A Review of Forwarding Strategies in Transport Software-Defined Networks

Awais Aziz Shah, ***Student Member, IEEE***
Giuseppe Piro, ***Member, IEEE***
Luigi Alfredo Grieco, ***Senior Member IEEE***
Gennaro Boggia, ***Senior Member IEEE***
Dept. of Electrical and Information Engineering, Politecnico di Bari, Via Edoardo Orabona 4, 70126 Bari, Italy
CNIT, Consorzio Nazionale Interuniversitario per le Telecomunicazioni, Via G. Moruzzi 1, 56127 Pisa, Italy
e-mail: {awais.shah, giuseppe.piro, alfredo.grieco, gennaro.boggia} @poliba.it

ABSTRACT
Software-defined networking (SDN) is an innovative technology that aims to improve the network control, while providing an improved usage of virtual resources deployed across modern networks. Recently, telco operators started to adapt the SDN technology in their transport networks, thus boosting the research activities around the Transport-SDN (T-SDN) paradigm. The integration of SDN in transportation networks, however, poses numerous challenges related to the design of efficient routing approaches, working in large-scale and distributed networks. In this context, this paper investigates the design issues addressed by the current scientific literature and provides a cross-comparison of routing techniques published during recent years. The analysis of key features and drawbacks characterizing the reviewed methodologies reveals the lack of routing strategies that could ensure both energy effectiveness and better bandwidth requirements also known as quality of service in a real-time scenario, which is the primary requirement of the modern large-scale telecommunication networks.

Keywords: Software-Defined Networking · Transport Network · Forwarding Policies.

1. INTRODUCTION

Modern telecommunication networks demand high performance, agility, pervasive control with reduced power consumption. Software-Defined Networking (SDN) emerged as a pivotal technology for the deployment of programmable and virtualized service infrastructures [19]. On the other hand, Network Function Virtualization (NFV) is a new network architecture approach that uses Information Technology (IT) virtualization technologies to virtually deploy network functions. Research shows the combination of SDN and NFV enables unprecedented levels of centralized network control, dynamicity, and flexibility [10]. It provides the opportunity for telco operators to make their network architectures more programmable, cost-reductive, energy-efficient, and service-oriented. This new phenomenon of adaptation of SDN in the transport networks is known as T-SDN.

However, this adaptation poses numerous technological and communicational challenges. In the context of communication, the communication in T-SDN should be configured in order to guarantee high quality of service requirements (i.e., strict delay constraints, very high bandwidth) and low energy consumption. This eventually highlights the importance of an efficient routing strategy that provide both quality of service and consume less energy [9]. Unfortunately, due to the large size of the network and multiple networking elements involved in the network, it is an ambitious task to design a routing strategy that could meet all the expectations of the telco operators for their T-SDN environments.

This paper investigates the design issues addressed by the current scientific literature and provides a cross-comparison of routing techniques published during recent years. It has been executed in the context of INTENTO project (recently funded by the Apulia Region, Italy), which targets the development of advanced optimization algorithms in the real-time and complex T-SDN environment. The comparison is based on the set of features provided by each strategy such as energy-efficiency, quality of service, type of supported network, and comparison with other methods. On the other hand, it also highlights the drawbacks of each of the given methodology. The results of the review suggests a need for an effective routing strategy that could meet the real-time demands of the network, should be dynamically reactive to the changing size of traffic, and should be able to ensure both high quality of service (in terms of bandwidth required by the network) and reduced energy consumption.

The rest of the paper is organized as follows: Section 2 presents the summary of problems related to routing strategies identified in the current literature. The comparison of the state-of-the-art routing strategies is presented in Section 3. Finally, Section 4 draws the conclusions of this work.

2. ISSUES IDENTIFIED IN THE CURRENT LITERATURE

The design of the forwarding strategies for SDN and T-SDN deployments has been addressed in the scientific literature by addressing the following issues:

- How the current routing strategies can turn-off the underutilized links in the network that could eventually lead to reduced energy consumption in the network [3,5,13,23,24,25,26,30].
- How the routing strategy can dynamically manage the power of the network by automatically setting the active number network elements in response to the variability of traffic [1,7].
- There is an ever increase in the power consumption and carbon emissions by the large data networks, how it can be reduced? [4].
- While most of the routing strategies focus on selecting the shortest flow path to deliver packets, it may result in network congestion if the bandwidth overhead is not considered and a lot of traffic enters in the network. How the network congestion can be prevented in such scenarios? [9].
- How to achieve energy-aware routing in the networks? [10,14,17].
- How to better exploit network bandwidth also known as quality of service, in order to ensure the demanded throughput by the network users? [12,8].
- Although several works on SDN have been proposed to improve the energy efficiency, these techniques may lead to performance degradations when the quality of service requirements are neglected. How is it possible to achieve energy efficiency and quality of service together at the same time? [2,18,20].

3. ROUTING STRATEGIES DISCOVERED IN THE STATE OF THE ART

This section provides a comparison between some of the important routing strategies recently published in the literature. The analysis has been done in order to provide answers to the following questions:

- Is the strategy designed to achieve energy efficiency?
- Does the strategy provide quality or service?
- What kind of network is supported or tested on?
- Does the paper provide comparison with other methods?
- Finally, what are the cons of the given strategies?

The results of the comparison presented in Table 1 demonstrates that most of the employed approaches individually focus on either achieving energy efficiency in the network [1,3-6,9,11-13,16-20] or enable quality of service based routing [7,8,10]. Unfortunately, only a few of them jointly considers energy efficiency and quality of service in their studies [2,14,15], but their drawbacks, such as extra delay and loss of packets in the network, traffic congestion during peak periods, increased latencies due to non-direct communication with the controller, lacks in reacting to the variability of the actual traffic load, and infeasibility in large-scale scenarios results in a demand for more efficient routing strategies that could tackle these limitations and ensure both energy effectiveness and better bandwidth requirements (i.e., quality of service) to facilitate the telco operators in the potentially large-scale T-SDN environments.

Characterizing the state-of-the-art, it is eventually desired that a novel methodology should be designed that could be dynamically reactive to the traffic variability and achieve an improved quality of service with low energy consumption in potentially large-scale T-SDN networks. Thanks to the SDN paradigm, this ambitious task can be achieved through utilizing the benefits of its architecture, like optimal communication control architecture and generalized protocols (e.g., OpenFlow, RESTCONF, NETCONF, and T-API) that facilitates the communication between network elements apart from any vendor-specific requirements.

4. CONCLUSIONS

This paper provided a review of the forwarding strategies in Transport Software-Defined Networks. It investigated the design issues addressed in the current literature related to the forwarding strategies and made a cross-comparison between the state-of-the-art routing methodologies. The comparison is based on the set of features provided by each strategy such as energy-efficiency, quality of service, type of supported network, and comparison with other methods. At the same, it also highlighted the drawbacks of each methodology. The findings of the study suggest a need for an effective forwarding strategy that could implicitly meet the real-time demands of the network, should be dynamically reactive to the variability of traffic and should be able to ensure both high quality of service and reduced energy consumption in the network.

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Table 1: Review of state-of-the-art routing strategies

Ref. No.	EF*	QoS**	Network Type	Comparison with other methods	Drawbacks
[1]	✓	-	Hybrid-SDN	Fat Tree	Does not focus on QoS and TCP connection capacity limit cannot be 1.
[2]	✓	✓	Partial SDN	Dijkstra, modified Dijkstra, simple heuristic, and greedy algorithm.	Algorithm may cause extra delay and loss of packets in the network. Also. it may increase traffic congestion during peak periods or when traffic loads are not high in the network.
[3]	✓	-	SDN	Classical EAR approach	Rule space constraint of the strategy could affect QoS.
[4]	✓	-	SDN	Data gathered from GEANT network	Lack of restoration mechanisms to improve the fault tolerance capacity.
[5]	✓	-	Generic	Data from SNDLib	Results show 27% increase in average path length and there is no focus on bandwidth requirement.
[6]	✓	-	SDN	Dijkstra and extended Dijkstra algorithm	Limited to a certain environment that has fixed traffic generation rate and bandwidth.
[7]	-	✓	SDN	Shortest Path Round Robin and ACS	Targets throughput and latency through load balancing. No EF achievements.
[8]	-	✓	SDN	-	Focuses on selecting shortest path to minimize delay, no congestion episodes detection in case of dynamic traffic changes.
[9]	✓	-	SDN	Greedy Bin Packing and ElasticTree	Claims EF but no methodology to dynamically shut down links or monitor the changes the network.
[10]	-	✓	SDN	Dijkstra’s and Extended Dijkstra’s	Focuses on end-to-end latency and throughput, but no focus on energy constraints.
[11]	✓	-	SDN	-	No implementation with an SDN controller. Only simulations with C++ code.
[12]	✓	-	Hybrid-SDN	-	Designed for hybrid-SDN. All the switches are not directly connected with the central controller, therefore real-time changes in the network cannot be monitored and delayed decisions will occur.
[13]	✓	-	SDN	Methodology presented in [3] and [5]	No calculations for amount of bandwidth allocated to the flows and no real-time strategy to cater congestion episodes.
[14]	✓	✓	SDN	-	In-band communication increases the latencies of the exchange of control messages which makes the resulting implementation infeasible in large-scale scenarios.
[15]	✓	✓	SDN	data gathered from GEANT network	lacks in reacting to the variability of the actual traffic load.
[16]	✓	-	SDN	-	Only tested on four types of Flow Arrival Rate of 0.05, 0.10, 0.50, and1.00. No implementation on real traffic data.
[17]	✓	-	SDN	First and Second Waxman Network Topology	Applied to the case only when the traffic load is low.
[18]	✓	-	Hybrid-SDN	Shortest path algorithm (SP)	trade-off in average path length is limited to 0.2 hops. No comparison of bandwidth allocated to the traffic.
[19]	✓	-	SDN	SPF (Shortest Path First) and NSP (Next Shortest Path)	No experiments for measuring the average path length and throughput on the links
[20]	✓	-	SDN	SPF and NSP	The method is based on traces and data provided for min, average, and max traffic load. Not tested on dynamic traffic.

*Energy-Efficiency; **Quality of Service.

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