Hybrid Software-Defined Networking Traffic Scheduling: Energy-Aware Load Balancing Perspective

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***Abstract*—This paper presents a review of the most recent energy-aware routing and load balancing optimization strategies for traffic flow engineering in Hybrid Software-Defined networks. The purpose is to avail researchers with insights regarding current and future developments in Hybrid SDN to stimulate more research efforts in the area.**

I. Introduction

Software-Defined Networking (SDN) is a revolutionary design which separates the control plane from the forwarding devices leading to increased programmability and centralized flexibility control advantage in communication networks [1][4]. SDN offers such benefits as improved network configuration, improved performance and innovation potential. Moreover, the routing and scheduling decision can be separated from the forwarding switches, permitting the desired decisions to be enhanced, reconfigured and optimized by the central controller [2]. But the deployment of full SDN is currently unattainable in the interim owing to financial, organisational and technical issues [2]. A preferred alternative is Hybrid SDN, reasons being budget constraints and technical restrictions.

Existing Hybrid SDN-based optimisation solutions that jointly address energy-efficiency, load balancing with QoS requirement do not combine all the QoS metrics [5], namely bandwidth, packet delay, Jitter, path failure, and yet such metrics are critical to the accurate realisation of Hybrid SDN, in support of the growing level of differentiated services. To realise additional benefit, moreover in the wake of current dramatic increases in traffic load especially in the backhaul network and the growing demand for differentiated services, which has worsened the need for QoS provisioning, it would be important for future research works to consider the need to priorities all the metrics to ensure accurate and energy-aware routing, with congestion avoidance by reassigning traffic during load balancing.

Currently, one issue which has recently been resolved in pure SDN networks [42],[43], but remain unresolved and hence real a problem in Hybrid SDN networks, demanding for urgent solution is: how to dynamically ensure routing and load balancing to optimise QoS provisioning with energy-efficiency when allocating traffic flows to real-time demands without degrading network performance [45],[46]. This is one of the major problems faced by researchers in advancing green energy-aware routing and traffic load balancing. We acknowledge that much as there are a majority of solutions that jointly address the issue of energy saving and load balancing with QoS requirements, most of these solutions do not consider all the defined QoS metrics together in the study [5],[28],[41]. In these studies, the metrics considered include bandwidth, throughput, packet delay, jitter and path failure, which are in totality critical to the perfect operation of such Hybrid SDN networks. Thus, to reap more benefit, future studies should consider prioritising all these metrics to provide accurate and hence energy-aware routing, with congestion avoidance through traffic reassignment in load balancing.

Clearly, it is important for future networks to address the need for more dynamic energy efficient routing and load balancing with strict QoS provisioning. Prioritising all the metrics is imperative to obtainment an effective and perfect solution, which on the contrary can lead to significant network performance degradation [5]. Precisely, the issue stated above is an open research gap demanding for suitable solutions

The remaining part of the paper is based on the following organisation: Section II presents related works to load balancing and energy-aware routing in Hybrid SDN networks. Section III presents challenges and future direction. Lastly, Section VI gives the conclusion.

II. Related work

Load balancing is an important traffic engineering (TE) approach whose goal is to improve the distribution of traffic loads across multiple resources based on a specific performance criterion [6-10]. In Hybrid SDN, the TE objective of maximizing link utilization, can be realized through traffic flow load balancing to make the network congestion free. Since load balancing is aimed at determining the average link rate utilization for all the network links, carrier companies can reduce OPEX, thus accommodating more users in their network [10-16], reflecting improved network performance in terms of throughput, link failure, packet loss rate, delay and jitter. Due to the current growth in data traffic and industry concerns such as capital expenditure (CAPEX) and operational expenditure (OPEX), energy efficiency, QoS service guarantees and load balancing problem in a multipath network scenario has become a very important issue in such SDN networks [17].

Recently Vanbever and Vissicchio [18], considered the issue of load balancing to address the problem of network congestion through network configuration management. The authors proposed a simple runtime SDN-based Application Programming Interface (API) model, executable in a legacy network. The module allows the input of the physical network topology and path requirements, to generate a virtual network topology which is employed by the routers to perform packet forwarding, to ensure traffic load balancing and hence avoid congestion. However, network management convergence is a major problem of the proposed mechanism.

Guo et al. [19] addressed the problem of inefficient routing and scheduling to overcome network congestion. The authors developed a novel routing and scheduling mechanism that employs the SOTE algorithm, to ensure path reduction, to improve network performance. The proposed mechanism was devised to jointly adjust OSPF weight setting and traffic flow splitting ratio to minimise the maximum link utilisation (MLU) in an ISP network, during migration. A centralised SDN controller is employed to optimise OSPF weight setting by splitting the incoming traffic flows at the SDN nodes, this being to minimise maximum link utilisation.

Caria et al. [20] proposed a concept to partition an OSPF domain to achieve SDN-based TE. The strategy was to leverage SDN-based edge routers to enhance control over the various routes that interconnect the sub-domains. In TE perspective, the focus was to address routing inefficiency to balance traffic load through improved link state updates. The author proposed a unique routing mechanism where the whole network is partitioned into many small sub-domains which are interlinked through SDN-enabled edge located router devices.

Chu et al. [21], investigated the aspect of reachability of traffic and recovery from a single link failure scenario. They contextualized a scenario where a single link failure occurs, in which case the target legacy router has to forward the affected packet to a particular SDN switch, bypassing the failed link. When traffic flows on the failed network is redirected to a given SDN-enabled switches, through the pre-computed IP-tunnel, the network system can rapidly respond to failures. Given the coordinator support among SDN-enabled switches, with global view of the controller, the system is capable of generating more backup paths to ensure traffic recovery with good load balancing. This in turn helps to overcome network congestion and better load balancing in view of the post network recovery.

Ren et al. [22] examined the routing and scheduling in TE with the aim of improving the management of network traffic flows. They suggested a routing and flow splitting mechanism to ensure efficient route management, by optimising the maximum link utilisation and flow splitting ratio. Though, the mechanism suffers routing efficiency degradation due to the lengthier path created, as compared to routing mechanism without flow splitting.

Guo et al. [23] addressed the problem of sub-optimal routing and scheduling. They proposed a routing and traffic scheduling mechanism that leverages multiple TMs to achieve network node update logical plan that can minimize maximum link utilisation. They considered a joint nodes selection and network topology optimization strategy to determine the appropriate node update sequence to minimalise network maximum link utilization.

Zhang et al. [24] investigated hybrid routing to obtain load balancing, while featuring multiple traffic classes. They proposed a hybrid routing mechanism that combines explicit routing and destination-driven routing, that employs multiple traffic classes to achieve load balancing, with reduced complexity and good scalability gains.

Hu and Wang [25] investigated the problem of routing in TE, with the aim of maximizing controllable traffic. The authors suggested a mechanism based on a fully polynomial-time approximation scheme (FPAS). They considered a single traffic class, with the goal of maximising network traffic flow, by leverage of barrier and hybrid modes of network deployment.

He and Song [26] addressed the problem routing and scheduling in TE. They proposed a TE routing and scheduling design based on barrier mode with an overlay network configuration. Performance of the proposed mechanism was compared against that of OSPF routing scheme, mainly focusing on source redirection for the TE problem, using maximum link utilisation.

Lin et al [27] addressed the problem of QoS-based routing. They proposed a network architecture that employs QoS-aware routing (SAQR) technique based on simulated annealing to dynamically update delay weights, rate of loss and link bandwidth demands. Besides, it employs the spanning tree algorithm to discover legacy switches in the Hybrid network, to dynamically determine appropriate paths and hence route traffic through path that meet the specific QoS routing demands of multiple applications, given the current network state.

In traditional networks [28-29], the increasing energy consumption of networking devices lead to issues of increased carbon dioxide (CO_2) emission and network cost of operations. Precisely, a big share of this consumption is attributed to the backbone and core network, particularly the IP routers, whereas a marginal contribution is due to the relayed traffic load.

Rationally, networks are engineered to provide for traffic demand during peak period, but during off-peak periods, traffic volume fall well below the marked network capacity [29]. This has made researchers to suggest novel energy aware (EAR) approaches and mechanism to reduce the number of active network links [32], meant to route and forward all the data traffic demands without any link overload. Much as recent studies have been focused on performance and cost concerns of ICT, there is a dire need to address the energy issue due to ICT systems. The above requirements can be achieved by designing energy-efficient optimisation networks commonly called green networks, to meet the energy-efficient design criteria [30-32][38].

Lately, Huin et al. [33] considered routing in TE to address the problem of high energy aware utilisation. The authors proposed a two stage energy-aware routing mechanism which is capable of turning unused network links into a sleep state to minimise energy consumption in such Hybrid SDN networks. But, a major challenge of the proposed mechanism is the requirement to maintain high levels of network QoS when certain network devices are in their sleep state. Precisely, the mechanism does not reflect link performance indicators, and yet these are essential in the accurate operation of such Hybrid SDN networks.

Wang et al. [34] considered the issue to minimise unnecessary network energy consumption. They proposed a dynamic spanning tree grouping mechanism aimed at determining the minimal-energy network subsets, to subsequently turn off idle devices and network links to meet the varying traffic loads. However, given the static nature of the mechanism, it can only save energy when network traffic loads are low, typically at night-time. This can be a great limitation in the perspective of routing and energy efficiency in real-world deployment scenarios.

Besides, Wei et al. [35] considered energy-efficient routing and traffic scheduling in SDN/IP backbone networks and suggested a heuristic-based hybrid energy-aware traffic engineering (HEATE) scheme for such hybrid networks. The aim was to minimise network energy consumption by calculating the optimal link weight setting legacy OSPF and the splitting fraction of the deployed SDN switches. The proposed scheme can in a joint manner optimise the OSPF link weight setting of IP-based routers and traffic flow splitting fraction of SDN switch, allowing the controllable and uncontrollable flows to be aggregated onto partial links, hence putting off under-utilised links to achieve energy saving.

Galan-Jimenez et al. [36] conducted studies to resolve the energy consumption problem, in a migration progression scenario where just a subset of SDN nodes are can be controlled. They examined the most suitable ratio of conventional IP nodes that ought to be elevated to SDN and the selection technique for their placement to achieve considerable power gains in the migration progression. They proposed a heuristic algorithm that uses the rate-based technique and sleeping technique to determine and select the candidate for replacement.

Jia et al. [37] considered segmented routing and scheduling. Their work examined the issue of path control and energy efficiency in an incrementally deployed hybrid network, featuring ISPs and data center networks (DCNs). The authors proposed a more feasible explicit path control (EPC) solution that focuses on network flow level to shutdown redundant networked switches and links, to guarantee energy saving in a segment routing and scheduling scenario. Recall that the requirement to achieve energy saving demands for fine-grained traffic flow scheduling in order to put-off switches and network links. An SDN switch can achieve the need got fine-grained scheduling by re-routing packets on the forwarding SDN ports. Essentially, energy saving can be achieved by re-routing the flows to turn off the idle links and switches.

Lastly, Maaloul et al. [39] addressed the problem of energy saving in carrier-grade Ethernet network. The authors proposed a traffic-aware routing and load balancing mechanism to shutting down the minimum set of network devices and links, to achieve energy-saving and QoS provisioning without network performance degradation. The proposed mechanism considers aspects that include rule space capacity restriction of the switches, including network traffic flow conservation and resource usage restriction. In terms of performance, the techniques can achieve a trade-off between energy utilisation, use of network resources and link performance. The mechanism can provide near-optimal solution within a reduces time period. However, the adaptation of the mechanism to process port power status and line rate can lead to overheads at the control plane level, thus increasing the delay in communication amidst the centralised controller device and the forwarding plane devices.

III. CHALLENEGS AND FUTURE DIRECTION

Provided in Table I is a summary of the reviewed routing and load balancing studies in Hybrid SDN Network. Most of these works have focused on a single QoS metric, without considering a combination of all the QoS metrics all together, in the same study. To support the growing diversity of future user traffic and multimedia application with strict QoS requirements, it is imperative to integrate all these metrics, hence devising a comprehensive mechanism that reflects all the major QoS performance metrics.

TABLE I. A COMPARITIVE SUMMARY OF DIFFERENT RUOTING MECHANISM WITH TRAFFIC LOAD BALACING

Study	Objective, Mechanism, Metric, Emulation or Simulation Tool and Target Environment	Issues and Challenges
Vanbever and Vissicchio (2014)[18]	**Objective:** To address issue of network configuration management, to achieve traffic load balancing and overcome congestion **Mechanism:** Suggested an API-based mechanism that uses routing protocol messaging to control both SDN and legacy switches. **Metric:** Maximum Link Utilisation	• Network management convergence is a major challenge, leading performance problems in data delivery. • The study does not consider energy saving objective.
Guo et al. (2014) [19]	**Objective:** To address the problem of routing and scheduling during weight setting for flows and TE in OSPF-SDN networks **Mechanism:** proposed a re-routing strategy to optimise OSPF weight setting to minimise link utilisation and CPU time. **Metric:** Maximum Link Utilisation and CPU time	• The study only considers the problem of network congestion. • Does not consider the objective of failure tolerance • Does not consider energy saving objective.
Zhang et	**Objective:** Considered of hybrid	• Difficult to

al. (2014) [24]	routing and load balancing for multiple traffic classes with TCAM optimisation in Hybrid SDN network. **Mechanism:** Proposed a mechanism which leverages explicit routing and destination-based routing in the context of multiple traffic classes to achieve load balancing **Metric:** Maximum Link Utilisation.	optimise TCAM memory size because further reduction of TCAM can lead to regular flow entry replacement during installation of new flows, leading to additional accesses to TCAM, which can result in more energy utilisation. • Does not consider energy saving TE objective.
Caria et al. (2015) [20]	**Objective:** Addressed the need to partition OSPF network into sub-domains to realise SDN-based TE by enhancing control over the interconnecting sub-domain routes. **Mechanism:** Devised a strategy of partitioning the entire OSPF network is into sub-domains, moreover interlinked only by SDN-enabled devices strategically located at the edges, to achieve route control over traffic between sub-domains. **Metric:** Throughput was used to measure the extent of data loss.	• Does not consider energy saving TE objective.
Chu et al. (2015) [21]	**Objective:** Addressed the problem of reachability and fault tolerance in Hybrid SDN networks **Mechanism:** Devised a fast response failure recovery strategy based on tunnelling to assure reachability **Metric:** Maximum Link Utilisation.	• Does not consider the objective of energy saving in TE. • Can lead to network congestion.
Ren et al. (2016) [22]	**Objective:** Addressed the routing problem of congestion in TE by improved management of flow routing and splitting **Mechanism:** Suggested a TE flow management mechanism which make it compulsory for every flow to path through an SDN-based switch to enhance flow control and TE **Metric:** Maximum Link Utilisation and Latency.	. • The mechanism does not consider energy saving
Guo et al. (2017) [23]	**Objective:** To improve the routing efficiency and traffic scheduling in Hybrid SDN networks **Mechanism:** To optimise TE by using multiple TMs to optimise routing, by employing legacy devices offline weight setting and a splitting ration that is online, for many TMs. Data mining algorithm is employed to store historic data for all the TMs. **Metric:** Maximum Link Utilisation and Latency	• Managing rule placement is hard because this can directly affect routing, network performance and energy saving efficiency. • Does not consider the objective of energy savings in TE
Hu et al. (2015) [25]	**Objective:** Addressed the issue of routing inefficiency in TE by maximising the network traffic flow through the deployed SDN switches **Mechanism:** Suggested a routing mechanism that tunes SDN switch behaviour in terms of flow forwarding to enhance the capability of legacy devices.	• Does not consider the TE objective of energy savings
	Metric: Maximum Link Utilisation.	
He et al. (2015) [26]	**Objective:** Addresses the TE optimisation problem of routing and scheduling in Hybrid SDN networks. **Mechanism:** Suggested a routing and scheduling strategy which combines the capacity of the legacy networks and control capability of SDN to attain efficient traffic delivery and link utilisation. **Metric:** Maximum Link Utilisation and TE flexibility	• The mechanism does not consider energy savings objective
Lin et al. (2017) [27]	**Objective:** Addresses the problem of QoS routing in Hybrid SDN data center networks. **Mechanism:** Suggested a QoS-aware routing mechanism built on simulated annealing technique for a multi-service multi- constraints network scenario. **Metric:** Packet Loss Rate, Delay and bandwidth utilisation	• The procedure exhibit high overheads and is not resilient to path failure. • Does not consider energy savings requirement in TE.

TABLE II. A COMAPRATIVE SUMMARY OF DIFFERENT ENERGY-AWAY ROUTING

Study	Objective, Mechanism, Metric, Emulation/Simulation Tool and Target Environment	Issues and Challenges
Huin et al. (2017) [33]	**Objective:** Routing and traffic load rate adaptation in TE to address the high energy utilisation problem using OSPF and OpenFlow. **Mechanism:** Mechanism that adapts routing to traffic load to spare and turn off unused network devices and links into a sleep state to minimise energy consumption, while ensuring failure tolerance. **Metric:** Throughput was used to measure the extent of data loss.	• Fail to maintain high levels of network QoS when certain network devices are in their sleep state
Wang et al. (2016) [34]	**Objective:** To address the issue of high power consumption using a Heuristic Algorithm and OSPF **Mechanism:** Mechanism to ensure efficient link utilisation based on the use of minimum power network subsets. **Metrics:** Maximum Link Utilisation	• The mechanism does not consider the TE objective of load balancing
Wei et al. (2016) [35]	**Objective:** Routing and scheduling based on flow splitting to ensure energy-efficiency in the backbone networks scenario. **Mechanism:** To determine the optimal link weight setting and flow splitting fraction for OSPF, and aggregating flows on partial links, thus putting off underutilised links to save energy. **Metric:** Maximum Link Utilisation	• Does not consider QoS parameter such as delay, jitter, and throughput • Does not consider fault tolerance requirement, with backup path
Galan-Jimez et al. (2017) [36]	**Objective:** To solve the issue energy utilisation in a scenario in which a sub-set of SDN nodes can be controlled, during the migration progression. **Mechanism:** Proposed a strategy to compute the most suitable ratio of IP nodes that ought to be selected for elevation to SDN so as to attain considerable power gains. **Metric:** Power saving gain with respect to the number of nodes replaced	• The mechanism does not consider the TE object of load balancing

Jia et al. (2018) [37]	**Objective:** To examine and address the problem of path control with energy saving in Hybrids SDN/IP ISP and DCNs with incremental switch deployment using OSPF **Mechanism:** Devised a two-stage strategy to turn-off redundant networked switches and links while leveraging segment routing between SDN switches to guarantee energy saving. **Metric:** Network Control Ability (NCA) and Power saving gain	• Performance optimisation in large sized multi domain network deployment in accommodating different traffic patterns fail to achieve.
Galan-Jimez (2017) [38]	**Objective:** To address the problem of path control with energy saving during migration process in Hybrids SDN/IP ISP and Data Center Networks **Mechanism:** Proposed a strategy to compute, select and replace legacy IP nodes with SDN devices for considerable energy gains **Performance Metric:** Maximum Link Utilisation was used to measure the improvement in link performance	• Performance optimisation in a dynamically network can be very hard given the complexity, when balancing between energy saving, tolerance to delay and throughput.
Maaloul et al. (2018) [39]	**Objective:** To addressed the problem of energy saving with QoS guarantees in ISP networks **Mechanism:** Proposed traffic-aware routing mechanism to ensure trade-off between energy saving and performance by shutting down unused network subset **Performance Metric:** Traffic Load, Fairness of Traffic distribution, Network Connectivity, Average path length	• Hard to implement due to complexity

Table II provides a summary of the reviewed energy efficient routing solutions in Hybrid SDN networks.

Majority of the above routing and energy saving mechanisms do not consider the TE objective of load balancing; many suggested mechanisms do not consider all the QoS metrics together [26][40][41]. But, the need to deliver a growing range of future user specific application classes, with strict QoS requirements demands for novel dynamic solutions to be developed. This is an essential requirement in the accurate operation of such hybrid networks to achieve the much desired network performance optimisation efforts, in terms of improved bandwidth utilisation, better throughput, reduced packet loss, low latency and jitter [26].

An important issue to observe is that single or none combined use of all QoS metrics can still lead to network performance degradation in such hybrid networks. So, to reap more benefit, this work recommends future studies to consider prioritising such requirements, to deliver effective and suitable energy-aware routing and load balancing solutions, to optimise network performance.

VI. Conclusion

This paper has reviewed the most recent energy-aware routing and load balancing solutions in Hybrid SDN networks. Based on review, it was observed that much as many Hybrid SDN studies have jointly considered energy-saving, load balancing with QoS guarantees, however they do not together factor in all the required QoS metrics in the same study, and yet joint consideration of these metrics is vital to the obtainment of perfect network operation. So, this requirement should be prioritised to provide an effective and suitable solution, for support the ever widening plethora of QoS stringent future user services and applications. Arguably, it would be beneficial to develop routing solutions that jointly consider energy saving, load balancing with QoS guarantees, in real-time to optimise network performance. Such critical issues pointed out should be urgently tackled to successfully commercialise Hybrid SDNs, in the transition towards full SDN deployment, moreover to support a plethora of high bandwidth next generation bandwidth hungry services and applications.

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