Optimizing Green Clouds through Legacy Network Infrastructure Management

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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 datacenters. In this paper, the basic principles pointed out in recent works for power management in legacy network equipment are presented, and a model for its use to optimize green cloud approach is proposed.**

Keywords - Green IT; Green Networking; Green Cloud Computing

I. INTRODUCTION

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 energy consumption of the data center without affecting the system's performance. This approach is known as Green Cloud Computing [1].

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 [2].

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.

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 consumption, has not received much attention, and the proposed algorithms for load consolidation of servers, usually disregard the consolidation of network traffic.

The concepts of Green IT, albeit late, have also achieved design and configuration of network equipment, leading to Green Networking, which has to deal with a central problem: the energy consumption of traditional network equipment is virtually independent of the traffic workload. The Green Networking has as main strategies proportional computing that applies to adjust both the equipment processing speed such as the links speed to the workload, and the traffic consolidation, which is implemented considering traffic patterns and turning off components not needed. According to Bianzino et al. [3], traditionally the networking system design has followed two principles diametrically opposed to the aims of Green Networking, over-sizing to support demand peaks and redundancy for the single purpose of assuming the task when other equipment fail. This fact makes Green Networking technically challenging, with the primary objective of introducing the concept of energy-aware design in networks without compromising performance or reliability.

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

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infrastructure of current data centers. In the 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.

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.

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.

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 our approach of green cloud is proposed.

After this introduction, section 2 presents related works on which is based our proposal that is presented in section 3. Section 4 presents possible results of the application of the model and, finally, in section 5, concluding remarks and proposals for future work are stated.

II. Related Work

Mahadevan et al. [4] 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.

Mahadevam et al. [5], 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.

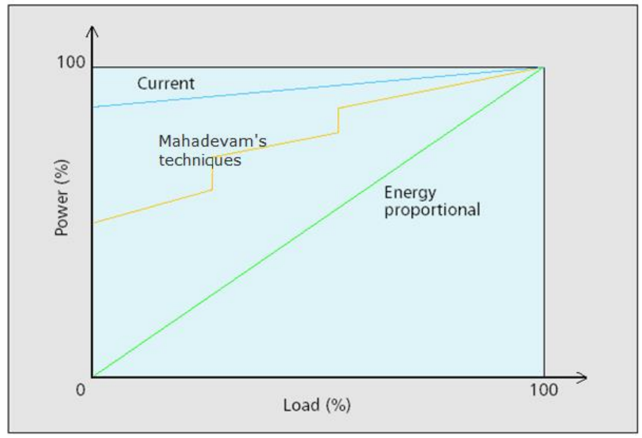

Figure 1 - Consumption in computer networks as a function of the workload [5].

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 “Mahadevam’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 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 [6] proposes a solution for the integrated control of servers and support systems for green cloud model based on the Theory of Organization (Organization Theory Model - OTM). This approach 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 Service Level Agreement (SLA) 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.

Freitas [7] made extensions to the CloudSim simulator by CALHEIROS et al. [8], developed at the University of Melbourne, creating the necessary classes to support the Organization Theory Model, presented in the previous

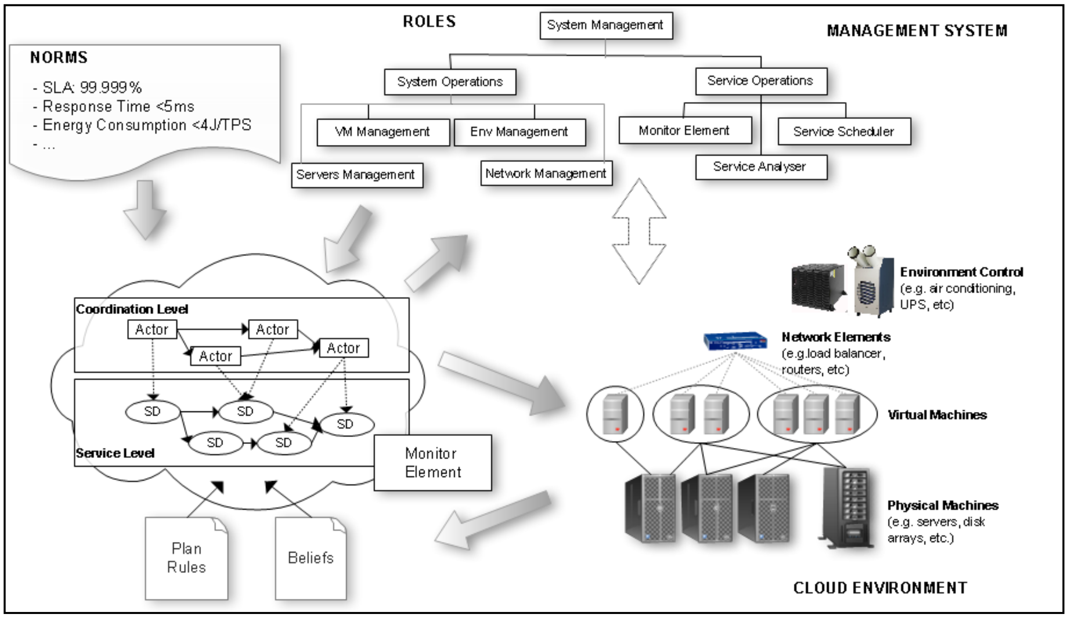

Figure 2 – Green Cloud management system based on OTM [6].

paragraphs, which allowed to calculate the energy savings and SLA violations in various scenarios.

In the next section, a proposal to include the management of legacy network devices in Organization Theory Model and the rules and beliefs for the proper functioning of the model based on the findings of the works described above are presented. The rules and equations required to include this extension in CloudSim simulations are also presented and validated through a study case.

III. Proposal For Data Center Network Management In Green Cloud Approach

The proposal considers the network topology of a typical datacenter 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.

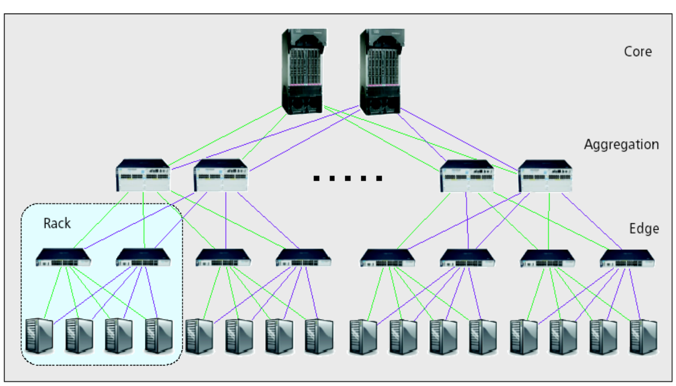

Figure 3- Typical network topology of a datacenter [5].

Consequently, we consider, in our model, 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, and each server has two Gigabit Ethernet NICs each one connected to a different access switch.

We also consider 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, the model assumes 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 traditional facilities, the implementation and management of this redundancy is done by the Spanning Tree Protocol and in most recent configurations by the Multichassis Links Aggregation Protocol (MC-LAG), which allows using redundant links simultaneously expanding its capacity, as described in [9].

A. Extensions To The Organization Theory Model

To include the management of legacy network equipment in the model proposed by WERNER et al [10], 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

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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 [5], already presented, the following rules are proposed:

- If a physical machine (PM) 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. [11], examples include:

- Disconnecting a port on a switch access layer 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 datacenter 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. As already done in previous works by WERNER [6] and FREITAS [7], it is possible to expand the CloudSim [8] or work on some of its extensions as TeachCloud [12].

The simulator must create the network topology and calculate their initial consumption 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.

The equation to calculate the consumption of the switches and modules is:

$$\text{Power (W)} = \text{BP} + \text{no. P 10Giga x 5} + \text{no. P Giga x 0,5} + \text{no. P Fast x 0,3} \quad (1)$$

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 the 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.

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

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, and update the calculation of the total consumption of the network.

In order to analyze the system performance and SLA violations, the model must know the time needed to put into operation each type of equipment, and at the moment of the server's activation, compare the uptime of the server with the uptime of the network equipment and use the greatest.

IV. 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 10 access layer switches with 40 Gigabit Ethernet ports and two 10 Gigabit Ethernet empowered ports, and two aggregation layer switches with 12 connected ports each, 10 ports for access layer switches and two ports for uplink interconnection between them.

A. *Scenario 1: All network equipment with all its ports connected*

The consumption of the network will be:

$$\text{Access layer switches} = 10 \text{ x } (60 + 2\text{x}5 + 48\text{x}0{,}5) = 940 \text{ W} \quad (2)$$

$$\text{Aggregation layer switches} = 2 \text{ x } (140 + 24\text{x}5) = 520 \text{ W} \quad (3)$$

$$\text{Total network consumption} = 1.460 \text{ W} \quad (4)$$

B. *Scenario 2: Initial configuration with unused ports off*

The consumption of the network will be:

$$\text{Access layer switches} = 10 \text{ x } (60 + 2\text{x}5 + 40\text{x}0{,}5) = 900 \text{ W} \quad (5)$$

$$\text{Aggregation layer switches} = 2 \text{ x } (140 + 12\text{x}5) = 400 \text{ W} \quad (6)$$

$$\text{Total network consumption} = 1.300 \text{ W} \quad (7)$$

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 11%.

C. *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 (8), two access layer switches working with twelve 1 Gbps ports, 10 for servers and 2 uplink ports with its speed reduced (9), and 2 aggregation layer switches with four 1 Gbps ports and two 10 Gbps ports (10), and the network consumption will be:

$$\text{Access layer switches 1} = 4 \text{ x } (60 + 2\text{x}5 + 40\text{x}0{,}5) = 360 \text{ W} \quad (8)$$

$$\text{Access layer switches 2} = 2 \text{ x } (60 + 12\text{x}0{,}5) = 132 \text{ W} \quad (9)$$

$$\text{Aggregation switches} = 2 \text{ x } (140 + 4\text{x}5 + 2\text{x}0{,}5) = 322 \text{ W} \quad (10)$$

$$\text{Total network consumption} = 814 \text{ W} \quad (11)$$

In this scenario, there is a power saving of approximately 45% in network consumption.

V. CONCLUSIONS

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 Organization Theory Model (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 load consolidation on servers.

It was also proposed a model to determine the data center network topology based on the number of physical servers, the rules to manage and set the network devices according to the servers' state changes, and equations to calculate the switches consumption and the total network consumption. This model is the basis to create a simulator and perform simulations to test the viability and the impact of the proposal application in different configurations, with different performance requirements and with different rules and beliefs.

The 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.

It was also demonstrated, that in the described scenario it is possible to get a power saving of approximately 11% only by the proper initial configuration of the network and without any compromise of the performance. In a hypothetical situation of low utilization as described in scenario 3, a power saving of approximately 45% through proper workload consolidation is possible. It was thus demonstrated the possibility and desirability of extending the green cloud management model as proposed.

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 as described in [13], but its application will be still convenient.

As future research, it is proposed to continue this work by developing the necessary extensions to CloudSim to implement the model, and perform experiments to determine the most effective rules and virtual machine allocation policies, and the actual contribution of the model in scenarios with different configurations, real workloads and taking into account possible violations to the SLA.

To evaluate the applicability of the model, it is also proposed to determine, through simulation, how many times a day a port or a device is turned on and off in real scenarios, and its possible impact in equipment failure rate.

Finally, 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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