

Electronics - Reply Letter on Manuscript No.
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Improving the Energy Efficiency of
Software-Defined Networks Through the
Prediction of Network Configurations

We thank the Reviewers for providing valuable feedback, which will help us to improve our manuscript. We answer the reviewers comments in-line below.

REVIEWER 1

Q1. Describe a subsection after introduction i.e., research gap between the previous works (Research Gap).

Thank you very much for the proposal. You are right. We did not have any section detailing and comparing several related works in the field. Such section is important to better motivate our work. Therefore, we added the "Research Gap" section after the Introduction, as suggested. In addition, below you can also find the new section:

Research Gap

Over the last few years, extensive work has been done on power consumption management to improve the energy efficiency of communication networks. For instance, some works, such as [18-21], focus on reducing the energy consumption of satellite and terrestrial networks while trying to maximize the quality of service. Recent works focus also on SDN networks. The flexibility these networks provide, such as the separation of the data plane from the control plane and its consequent advantages, creates new opportunities to define more dynamic and energy-aware networks.

Recent works in this area have focused on ILP-based approaches [22,23]. These works allow researchers to identify the optimal network configuration, but they cannot be used for large networks due to the complexity of the problem to address. Since the power consumption problem in SDN can be modeled as Multi-Commodity Network Flow problem, which is known to be NP-hard, other works focused on applying heuristics, such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO), among others [12,23]. Nevertheless, compared to the dynamicity that SDN networks (time scale of the order of milliseconds) require, these techniques take longer to identify

an appropriate network configuration.

In order to reduce the re-configuration time, ML is used to improve network performance. For example, in the field of Traffic Engineering (TE), several works exploit the use of Reinforcement Learning to adapt the network configuration to the current traffic load and minimize the Maximum Link Utilization (MLU) [24,25]. In order to save energy, [26] proposes an algorithm based on DRL to predict traffic in order to optimize the energy efficiency and to perform real-time load balancing. To the best of our knowledge, this is the closest solution to the problem we aim to tackle. In this paper, we focus on using Logistic Regression with the aim of reducing the complexity of the problem addressed. This technique is used to identify the subset of links to be turned off depending the network traffic load.

In the following section, the power consumption problem is studied in order to achieve the goal of this article, bearing in mind the previous work that have just been presented.

Q2. On page 2, lines 47-49, the importance of central management is described in SDN. Hence, I recommend mentioning some related literature to it. For example, the following works describes the significance of central management and controller in SDN. 1. "Quality of service improvement with optimal software-defined networking controller and control plane clustering." Comput. Mater. Contin 67 (2021): 849-875. 2. "QoS improvement with an optimum controller selection for software-defined networks". Plos one, 14(5), p.e0217631.

Thank you very much for the suggestion. The detailed references are perfect to support our argument. We included both of them in the suggested section.

Moreover, the central vision, flexibility and programmability of the Software-Defined Networking (SDN) paradigm enable this combination of techniques to re-think and build highly energy-efficient programmable networks [13-15].

Q3. Mention the main contribution points in numbered or bullets form after the introduction section.

Many thanks for this comment. The contributions were detailed at the end of the Introduction section. However, we agree that they were not clear and mixed with different explanation. Therefore, as suggested, we listed the main contributions at the end of the Introduction section. The text included in the document is the following one:

The main contributions of this work are:

- The definition of a novel algorithm to predict energy-efficient network configurations based on Logistic Regression (LR).
- The evaluation of the proposed LR-based algorithm over a realistic network topology.
- The comparison of the obtained results with energy-efficient ad hoc solutions.

Q4. Include some future directions.

Thank you very much for your comment. Section 6 has been modified to include some future directions on which we are currently starting to work. The new text has been highlighted with blue-colored text. Concretely, the text included is:

Regarding possible future research activities, we are working on testing different ML methods to compare them and select the one that provides the best results in terms of power savings and computation time. We are also working on defining a framework able to select the ML technique to be used depending on the network topology and other features. In this sense, we plan to use different cluster configurations depending on the network behavior. Finally, we aim to evaluate the proposed algorithm over larger networks to check the scalability of the solution and how it behaves in emulated environments.

REVIEWER 2

Q1. The authors should check the whole paper to avoid writing and grammar errors, such as “Several studies have been published showing the positive sustainability impacts ICT solutions may have [3,4], and”

Thank you very much for the suggestion. You are right. There were different typos along the paper. We have carefully proof-read it and solve all of them. We did not highlight these changes in the paper because they are throughout the whole document.

Q2. It is suggested to use short sentence to make the contents more clear for readers.

We are really sorry for the long sentences. You are right. Long sentences are more difficult to understand. We have reviewed the whole paper trying to use short sentences. All the changes have been highlighted using blue-colored text. The modified text is not included in this answer because they are spread along the whole document.

Q3. The introduction of works published in recent 5 years is not sufficient. The following recent works in energy efficiency [R1]-[R2] and SDN [R1]-[R4] fields should be referred to highlight the state-of-the-art of this paper. [R1] “Refracting RIS aided hybrid satellite-terrestrial relay networks: Joint beamforming design and optimization,” IEEE Transactions on Aerospace and Electronic Systems, vol. 58, no. 4, pp. 3717-3724, Aug. 2022. [R2] “SLNR-based secure energy efficient beamforming in multibeam satellite systems,” IEEE Transactions on Aerospace and Electronic Systems, early access, Jul. 2022, doi: 10.1109/TAES.2022.3190238. [R3] “Joint beamforming and power allocation for satellite-terrestrial integrated networks with non-orthogonal multiple access,” IEEE Journal of Selected Topics in Signal Processing, vol. 13, no. 3, pp. 657-670, June 2019. [R4] “Supporting IoT with rate-splitting multiple access in satellite and

aerial-integrated networks,” *IEEE Internet of Things Journal*, vol. 8, no. 14, pp. 11123-11134, Jul. 2021.

Many thanks for this comment. These papers are very important to better motivate our work. We added all of them.

Over the last few years, extensive work has been done on power consumption management to improve the energy efficiency of communication networks. For instance, some works, such as [18-21], focus on reducing the energy consumption of satellite and terrestrial networks while trying to maximize the quality of service. Recent works focus also on SDN networks. The flexibility these networks provide, such as the separation of the data plane from the control plane and its consequent advantages, creates new opportunities to define more dynamic and energy-aware networks.

Q4. Both the motivations and contributions are not referred clearly, which should be emphasized to demonstrate the novelty of this paper.

We are really sorry for this issue. In order to better highlight the contributions and the motivations of our work, we have added the list of contributions at the end of the Introduction section. Moreover, we have added a new section, named Research Gap, that details different related works and motivates our work.

The new text detailing the contributions of this work is the following one:

The main contributions of this work are:

- The definition of a novel algorithm to predict energy-efficient network configurations based on Logistic Regression (LR).
- The evaluation of the proposed LR-based algorithm over a realistic network topology.
- The comparison of the obtained results with energy-efficient ad hoc solutions.

Finally, the Research Gap section contains the following text motivating our work:

Research Gap

Over the last few years, extensive work has been done on power consumption management to improve the energy efficiency of communication networks. For instance, some works, such as [18-21], focus on reducing the energy consumption of satellite and terrestrial networks while trying to maximize the quality of service. Recent works focus also on SDN networks. The flexibility these networks provide, such as the separation of the data plane from the control plane and its consequent advantages, creates new opportunities to define more dynamic and energy-aware networks.

Recent works in this area have focused on ILP-based approaches [22,23]. These works allow researchers to identify the optimal network configuration, but they cannot be used for large networks due to the complexity of the problem to address. Since the power consumption problem in SDN can be modeled as

Multi-Commodity Network Flow problem, which is known to be NP-hard, other works focused on applying heuristics, such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO), among others [12,23]. Nevertheless, compared to the dynamicity that SDN networks (time scale of the order of milliseconds) require, these techniques take longer to identify an appropriate network configuration.

In order to reduce the re-configuration time, ML is used to improve network performance. For example, in the field of Traffic Engineering (TE), several works exploit the use of Reinforcement Learning to adapt the network configuration to the current traffic load and minimize the Maximum Link Utilization (MLU) [24,25]. In order to save energy, [26] proposes an algorithm based on DRL to predict traffic in order to optimize the energy efficiency and to perform real-time load balancing. To the best of our knowledge, this is the closest solution to the problem we aim to tackle. In this paper, we focus on using Logistic Regression with the aim of reducing the complexity of the problem addressed. This technique is used to identify the subset of links to be turned off depending the network traffic load.

In the following section, the power consumption problem is studied in order to achieve the goal of this article, bearing in mind the previous work that have just been presented.

Q5. In simulation results, the comparison to existing works is limited, which should be improved.

Many thanks for this comment. We agree with the reviewer that it should have been interesting to have compared our solution with other state-of-the-art approaches. As stated in the new *Research Gap* section, the closest work to ours is [26]. However, it largely focuses on traffic prediction to capture the temporal characteristics of network traffic, and then the authors use such prediction to minimize the energy consumption as well as to perform load balancing. However, tackling both objectives at the same time (which are contradictory, please see [1, 2]) would lead to obtain unfair results, since a weighted parameter should be used to select whether the preference is to optimize the energy savings or to reduce the MLU. In this sense, we perform a comparison with our GA-based heuristic [23], that aimed at uniquely minimizing the power consumption in SDN networks.

References

- [1] J. Galán-Jimenez, M. Polverini, F. G. Lavacca, J. L. Herrera, and J. Berral, “On the tradeoff between load balancing and energy-efficiency in hybrid ip/sdn networks,” in *2021 12th International Conference on Network of the Future (NoF)*, 2021, pp. 1–9.
- [2] J. Galán-Jiménez, M. Polverini, F. G. Lavacca, J. L. Herrera, and J. Berral, “Joint energy efficiency and load balancing optimization in hybrid ip/sdn networks,” *Annals of Telecommunications*, 2022, on press.