud Computing builds on the concepts of Green IT and Cloud in order to provide a flexible and efficient computing environment, but their strategies have not given much attention to the energy cost of the network equipment. While Green Networking has proposed principles and techniques that are being standardized and implemented in new networking equipment, there is a large amount of legacy equipment without these features in data centers. In this paper, the basic principles pointed out in related work for power management in legacy network equipment are presented, and a model for its use to optimize green cloud approach is proposed. It is also presented NetPowerCloudSim, an extension to the open-source framework CloudSim, which was developed to validate the aforementioned model and adds to the simulator the capability of representing and managing network equipment according to the state changes of servers. Experiments performed to validate the model showed that it is possible to significantly increase the data center efficiency through its application. The major contributions of this paper are the proposed network infrastructure management model and the simulator extension.**

Keywords - Green IT; Cloud Computing; Network Management; Data center; CloudSim.

I. INTRODUCTION

This paper extends [1], which proposes a data center's network equipment management model to optimize the green cloud approach, presenting an extension to the CloudSim simulator and the experiments performed to validate the aforementioned model.

Traditionally, computer systems have been developed focusing on performance and cost, without much concern for their energy efficiency. However, with the advent of mobile devices, this feature has become a priority because of the need to increase the autonomy of the batteries.

Recently, the large concentration of equipment in data centers brought to light the costs of inefficient energy management in IT infrastructure, both in economic and environmental terms, which led to the adaptation and application of technologies and concepts developed for mobile computing in all IT equipment.

The term Green IT was coined to refer to this concern about the sustainability of IT and includes efforts to reduce its environmental impact during manufacturing, use and final disposal.

Cloud computing appears as an alternative to improve the efficiency of business processes, since from the point of view of the user, it decreases energy costs through the resources sharing and efficient and flexible sizing of the systems. Nevertheless, from the standpoint of the service provider, the actual cloud approach needs to be seen from the perspective of Green IT, in order to reduce the data center energy consumption without affecting the system's performance. This approach is known as Green Cloud Computing [2].

Considering only IT equipment, the main cause of inefficiency in the data center is the low average utilization rate of the resources, usually less than 50%, mainly caused by the variability of the workload, which obliges to build the infrastructure to handle work peaks that rarely happen, but that would decrease the quality of service if the application was running on a server fully occupied [3].

The strategy used to deal with this situation is the workload consolidation that consists of allocating the entire workload in the minimum possible amount of physical resources to keep them with the highest possible occupancy, and put the unused physical resources in a state of low energy consumption.

The challenge is how to handle unanticipated load peaks and the cost of activation of inactive resources. Virtualization, widely used in the Cloud approach, and the ability to migrate virtual machines have helped to implement this strategy with greater efficiency.

To validate green cloud management algorithms and strategies, simulators are used, since performing tests in real environments is not feasible due to the cost, the physical rigidity of the structure and the difficulty to reproduce experiments under controlled conditions.

Calheiros et al. [4] developed CloudSim, an open-source framework for modeling and simulating cloud computing environments, which allows performing simulations of large scale data center operation in a conventional computer. With this simulator, it is possible to conduct experiments to validate workload consolidation algorithms, measure power consumption and calculate violations to the hired service levels. However, its use demands effort to interpret the code and extend it.

Strategies to improve efficiency in data centers have been based mainly on the servers, cooling systems and power supply systems, while the interconnection network, which represents an important proportion of energy consumption, has not received much attention, and the proposed algorithms for load consolidation of servers, usually disregard the consolidation of network traffic [5][6].

According to Bianzino et al. [7], traditionally the networking system design has followed two principles diametrically opposed to the aims of Green Networking: oversizing to support demand peaks and redundancy for the single purpose of assuming the task when other equipment fails.

The concepts of Green IT, albeit late, have also achieved design and configuration of network equipment, leading to Green Networking, which primary objective is to introduce the concept of energy-aware design in networks without compromising performance or reliability, and has to deal with a central problem: the energy consumption of traditional network equipment is virtually independent of the traffic workload [8].

The Green Networking has as main strategies proportional computing that applies to adjust both the equipment processing speed and the links speed to the workload, and the traffic consolidation, which is implemented considering traffic patterns and turning off not needed components.

While the techniques of Green Networking begin to be standardized and implemented in the new network equipment, a large amount of legacy equipment forms the infrastructure of current data centers. In works to be presented in the next section, it is shown that it is possible to manage properly these devices to make the network consumption roughly proportional to the workload.

Taking into account that the more efficient becomes the management of virtual machines and physical servers, the greater becomes the network participation in the total consumption of the data center, the need to include network equipment in green cloud model is reinforced.

Thereby, there is the need and the possibility to add, to the Green Cloud management systems, means of interaction with the data center network management system, to synchronize the workload consolidation and servers shutdown, with the needs of the network traffic consolidation.

In this article, the principles suggested in recent papers by several authors for power management in legacy network equipment are presented, and their application to optimize green cloud approach is proposed. An extended version of the CloudSim called NetPowerCloudSim and the results of the experiments performed to validate the model are also presented.

The remainder of this paper is organized as follows: Section II describes related work on which is based our proposal that is presented in Section III, along with an analytic case study to show the model's application possible results. Section IV presents NetPowerCloudSim, the experiments performed with this extended simulator to validate the model, and the results obtained. Finally, in Section V, concluding remarks and proposals for future work are stated.

II. Related Work

Mahadevan et al. [9] present the results of an extensive research conducted to determine the consumption of a wide variety of network equipment in different conditions. The study was performed by measuring the consumption of equipment in production networks, which made it possible to characterize the energy expenditure depending on the configuration and use of the equipment, and determine a mathematical expression that allows calculating it with an accuracy of 2%. This expression determines that total consumption has a fixed component, which is the consumption with all ports off, and a variable component which depends on the number of active ports and the speed of each port.

Research has determined that the power consumed by the equipment is relatively independent of the traffic workload and the size of packets transmitted, and dependent on the amount of active ports and their speed. The energy saved is greater when the port speed is reduced from 1 Gbps to 100 Mbps, than from 100 Mbps to 10 Mbps.

This research also presents a table with the average time needed to achieve the operational state after the boot of each equipment category, and also demonstrates that the behavior of the current equipment is not proportional, as expected according to the proposals of the Green Networking, and therefore the application of traffic consolidation techniques have the potential to produce significant energy savings.

Mahadevan et al. [10], continuing the work presented in the preceding paragraphs, put the idea that the switches consumption should ideally be proportional to the traffic load, but as in legacy devices the reality is quite different, they propose techniques to make the network consumption closer to the proportional behavior by the application of configurations available in all devices.

The results are illustrated in Figure 1, which shows the ideal behavior identified as "Energy Proportional" which corresponds to a network with fully "Energy Aware" equipment, the actual curve of the most of the today's networks where the consumption is virtually independent of load, labeled "Current", and finally the consumption curve obtained by applying the techniques they proposed, labeled "Mahadevan's techniques".

The recommended configurations are: slow down the ports with low use, turn off unused ports, turn off line cards that have all their ports off and turn off unused switches. The authors, through field measurements, have shown that it

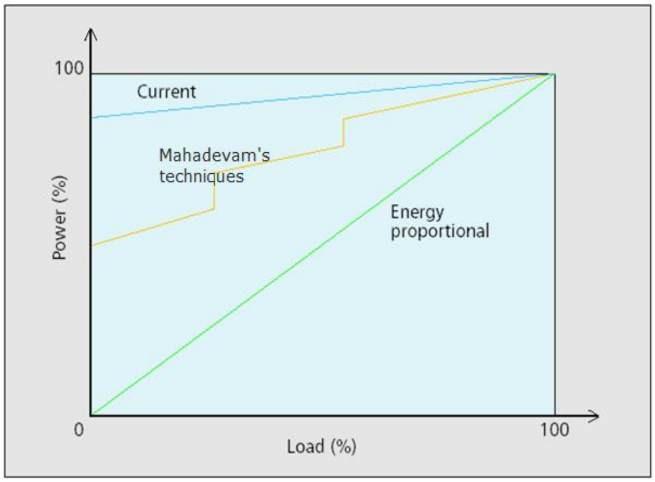

Figure 1. Consumption in computer networks as a function of the workload [10].

is possible to obtain savings of 35% in the consumption of a data center network with the application of these settings. Also, with the use of simulations, they have demonstrated that in ideal conditions savings of 74% are possible combining servers load consolidation and network traffic consolidation.

Werner [11] proposes a solution for the integrated control of servers and support systems for green cloud called OTM (Organization Theory Model). This approach, based on the Theory of Organization, defines a model of allocation and distribution of virtual machines that were validated through simulations and showed to get up to 40% energy saving compared to traditional cloud model.

The proposed model determines when to turn off, resize or migrate virtual machines, and when to turn on or off physical machines based on the workload and the SLA (Service Level Agreement) requirements. The solution also envisages the shutdown of support systems. Figure 2 shows the architecture of the management system proposed, which is based on norms, roles, rules and beliefs.

Calheiros et al. [4], from the University of Melbourne, present the CloudSim simulator, an open-source framework which supports large scale cloud environment modeling and simulation in a conventional computer with low consumption of computational resources. This tool was designed specifically for modeling cloud computing infrastructures, and offers support to virtualized environments simulation and to modeling data centers with large amounts of servers. This version of the simulator has a class called NetworkTopology, which provides information about entities communication latency, but does not allow representing network equipment and energy consumption.

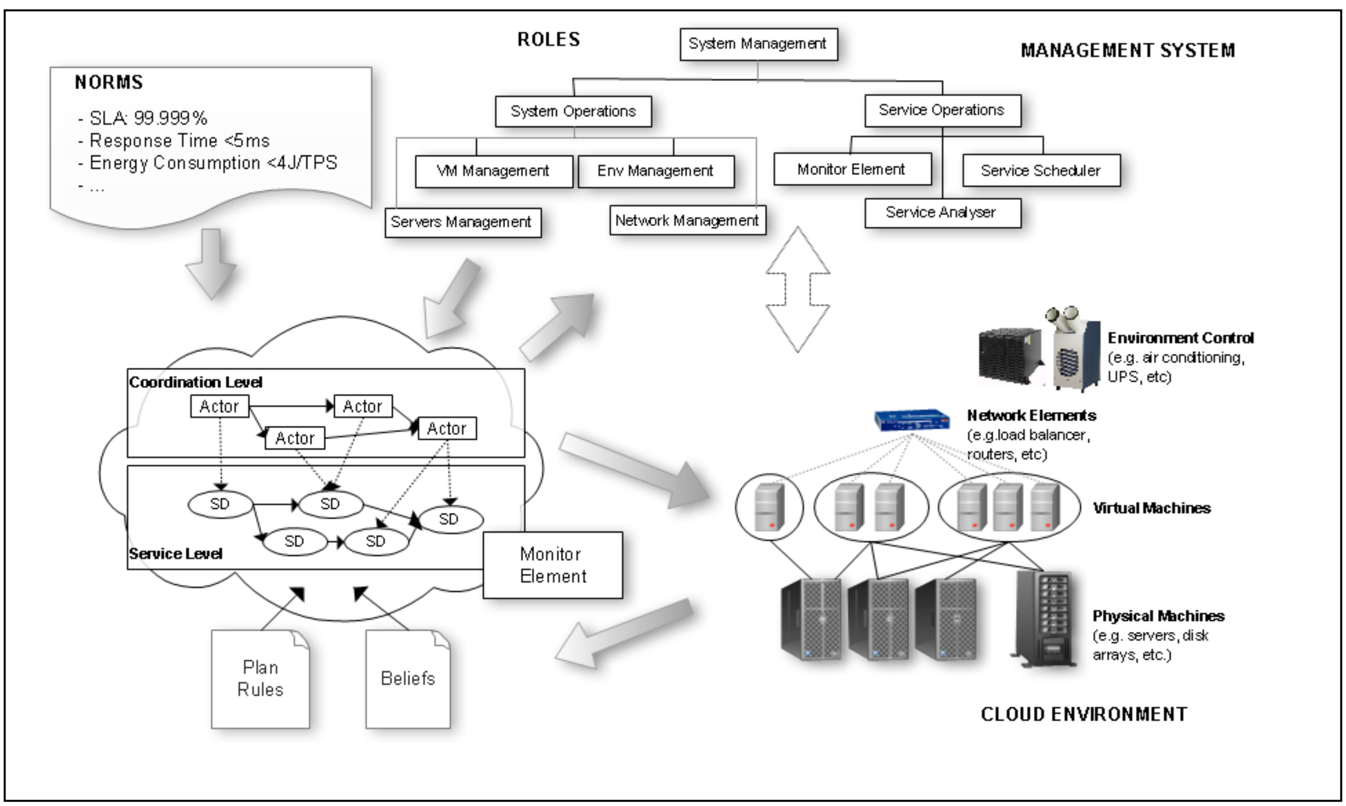

Figure 2. Green Cloud management system based on OTM [11].

Freitas [12] made extensions to the CloudSim simulator, creating the needed classes to support and validate the OTM, which allowed calculating energy savings and SLA violations in various scenarios. Neither the model nor the extensions consider the network equipment energy consumption.

Garg and Buyya [13] present NetworkCloudSim, an extension to CloudSim, which incorporates resources for modeling applications and data center network behaviors. This simulator has the necessary classes to represent network equipment and traffic, however, it does not allow representing and calculating data center equipment energy consumption.

Beloglazov [14] presented a new version of the simulator, the CloudSim 2.0, which allows representing the data center components energy consumption, capacity that was not contemplated by the framework core, and also incorporates applications with dynamic workloads. This version does not support network equipment and its energy consumption representation.

Based on the findings of the works described above, in the next section, a proposal to include the management of legacy and current network devices in OTM is presented. The rules and equations required to include this extension in CloudSim simulations are also presented and validated through a case study.

III. Proposal for Data Center Network Management in Green Cloud Approach

The proposal considers the network topology of a typical data center shown in Figure 3, where the switches are arranged in a hierarchy of three layers: core layer, aggregation layer and access or edge layer. In this configuration, there is redundancy in the connections between layers so that the failure of a device does not affect the connectivity.

In traditional facilities, the implementation and management of this redundancy is done by the Spanning Tree Protocol and in most recent configurations by the MC-LAG (Multichassis Links Aggregation Group), which allows using redundant links simultaneously expanding its capacity, as described in [15].

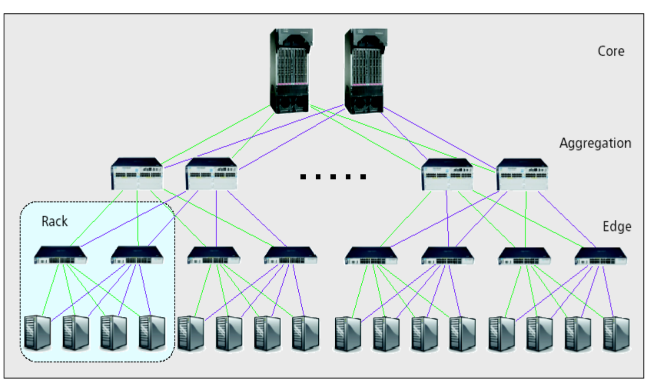

Figure 3. Typical network topology of a data center [9].

The racks are the basic unit of this configuration and each rack accommodates a certain amount of servers and two access layer switches. The servers have two NICs (Network Interface Card) each one connected to a different access switch.

A. *Extensions To The Organization Theory Model*

To include the management of legacy network equipment in the model proposed by Werner et al. [16], such that the network consumption becomes relatively proportional to the traffic workload and the energy savings contribute to the overall efficiency of the system, it is proposed to add the following elements to its architecture:

1) *Management Roles*

Add to the "System Operations" components the “Network Equipment Management" role, which acts as an interface between the model and the network equipment being responsible for actions taken on these devices such as: enabling and disabling ports or equipment or change MC-LAG protocol settings.

The "Monitoring Management" role, responsible for collecting structure information and its understanding, should be augmented with elements for interaction with the network management system to provide data, from which decisions can be made about the port speed configuration, or turning on or off components and ports. These decisions will be guided by the rules and beliefs.

2) *Planning Rules*

These rules are used when decisions must be taken, and therefore, rules to configure the network equipment in accordance with the activation, deactivation and utilization of physical machines should be added.

To implement the settings pointed out in [9], already presented, the following rules are proposed:

- If a PM (Physical Machine) is switched off, the corresponding ports of access layer switches must be turned off.
- If the occupation of a PM is smaller than a preset value, network interfaces and corresponding access switches ports must be slowed down.
- If the aggregate bandwidth of the downlink ports of an access layer switch is smaller than a preset value, their uplink ports must have their speed reduced.
- If an access layer switch has all its ports off, it must be turned off.
- If an access layer switch is turned off, the corresponding ports of the aggregation layer switch must be turned off.
- If the aggregate bandwidth of the downlink ports of an aggregation layer switch is smaller than a preset value, their uplink ports must have their speed reduced.
- If an aggregation layer switch has all its ports off, it must be turned off.
- If an aggregation layer switch is turned off, the corresponding port of the core layer switch must be turned off.

- If a module of a core layer switch has all its ports off, it must be turned off.
- If a core layer switch has all its ports off, it must be turned off.
- All reversed rules must also be included.

The application of these rules does not affect the reliability of the network, since port and devices are only turned off when servers are turned off. The system performance will only be affected if the network equipment activation cost is bigger than the server activation cost.

For more efficiency in traffic consolidation, the model should consider the racks in virtual machines allocation and migration strategies, and rules that consolidate active physical machines in as fewer racks as possible are necessary.

3) Beliefs

They are a set of empirical knowledge used to improve decisions, and are linked to the used resources characteristics and to the type of services implemented in each specific case.

For each of the rules listed in the previous paragraph, a belief related to energy consumption should be stated. If we consider Christensen et al. [17], examples include:

- Disconnecting a port of an access layer switch generates a saving of 500 mWh.
- Decreasing the speed of a port from 10 Gbps to 1 Gbps generates a saving of 4.5 Wh.

It will also be necessary to include beliefs about the time required for a deactivated port or device to become operational after the boot. These beliefs will be used to make decisions that must consider performance requirements.

B. Simulation Model

The typical data center network topology, rules and beliefs proposed form the basis for building a simulation model to validate different strategies and rules in specific settings and with different workloads.

For the simulator implementation, it was considered that each rack accommodates forty 1U servers and two access layer switches. Each of these switches has 48 Gigabit Ethernet ports and two 10 Gigabit Ethernet uplink ports. Each server has two Gigabit Ethernet NICs (Network Interface Card) each one connected to a different access switch.

It was also considered that if there is only one rack, aggregation layer switches are not required, and up to 12 racks can be attended by 2 aggregation layer switches with twenty four 10 Gigabit Ethernet and two 10 Gigabit Ethernet or 40 Gigabit Ethernet uplinks, with no need for core switches.

Finally, it was assumed that, with more than 12 racks two core switches with a 24 ports module for every 144 racks will be required. The module’s port speed may be 10 Gigabit Ethernet or 40 Gigabit Ethernet, according to the aggregation switches uplinks.

In the next subsections the central aspects of the simulation model are presented.

1) Network Topology Definition

The simulator must create the network topology based on the amount of physical servers using the following rules:

- If the number of servers is smaller than 40, the topology will have only two access layer switches interconnected by their uplink ports. Turn off unused ports.
- If the number of servers is greater than 40 and smaller than 480 (12 Racks), put two access layer switches for every 40 servers or fraction and two aggregation layer switches interconnected by their uplink ports. Turn off unused ports of both layers switches.
- If the number of servers is greater than 480, apply the previous rule for each group of 480 servers or fraction, add two core layer switches and put on each switch a 24 ports module for each 5,760 servers (144 racks) or fraction. Turn off unused port.

2) Network Energy Consumption Calculation

The total consumption of the network is given by the sum of all its switches consumption and, based on the findings of Mahadevan et al. [9], the equation to calculate switches and modules consumption is:

$$\text{Power (W)} = \text{BP} + \text{no. P 40Giga} \times 10 + \text{no. P 10Giga} \times 5 + \text{no. P Giga} \times 0.5 + \text{no. P Fast} \times 0.3 \tag{1}$$

In this expression, the power in Watts is calculated by summing the base power (BP), which is a fixed value specific to each device, and the consumption of every active port at each speed, which is a variable component. The consumption of each type of port is specific to each device, but the proposed values are the average values according to the works already cited.

The simulator must permit to set each kind of port consumption and the BP in order to represent different scenarios and to calibrate the model.

In (1), if the switch is modular, the base power of the chassis must be added.

At the end of each simulation frame, the simulator must update the calculation of the network total consumption by summing each switch consumption during the frame.

3) Interconnection calculation

Since the network topology is a hierarchy, it is possible to establish a mathematical relationship in the equipment interconnection if these are identified by numbers. Thus, it is not necessary to include information about these interconnections in the state vector.

When the simulator needs to determine the switch port number that corresponds to a specific server network interface, or to a specific uplink port of a switch, it is possible to calculate it using a mathematical expression applied to the server or switch identifier.

4) Network Management

During the simulation, when servers are connected or disconnected, the simulator must apply the network management rules by turning on or off the corresponding ports or configuring its speed.

The sequence of the application of the rules according to the state changes of servers is represented by the activity diagram in Figure 4. This diagram considers, besides the events of turning servers on and off, events based on the utilization rate of the server.

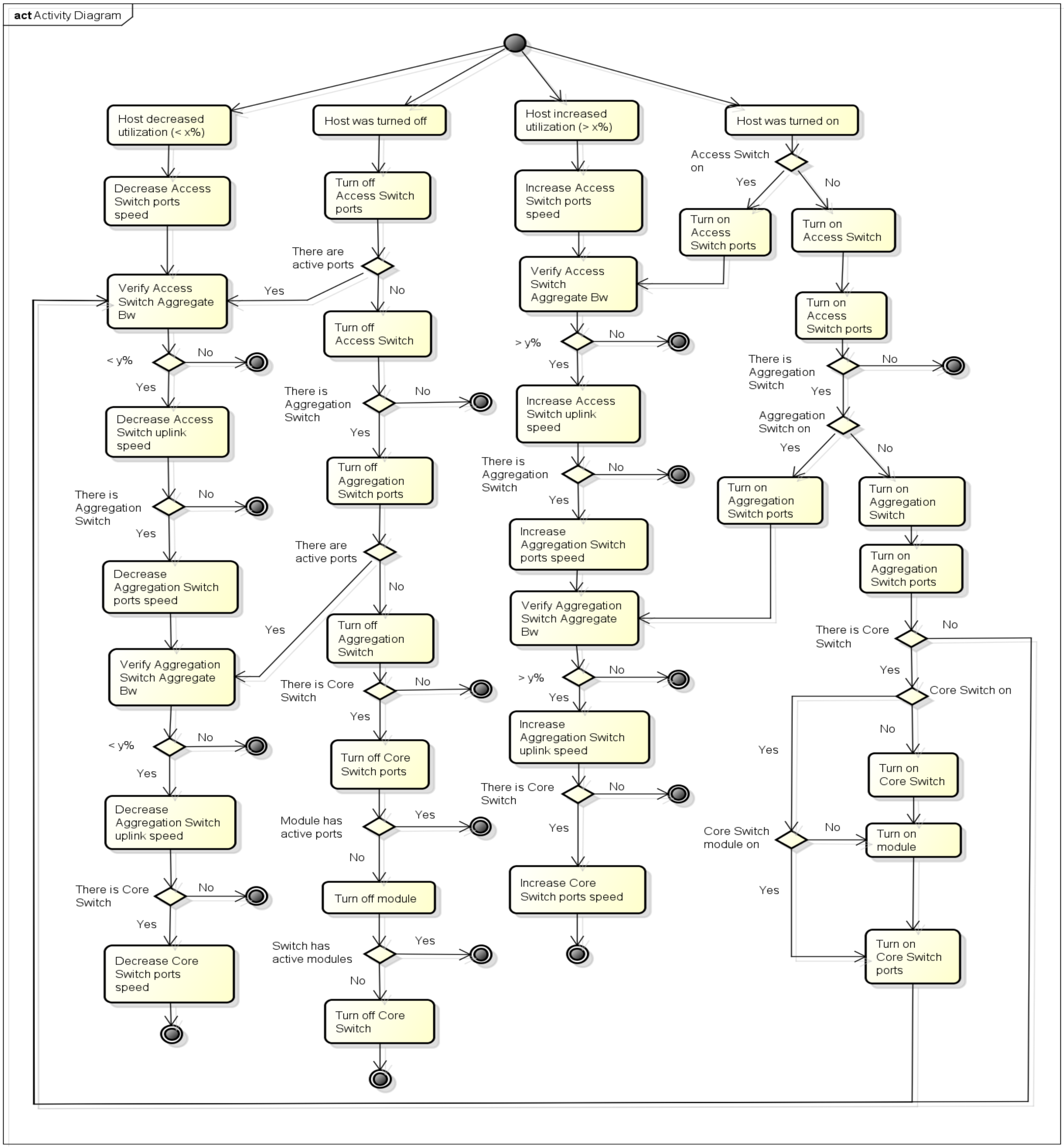

Figure 4. Activity Diagram of the application of the model rules.

C. Case Study

To validate the model and the potential of the proposal, it was applied to a hypothetical case of a cloud with 200 physical servers, creating the topology, calculating its initial consumption without network equipment management and illustrating two possible situations in the operation of the system. It was considered for this scenario that the base power is 60 W for access layer switches and 140 W for aggregation layer switches.

Applying the rule to calculate the topology, it is determined that it comprises 5 racks housing a cluster of 40 servers each and, therefore, there will be ten access layer switches with forty Gigabit Ethernet ports and two 10 Gigabit Ethernet empowered ports, and two aggregation layer switches with ten 10 Gigabit Ethernet connected ports for access layer switches and two 40 Gigabit Ethernet ports for uplink interconnection between them.

1) Scenario 1: All network equipment with all its ports connected

Access layer switches = 10 x (60 + 2x5 + 48x0.5)
= 940 W
Aggregation layer switches = 2 x (140 + 2x10 + 24x5)
= 560 W
Total network consumption = 1,500 W

2) Scenario 2: Initial configuration with unused ports off

Access layer switches = 10 x (60 + 2x5 + 40x0.5)
= 900 W
Aggregation layer switches = 2 x (140 + 2x10 + 10x5)
= 420 W
Total network consumption = 1,320 W

In this scenario, it is observed that only by the proper initial configuration of the network it is possible to get a power save of approximately 12%.

3) Scenario 3: 90 active servers, workload consolidated in the first three racks and network configuration rules applied.

In this situation, according to the rules, there are 4 access layer switches working in initial conditions (2), two access layer switches working with twelve Gigabit Ethernet ports, 10 for servers and 2 uplink ports with its speed reduced (3), and 2 aggregation layer switches with four 10 Gigabit Ethernet and two Gigabit Ethernet downlinks ports and two 40 Gigabit Ethernet uplinks (4), and the network consumption will be:

Access layer switches 1 = 4 x (60 + 2x5 + 40x0.5)
= 360 W (2)
Access layer switches 2 = 2 x (60 + 12x0.5)
= 132 W (3)
Aggregation switches = 2 x (140 +2x10 + 4x5 + 2x0.5)
= 362 W (4)
Total network consumption = 854 W

In this scenario, there is a power saving of approximately 43% in network consumption.

IV. NetPowerCloudSim

To validate the network management model proposed in the previous section, extensions to the CloudSim were developed and the extended simulator was called NetPowerCloudSim.

A. Extensions development

To represent the network and manage it according to the rules of the model, the PowerSwitch, NetTopology, NetworkManager and NetPowerDatacenter classes were developed as presented in the simplified class diagram in Figure 5.

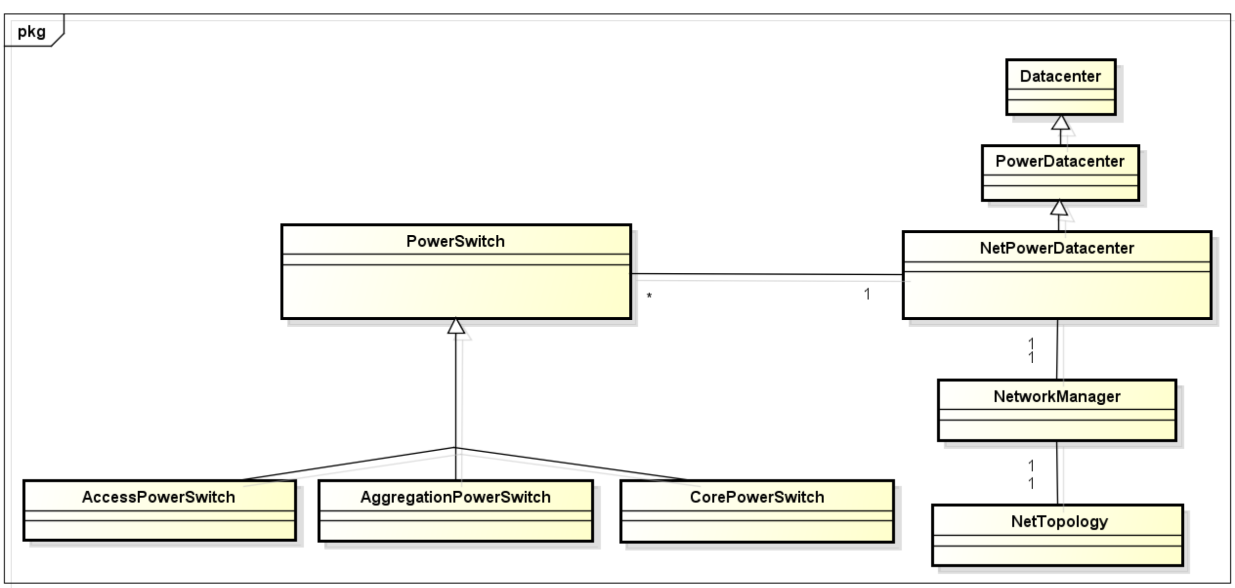

Figure 5. NetPowerCloudSim simplified class diagram.

The PowerSwitch class represents network equipment and is extended by other classes that represent specific layer switches (access, aggregation and core). The switches have attributes such as status (on/off), current consumption, quantity of ports and each port's speed; and methods that allow to turn them on and off, to set the speed of a specific port and to calculate their consumption at a given time, as well as the energy consumed during a simulation frame, which is done through linear interpolation.

The NetTopology class represents the network topology and is responsible for calculating the quantity of each kind of switch and their interconnection. Before the simulation start, based on the data center physical machines amount, this class calculates the number of racks needed to accommodate them. The quantities of access, aggregation and core switches are then calculated from the amount of racks.

The NetworkManager class contains the attributes and the logic required to turn on and off network equipment and ports, and to set ports speed when the state of servers changes, based on the management model rules and beliefs. Before the simulation start, helped by the NetTopology class, it determines which ports are not connected to any equipment and turn them off. Then, it verifies if the aggregate bandwidth of the switches that had ports turned off is under a predefined threshold to determine whether their uplink ports speed should be reduced.

Finally, the PowerDatacenter class was extended by NetPowerDatacenter class to integrate the network model to CloudSim, allowing interaction with the events generated by other entities of the simulator. This class represents a data center with a network that comprises physical machines and access, aggregation and core switches; and computes its consumption during a simulation. Therefore, in each simulation frame, this class calculates the network power consumption, adds it to the data center's total power consumption and informs the state changes of servers to the network manager so it can reconfigure the network equipment according to the rules.

To perform the experiments, a main class, responsible for creating the scenario, starting the simulation and retrieving results, was implemented. It allows setting the characteristics of all the needed objects and the simulation parameters.

In order to facilitate simulations, a graphical interface that allows setting the scenario and repeating simulations with different parameters without modifying the source code was developed. This interface is showed in Figure 6.

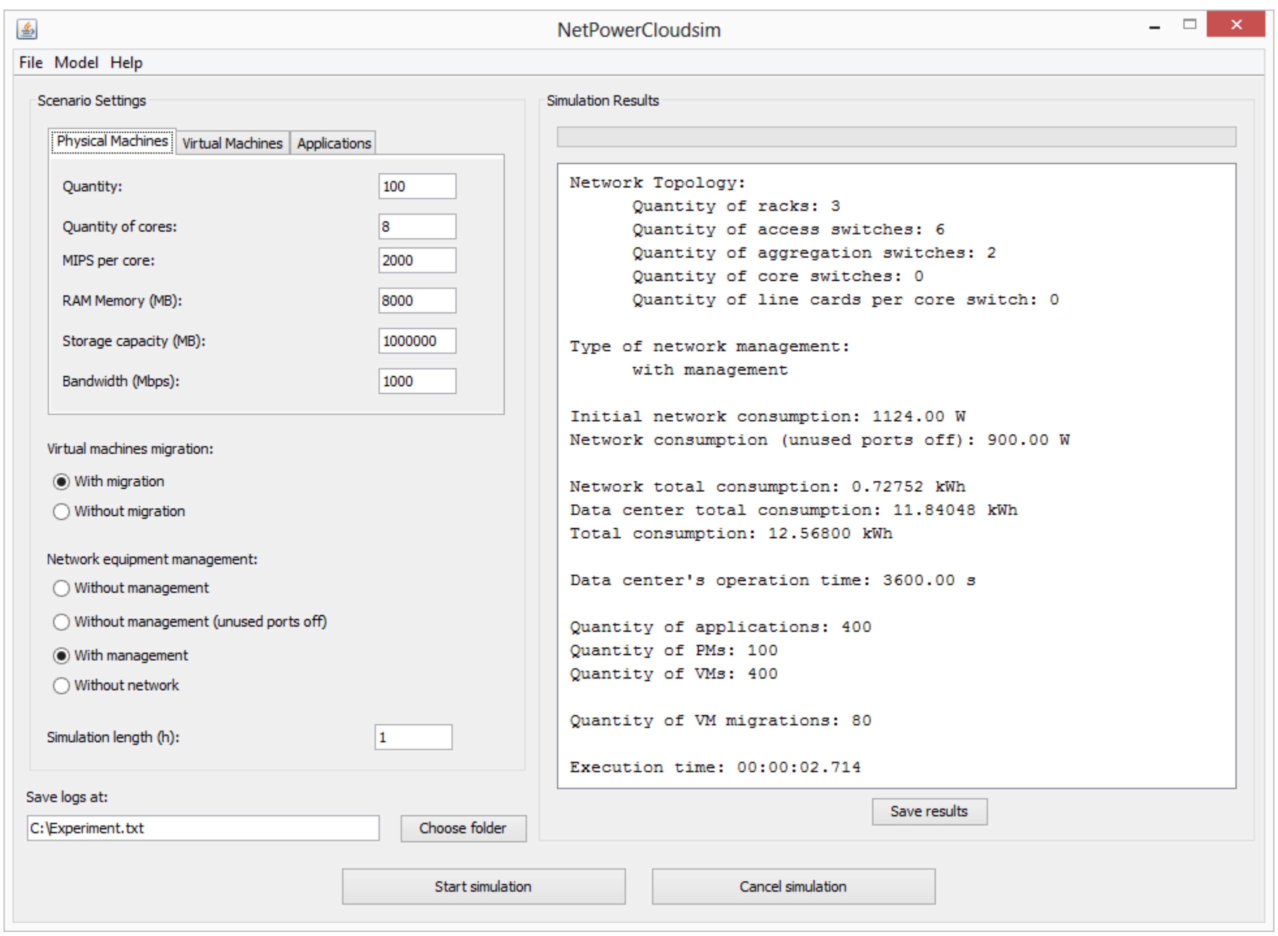

Figure 6. NetPowerCloudSim graphical user interface.

The version used for the extensions developing was CloudSim 3.0.3 and the implementation was made with the object oriented programming language Java through the development environment Netbeans IDE 7.3.1 along with the graphic library Swing. To verify each class code correction, unit tests were conducted using the JUnit framework. The integration tests were performed with the aid of a class developed for this purpose and by simple simulations that allowed thoroughly analyzing the logs and comparing the obtained results with those expected.

Lastly, for the sake of helping in understanding the code and the algorithms operation, as well as facilitating future extensions, all the created classes were widely commented and documentation was generated with the Javadoc tool, provided by Sun Microsystems.

B. *Experiments and Results*

In order to validate the model and the extensions, three experiments with different scenarios were conducted in a single machine. The experiments were simulations executed in a microcomputer with the following characteristics: Intel Core i5-3230M 2.6 GHz processor; 8 GB DDR3 RAM memory; and 64-bit Windows 8 operational system.

The scenarios created for the experiments had the following common parameters: 1 data center; physical machines with eight 2000 MIPS processing cores, 8 GB RAM memory, 1 TB storage capacity and 1 Gbps bandwidth; virtual machines with two 1000 MIPS processing cores, 1 GB RAM memory and 100 Mbps bandwidth.

The experiments performed and the results obtained are described and discussed next.

1) *Experiment 1*

In this experiment, one hour of operation of a data center with only 2 physical machines, 4 virtual machines and 4 applications was simulated, in order to verify the correct operation of the extensions and their interaction with CloudSim. The simulation was repeated four times and the results are presented in Table I: the first one was performed with the original version of CloudSim (R1); the second one, with NetPowerCloudSim without representing the network (R2); the third one, with network representation but without managing it (R3); and the last one, managing the network (R4). The results and the logs of each simulation were compared with each other and to the expected results and the necessary adjustments were made to ensure the correction and coherence of the model.

This experiment allowed evaluating all the functionalities of the developed extensions since, despite of the simplicity of the scenario, VMs migrations, PMs shutdowns and reductions and increases in PMs utilization rates happen and, consequently, network equipment speed configuration and ports shutdowns are performed.

In Table I it is possible to observe that, as expected, the data center servers consumption was constant over the four simulation repetitions and the network consumption was greater when it was not managed. It can also be observed that the network consumption has a very close value to the data center servers consumption. However, this happens because a rack was set up with two access switches for only two physical machines, which would not happen in a real infrastructure.

TABLE I. EXPERIMENT 1 RESULTS.

	Simulation repetition			
	R_1	***R_2***	***R_3***	***R_4***
Execution time (ms)	69	67	77	109
Network initial consumption (W*s)	-	-	188	124
Data center servers consumption (kWh)	0.1304	0.1304	0.1304	0.1304
Network consumption (kWh)	-	-	0.1723	0.1076
Total consumption (kWh)	0.1304	0.1304	0.3027	0.2380
MV migrations	2	2	2	2
PM shutdowns	1	1	1	1

2) *Experiment 2*

In this experiment, six hours of operation of a data center with 500 PMs was simulated, so that the network was composed by the three layers of the topology. In order to have a considerable amount of VMs migrations and PMs shutdowns, 2,000 VMs and 2,000 applications were executed. The simulation was repeated three times and the results obtained are shown in Table II: the first one, without managing the network (R1); the second one, also without managing the network, but turning off unused ports in the initial configuration (R2); and the last one, managing the network (R3).

It is possible to observe that the network consumption without management was 32.21 kWh; that, by turning off unused ports, there was a saving of 4.40 kWh (13.66%); and that, by managing the network equipment, the saving was increased to 6.85 kWh (21.25%). Considering the data center total energy consumption (401.62 kWh), there was a saving of 1.09% with unused ports off and 1.70% managing the network.

TABLE II. EXPERIMENT 2 RESULTS.

	Simulation repetition		
	R_1	***R_2***	***R_3***
Execution time (min)	02:32.565	02:33.359	02:37.299
Network initial consumption (W*s)	5,444.00	4,700.00	4,700.00
Data center servers consumption (kWh)	369.4057	369.4057	369.4057
Network consumption (kWh)	32.2104	27.8084	25.3643
Total consumption (kWh)	401.6161	397.2141	394.7700
MV migrations	1,268	1,268	1,268
PM shutdowns	250	250	250

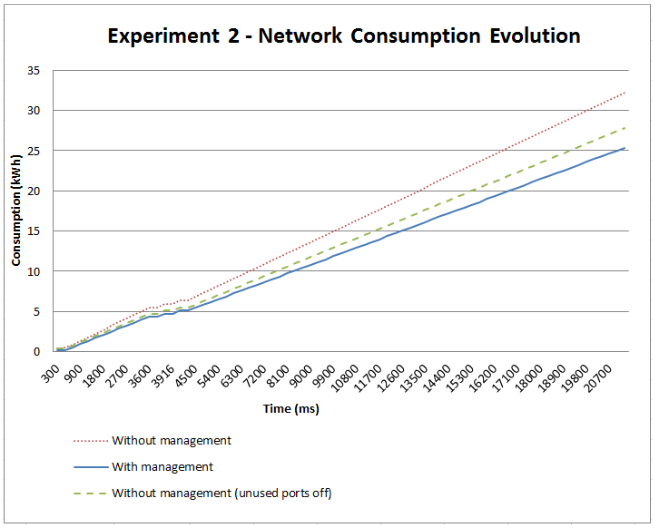

Figure 7. Experiment 2 network consumption evolution.

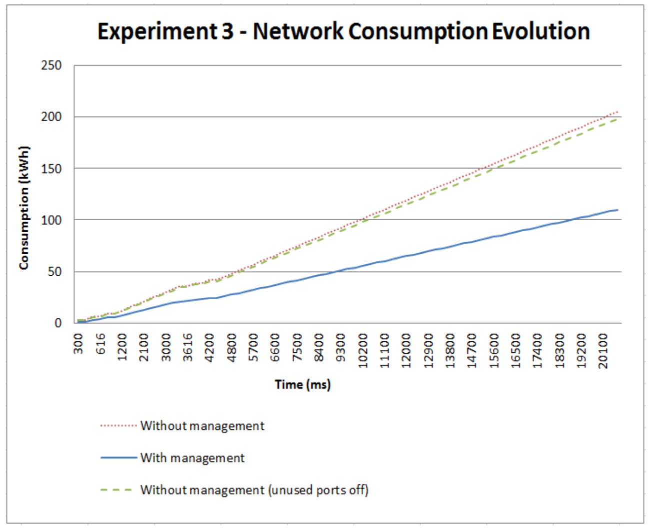

Figure 8. Experiment 3 network consumption evolution.

The chart in Figure 7 shows the evolution of the network energy consumption during the data center's 6-hour operation, representing the accumulated consumption in kWh at the end of each simulation frame.

3) Experiment 3

In this experiment, six hours of operation of a data center with 5,760 PMs, 10,000 VMs and 10,000 applications was simulated, with the purpose of testing the simulator representing a large scale data center and verifying the code's efficiency. As well as in Experiment 2, the simulation was repeated three times and the results are presented in Table III: the first one, without managing the network (R1); the second one, without managing the network, but turning off unused ports in the initial configuration (R2); and the last one, managing the network equipment (R3).

From the results of this experiment, it is possible to perceive that the network energy consumption without management was 211.06 kWh; that, by turning off unused ports in the initial configuration, there was a saving of 6.82 kWh (3.23%); and that, by managing the network equipment, the saving was increased to 97.92 kWh (46.39%). Considering the data center total consumption (2,071.77 kWh), there was a saving of 0.33% with unused ports off and 4.73% managing the network. The chart in Figure 8 shows the network energy consumption evolution during the data center's operation.

TABLE III. EXPERIMENT 3 RESULTS.

	Simulation repetition		
	R_1	***R_2***	***R_3***
Execution time (min)	24:49.597	25:28.382	27:09.126
Network initial consumption (W*s)	35,672.00	34,520.00	34,520.00
Data center servers consumption (kWh)	1,860.712	1,860.711	1,860.712
Network consumption (kWh)	211.060	204.244	113.141
Total consumption (kWh)	2,071.772	2,064.956	1,973.853
MV migrations	12,177	12,177	12,177
PM shutdowns	4,510	4,510	4,510

V. CONCLUSION AND FUTURE WORK

In this paper, basic concepts related to Green IT were first presented, i.e., Green Cloud and Green Networking, demonstrating the need of considering the network equipment in strategies designed to make data centers more efficient, since the network represents a significant percentage of total consumption, and this participation will be more expressive when the other components become more efficient.

Afterwards, in the related work section, a green cloud management model called OTM was presented, as well as network equipment management principles that, when properly applied, make the behavior of the total consumption of the network approximately proportional to the traffic load, even when legacy energy-agnostic equipment are used in. The proposal was to extend the OTM to manage the network traffic consolidation according to these management principles.

Then, the elements that must be added to the architecture of the OTM were described, including the rules and beliefs required for the correct network configuration according to the state changes of servers during the load consolidation process.

A model to simulate and validate the extensions to the OTM was also proposed. This model determines the data center network topology based on the number of physical servers, the rules to manage and set the network devices according to the state changes of servers, and equations to calculate the switches consumption and the total network consumption.

The simulation model was validated by its application in a case study, which allowed verifying that equations and rules are correct and enough to create the topology and to calculate the consumption of the network in each step of the simulation, as well as highlight the possible effects of the application of the proposal. This model was the basis to create a simulator and perform simulations.

The simulator was created by extending CloudSim and was called NetPowerCloudSim. New classes to represent network equipment and network topology were created as well as a network manager that applies the rules during the simulation. A graphical interface was also developed in order to allow creating scenarios and perform simulation without the need to modify the application source code.

Finally, experiments to validate the extensions and the model were performed, demonstrating that it is possible to obtain significant energy savings in the data center consumption by the application of the model. It was thus demonstrated the possibility and desirability of extending the green cloud management model as proposed.

Although the actual results in each situation will depend on the data center configuration, the kind of network equipment and the workloads, it was demonstrated through the presented experiments that it is possible to obtain savings of nearly 50% in the network consumption and 5% in the data center total consumption in feasible conditions.

It is important to consider that the impact of applying the model is maximum in legacy energy-agnostic equipment, and will be smaller as the equipment becomes more energy-aware by applying the resources of the Green Networking but its application will be still convenient.

As future research, it is proposed to continue this work by performing experiments to determine the actual contribution of the model in scenarios with real configuration and workloads, as well as determine the most effective rules and virtual machine allocation policies. It is also proposed to compare these results to those obtained in real systems to calibrate the model.

Finally, the implementation of the model is proposed as future work and, since system performance may be affected if the network devices activation cost is bigger than the server activation cost, it is also suggested to study the proper network configuration and technologies to avoid this situation, with special consideration to protocols that manage the links redundancy and aggregation, like the Spanning Tree Protocol, MC-LAG, and other new networking standards for data centers.

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