Distributed SDN controllers optimization for energy saving

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***Abstract*—This paper presents a proposal for energy optimization on Software-Defined Network (SDN) by a proper controller placement. First, the discussion shows the definition of SDN and the role of controllers, then the current state-of-the-art on distributed SDN controllers is briefly discussed showing that current research on this topic focuses on fault-tolerance and load-balancing. Then the energy saving SDN strategies are presented and the problem of saving energy on the control-plane is given further details. A new approach based on parallelism and lower processor frequencies is demonstrated finally, the expected results and key contributions are defined.**

***Index Terms*—SDN, energy savings, controller placement, software-defined-network**

I. Introduction

Datacenter Networks (DCN) are the foundation of cloud services, these clusters of servers, switches, and routers form the necessary infrastructure to provide computing services around the world. There is a constant concern [1] with the energy amount consumed by these large centers.

As virtualization and cloud computing became more and more common on Data-Center Networks (DCN), the industry and researchers have turned their attention to software. The most common strategy to improve manageability and to follow the fast-changing requirements is the Software-Defined Network(SDN) [2]. This approach separates the data plane from the control plane on the network stack. The idea is to centralize control providing ways to reach programmability and cooperation between the network infrastructure and the applications that run on top of it.

The controller is the central point of an SDN it is responsible for forwarding and routing decisions that are then passed to the data-plane to be executed by simple switches, this communication is enabled by a protocol that both parties must agree, OpenFlow being the most common option.

Another important feature of SDN controllers is that they expose APIs to allow applications to change network operation, those applications are known as northbound. The northbound interface enables the programmability of the network, changing network behavior based on external information processed by any element that talks to the controllers‘ API.

The need to 24/7 availability of DCNs poses a challenge on energy efficiency, since the on-demand cloud provider needs to maintain available resources that may be used, but are not needed full-time. If part of a cloud provider, for instance, is not needed it should be put on sleep-mode or turned off to save energy. The turning on and off of different parts of networks is a complex problem as there is a cost on energy consumption to decide what to turn off and more cost to turn it on again when needed, besides the impact on the latency of the appliances' boot delay. It is estimated that the Datacenter Network energy consumption during 2012 was 28.9(TWh)[1].

II. Distributed controllers

As a central point of coordination on an SDN, the controller also poses as a single point of failure which leads to the need for redundancy of controllers, this can be achieved in an automatic way by two strategies: distributed controllers versus replicated controllers [2].

The most straightforward way is to replicate the controller, in this scenario the SDN has two or more controllers that are always aware of the full current state of the network and keep the same information. The second scenario is a distributed one, here the SDN has two or more controllers but each of them may not have full control or knowledge of network status, each controller is responsible for a portion of the network and talks to the other controllers to update them about any changes.

A replicated controller has the advantage of fast recovery time after failure since there is no need to synchronization between the failed controller and the new one, but this is achieved in the expense of the overhead to keep both (or more) controllers aware of every operation on the control-plane.

Since the distributed controllers need to share information for the correct working of the SDN two main concerns appear as important for scalability: the number of controllers and their location. The number of controllers impacts their capacity to process flow requests, it is important to not assign an excess of switches to the same controller, but it is also important not to allow controllers with no switch assigned or switches that can be offloaded to another controller [3].

The placement is yet another concern that impacts especially on flow-setup latency. If the controller is too far (in hops count) from the switch this latency may grow and degrade the SDN performance. The controller placement problem is a well known NP-Hard problem [4], many authors have proposed

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heuristics with different metrics, such as: maximizing resilience, minimizing controller processing latency, minimizing flow-setup latency, etc.

A. *Current State of the art*

Energy-efficient SDN applies different techniques to achieve good throughput while saving energy, those techniques may be applied in three levels: chip, node or entire network[5]. The chip level depends on hardware solutions, but node and network levels may be achieved by applying new software to controllers, one example of a chip level energy optimization is to reduce the data-rate of low used links. The node level energy optimization tries to reduce energy consumption based on information available to each node of the network, without the need to communicate the current state of the network, to understand this strategy consider a protocol of coalescing packets on low usage nodes. The network level is implemented on controllers and works based on the premises that the entire network state is known, an example of this level is to re-route packets from low-use switches to the ones that already have traffic flowing, this allows the system to sleep-mode or even completely shutting down the unused switches.

B. *Comparison on distributed controllers*

To guarantee resiliency the controllers must be physically distributed, to do so many authors and industry-level products already have some strategy to implement a distributed architecture to SDN controllers. The main component to allow this distribution is an East/Westbound protocol, responsible for communication between controllers, although there is no open standard for this protocol [6] many custom protocols are already in use such as: Ravana [7], publish/subscribe protocols, zookeeper, custom BGP, among others [3].

Table I presents the current state of distributed controllers and their strategy on Architecture and East-West Protocol utilization.

Project	Information Distribution Architecture	Protocol/API East-West
East/West Bridge	Flat	Custom BGP
Elasticon	Flat	Custom Protocol
DISCO	Flat	AMQP
HyperFlow	Flat	Publish/Subscribe
OpenDayLight	Flat	Akka, Raft
ONOS	Flat	Raft
ONIX	Flat	Zookeper
Controlling SDN	Flat	JGroups
Ravana	Flat	Ravana Protocol
D-SDN	Hierarchical	Custom protocol
IRIS	Hierarchical	Custom Protocol
Kandoo	Hierarchical	Messaging Channel
FlowBroker	Hierarchical	Broker Protocol

TABLE I

DISTRIBUTED CONTROLLERS AND THEIR STRATEGY ON ARCHITECTURE AND EAST-WEST PROTOCOL UTILIZATION. ADAPTED FROM [3]

The chosen method to implement controllers parallelism may impact on energy consumption since it is directly related to the amount of east-west communication.

III. RESEARCH PROBLEM

The main problem being addressed here is: Is it possible to reduce energy consumption on SDN controllers by parallelizing tasks maintaining latency and throughput? This section presents the three main aspects of the problem to be addressed, first the amount of energy consumed on large data centers; secondly the number of SDN controllers and their placement; thirdly the influence of this placement on energy consumption.

A. *Energy Consumption on large data centers*

Data centers of Cloud providers are known to be over-provisioned [8] since the provider can not know in advance the peak of its clients' demand. This scenario implies in waste of resources not only to own the equipment necessary but also to keep it running, to minimize this waste many techniques are researched and applied to create energy-efficient data centers[5]. One important aspect is that in data centers network equipment alone is responsible for 20%-30% [9] of total energy consumption, by looking at this data is clear that energy efficiency on the network components of a data center has a high impact on the energy consumption overall.

B. *The controller placement problem*

The CPP is a well-known problem that outputs the best location of one or more controllers given the switches locations, a variation of this problem is the dynamic one, where the demand for traffic between switches is another input and changes over time[3].

The work of [10] proposes an algorithm to solve the CPP using a heuristic to balance the network load between controllers by migrating switches from one controller to another. Two versions are shown an online and an offline one. The CPP is defined as an optimization problem which the objective is to minimize the number of controllers limited by some restrictions, such as: (i) the traffic demand of each switch must be satisfied through only one controller; (ii) the traffic demand of each switch must be delivered as a whole; (iii) there is a maximum number of switches that can be attached to a controller; (iv) there is a threshold of traffic volume that can delivered to a controller.

C. *Energy consumption on the control plane*

As explained before the main characteristic of an SDN is the separation of the data-plane form the control-plane, many works have demonstrated techniques to exploit the data-plane capabilities to better energy efficiency[5], and many non-SDN techniques are used on the SDN switches (in a more centralized and smart way), e.g., link-aggregation, sleep mode and bandwidth regulation.

With the separation of the two planes, the control-plane was left behind by researchers as a way to reduce energy consumption. The placement, number, coordination, and load balancing on controllers is deeply researched [4] as a way to minimize cost [11], improve performance of the network [4], attack-protection [12] or even fault tolerance [7].

IV. Proposed approach

This section describes in two parts the approach and justification to an energy efficient SDN control-plane. To do this is necessary to understand how to reduce energy consumption by parallelizing tasks.

A. Minimizing energy consumption by parallelization

The work of [13] showed that by lowering frequency on parallel applications it is possible to keep the same performance, also in a multi-core processor, the application speedup is related to a reduction on energy consumption. The same approach has been applied to Software Defined Radios by [14], those results show that an increase in parallelism and the number of processors can decrease energy consumption by more than 2 orders of magnitude compared to the conventional method.

B. Guaranteeing performance with less energy consumption

Since it is possible to reduce energy consumption by parallelizing tasks, while keeping the expected performance, the proposed approach to reduce energy consumption on SDN is to use the already distributed nature of the controllers, to decrease energy consumption while improving resiliency. As shown in section II many strategies to achieve fault tolerance rely on distributed controllers and as presented in section III-B CPP is designed to reduce the number of controllers. But the main focus here is not to reduce the number of controllers and instead to increase the number of less power-hungry (lower processor frequencies) controllers. This may look counter-intuitive, but it is important to also consider that there is already a need to distribute the controllers, to avoid the single point of failure that arises from the centralization of the control plane.

V. Key Contributions

The two main contributions of this work shall be placed on the efficiency of SDN controllers. First is necessary to define a good trade-off between parallelization of SDN controllers and network throughput, the second contribution is a new algorithmic way to determine controllers' placement that takes into account not only network performance, but also energy conservation.

A. Define the level of parallelization of SDN controllers

It is important to find the limit to parallelism on controllers, as the number of processing units rises, also rises the need for communication and synchronization between entities. Some works have already defined guidelines on distributing controllers to minimize Service Level Agreements (SLA) violation [15]. One key contribution of this work is to consider parallelism to cope with SLA while reducing energy consumption.

B. Define an optimal algorithm for controllers placement

As proposed an algorithm to define the location and number of controllers to an SDN will be defined, this algorithm may work offline to define a static allocation, based on historical traffic data, but may also work dynamically considering the current traffic data of the network.

VI. Expected Results

The validation of the hypothesis will be achieved by a small scenario experiment on real controllers and SDN switches. Once validated by those experiments, simulations with large scenarios with mathematical models constructed from the real controllers and other works [16] will be used to demonstrate the scale of applications on DCN.

Once finished, the results of simulations may show that is possible to reduce energy consumption on data centers by better placing the SDN controllers. If this reduced amount is negligible then it will point to a trade-off between fault-tolerance and energy consumption. To further validate the results will be compared with other control-plane centered approaches for the energy problem, such as [17], and non-energy-aware controller placement algorithms as described by [18].

A. Lowering energy consumption on data centers

Reducing energy consumption apart from being an economical matter is an environmental one, since less energy consumption leads to a smaller carbon footprint, and this footprint related to energy is expected to grow [1].

As CPU utilization is an important part of energy consumption on the SDN, as reported by [16], by lowering CPU frequency while guaranteeing the distributed performance of controllers, it is expected to achieve overall less energy consumption on the DCN.

B. Define an algorithm and best practices to controller placement

As many authors have shown [4] the controller placement is an NP-Hard problem, and most current solutions are based on heuristics to improve some aspect of the network. The results of this work's simulations may demonstrate that there is an optimal algorithmic (by a new heuristic) to determine the best location and number of controllers.

This algorithm may receive as input the number and of switches and nodes and may output the best scenarios to reduce energy consumption and what should be the level of performance expected from the controllers.

C. Balance trade-off between energy consumption and SLA requirements

The current state of energy consumption on data-centers networks is aimed at performance guarantees and SLA-aware services, but a reduction on energy consumption may affect this performance, so clearly there is a trade-off between energy reduction and SLA guarantees. It is also expected that reducing processor frequency on controllers may also reduce energy consumption keeping SLA violations levels.

VII. Conclusion

This paper has shown the importance of energy efficiency on datacenter networks and the influence of network equipment on this matter. The research has shown that control-plane is being left behind as an opportunity to enhance this efficiency since all research is being focused on data-plane efficiency. A new proposal on reducing energy consumption on SDN control-plane has being shown using parallelism and distribution of controllers on the network to low the energy consumption while maintaining fault-tolerance, the approach explained here will be assessed on real and simulated environments to prove its viability.

As the CPP is an NP-Hard problem the solution proposed will be compared to others already available on the literature, the final contribution will be an heuristic to solve the CPP for energy efficiency and SLA.

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