ARTICLE IN PRESS

Journal of Network and Computer Applications ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

Orchestration of energy efficiency capabilities in networks

Ana C. Riekstin [a,*], Guilherme C. Januário [a], Bruno B. Rodrigues [a], Viviane T. Nascimento [a], Tereza C.M.B. Carvalho [a], Catalin Meirosu [b]

[a] University of São Paulo, São Paulo, Brazil
[b] Ericsson Research, Stockholm, Sweden

ARTICLE INFO

Keywords:
Networks
Network management
Sustainability
Energy efficiency
Policy refinement

ABSTRACT

The energy demand for operating Information and Communication Technology (ICT) systems has been growing, implying in high operational costs and consequent increase of carbon emissions. Both in datacenters and telecom infrastructures, the networks represent a significant amount of energy spending. Given that, there is an increased demand for energy efficiency solutions, and several capabilities to save energy have been proposed. However, it is very difficult to orchestrate such energy efficiency capabilities, that is, coordinate or combine them in the same network, ensuring a conflict-free operation and choosing the best one for a given scenario, ensuring that a capability not suited to the current bandwidth utilization will not be applied and lead to congestion or packet loss. There is neither a way to do this taking business directives into account. In this regard, a method able to orchestrate different energy efficiency capabilities is proposed considering the possible combinations and conflicts among them, as well as the best option for a given workload and network characteristics. The business policies are refined down to the network level in order to bring high-level directives into the operation, and a Utility Function is used to combine energy efficiency and performance requirements. A Decision Tree able to determine what to do in each scenario is deployed in a Software Defined Network environment. The proposed method was validated with different experiments, testing the Utility Function, checking the extra savings when combining several capabilities, the decision tree interpolation and dynamicity aspects. The orchestration proved valid to solve the problem of finding the best combination for a given scenario, achieving additional savings due to the combination, besides ensuring a conflict-free operation.

1. Introduction

It is a known fact that the energy demanded by Information and Communication Technologies (ICT) is increasing worldwide annually. It is so that studies (Ericsson, 2013) indicate that in the next five years the consumption of the sector will reach 1100 TWh. In the U.S. alone, ICT facilities are responsible for 120 TWh of energy annually, corresponding to 3% of all U.S. demand. The country is the second in energy consumption, demanding nearly the same amount of energy as China and four times that of Japan, ranked in the third place (Cook et al., 2014). Attached to the energy demand is also the problem of greenhouse gases (GHG) emissions, and the users' increasing concern with the companies' responsibilities (Jppinen et al., 2013). Worldwide, ICT is responsible for 2% of the carbon emissions (GeSI, 2012), a figure that is predicted to grow to 2.3% by 2020.

Within the ICT sector, datacenters, embodied by servers, networking, and cooling, is the fastest growing source of energy consumption. Its demand grew 7% in 2013, when compared to the previous year, nearing 350 TWh (Cook et al., 2014). The prediction is that it will have grown 81% by 2020. However, how much of that amount corresponds to the network is not actually consensus: 4% in Emerson Electric Co. (2009), 12% in Abts et al. (2010), one third in Kliazovich et al. (2010), 9% in Koutitas et al. (2012), 23% in Kachris and Tomkos (2013), 22% in 2011, projected to 24% in 2020 in Cook et al. (2014). Even if not consensus, considering the current energy efficiency efforts on the other parts of the datacenters, the share of networking can become much higher, with the potential to raise its ratio up to about 50% (Abts et al., 2010). The numbers can be even more significant for telecom operators, for whom the energy costs are among the most relevant (Ericsson, 2013). Considering the associated GHG emissions, Verizon reported that the electricity to run its networks surpassed 92% of their total carbon emissions in 2013 (Verizon, 2013).

To mitigate such environmental costs, more energy efficient networking devices and techniques have been devised. However, such capabilities not always work together properly, thus lacking a

* Corresponding author. Tel.: +55 11 30911092.
E-mail address: carolina.riekstin@usp.br (A.C. Riekstin).

http://dx.doi.org/10.1016/j.jnca.2015.06.015
1084-8045/

Please cite this article as: Riekstin AC, et al. Orchestration of energy efficiency capabilities in networks. Journal of Network and Computer Applications (2015), http://dx.doi.org/10.1016/j.jnca.2015.06.015

specialized management layer to allow a better exploitation of their combined benefits. In this paper, we show a novel method to orchestrate energy efficiency capabilities of the network. Our method relies on Policy-Based Network Management (PBNM) and policy refinement to shorten the distance between management level and device-level operation, therefore making energy savings in the network more straightforward from the management point of view.

Examples of efforts in energy-efficient networking that tackle a single device and its immediate neighbors are the Adaptive Link Rate (ALR) (Gunaratne et al., 2008) and the techniques of Synchronized Coalescing, and Adaptive Coalescing (Mostowfi and Christensen, 2011). At the network level, there are the energy-aware routing mechanism proposed in Cianfrani et al. (2012), Green Traffic Engineering (GreenTE) (Zhang et al., 2010), Sustainability-Oriented Network Management System (SustNMS) (Costa et al., 2012), and ElasticTree (Heller et al., 2010), which targets Software Defined Networks (SDNs). Though straightforward the operation of a single capability might be in a homogeneous network, the necessary orchestration can be costly in a more heterogeneous environment, with capabilities varying among nodes or with nodes with more than one capability enabled. This can be even more challenging if we consider the alignment with business policies.

The expression of business-level policies and its subsequent translation to device-level actions and configuration increases the automation level of the network management, turning it less error prone and complex. This can be achieved through Policy-Based Network Management (PBNM). With the aid of PBNM, network managers can provide users with green Service-Level Agreements (SLAs), thus offering green services and products. These would be ultimately implemented as sustainability-oriented policies that manage the energy efficiency capabilities of the network. This way, a network operator can foster a reduction in GHG emissions and energy expenses. A PBNM scheme can be comprised of abstraction levels other than the two focused on business expressions and actions and configurations of devices. The translation between such levels is called Policy Refinement and, although this has been studied before, the lack of a standard (Craven et al., 2011) just accrues to the inherent difficulty of refining novel high-level sustainability-oriented policies, either in legacy networks or in more modern SDNs. For further insights in such challenges and related requirements, we refer the reader to Riekstin et al. (2015).

In this paper, we detail a method devised to orchestrate energy efficiency capabilities in a network, comprising the refinement of sustainability-oriented policies. We also show how a proof-of-concept of the proposed method was prototyped and then validated. Having as start point the business level and sustainability-oriented information models, randomically generated workloads, the network topology, the power profile of the devices, and the knowledge of the deployed energy efficient capabilities, the method generates an interpolated decision tree against which decisions are made. Decisions are such as which routing or local energy-efficient technique to apply, or a combination thereof, in which period of the day, under which network conditions.

The main contributions of this work are (i) a method to orchestrate energy efficiency capabilities, supported by a Utility Function that combines sustainability-oriented and performance aspects, able to choose the best capability (or a combination of capabilities) for a given scenario, ensuring the adequate quality of service; and (ii) the development of a prototype intended as a proof-of-concept of the proposed method in an emulated environment.

To the best of the author's knowledge, this is the first method to refine sustainability-oriented policies from business level down to network level and orchestrate energy efficiency capabilities, thus enabling a more energy efficient and automated network infrastructure. In detailing our method, for the first time we show a sequence diagram and elements of a structured language to be used with the implementation architecture first presented in Riekstin et al. (2014). The intrinsics and decision steps of the method are also discussed and exemplified for a given network and power profiles.

The remainder of this paper is organized as follows. Section 2 provides a common ground for further discussion and describes related work. Section 3 details the open issues considering the existing solutions. Section 4 details our method and has the bulk of the theoretical and general content, whereas in Section 5 we show how we implemented our proof-of-concept system to save energy in the network. The obtained results are reported in Section 6. Discussions and concluding remarks are drawn respectively in Sections 7 and 8.

2. Background

There are many proposals to improve the energy efficiency in a network. Such capabilities can act locally, inside a node and its components, or have a centralized view of the whole network. In this section, different energy efficiency capabilities are presented, including their scope of actuation. Such capabilities are expected to act in a network that already has another capabilities being applied, such as the Quality of Service (QoS) ones. However, managing a system with different capabilities with different purposes is not an easy task.

One solution to deal with such a complex task is Policy-Based Network Management (PBNM), which uses policies to manage systems, also presented in this section. Policies can be related to QoS, access control or, more recently, to sustainability. All these types of policies can have different levels of abstraction, and the translation between them is called Policy Refinement.

2.1. Energy efficiency capabilities

Several capabilities and protocols have been proposed to cope with energy efficiency in networks. Such capabilities can be separated by their scope of actuation: a component of a node, a complete node, or the whole network (Schlenk et al., 2013). Figure 1 lists some examples for each scope.

There are many proposals related to the node components scope, mainly because of the influence of personal computers and battery energy solutions. Adaptive Link Rate (ALR) is among the most cited; it allows reducing or increasing the link rate between two interfaces in accordance with the traffic. It is intended to use existing Ethernet data rates (Gunaratne et al., 2008). Another capability in the node components scope is ACPI (Advanced Configuration and Power Interface). It comprises rate adaption (P-States) and sleeping capabilities (C-States) (Bolla et al., 2009).

In the system scope, one can cite Synchronized Coalescing (SC) (Mostowfi and Christensen, 2011). The approach aims to create more idle periods during which it is possible to put not only

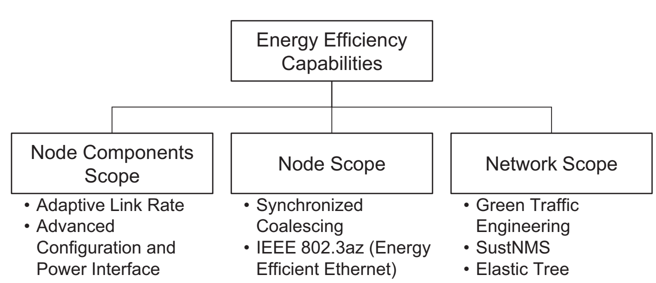

Fig. 1. Energy efficiency capabilities classification.

Please cite this article as: Riekstin AC, et al. Orchestration of energy efficiency capabilities in networks. Journal of Network and Computer Applications (2015), http://dx.doi.org/10.1016/j.jnca.2015.06.015