



HAL
open science

Mitigate the load sharing of segment routing for SDN green traffic engineering

Chakadkit Thaenchaikun, Gentian Jakllari, Béatrice Paillassa, Wasimon
Panichpattanakul

► **To cite this version:**

Chakadkit Thaenchaikun, Gentian Jakllari, Béatrice Paillassa, Wasimon Panichpattanakul. Mitigate the load sharing of segment routing for SDN green traffic engineering. 2016 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS 2016), Oct 2016, Phuket, Thailand. pp.1-6, 10.1109/ISPACS.2016.7824746 . hal-02749221

HAL Id: hal-02749221

<https://hal.science/hal-02749221v1>

Submitted on 3 Jun 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Open Archive Toulouse Archive Ouverte

OATAO is an open access repository that collects the work of Toulouse researchers and makes it freely available over the web where possible

This is an author's version published in: <https://oatao.univ-toulouse.fr/22132>

Official URL :

<https://doi.org/10.1109/ISPACS.2016.7824746>

To cite this version:

Thaenchaikun, Chakadkit and Jakllari, Gentian and Paillassa, Béatrice and Panichpattanakul, Wasimon *Mitigate the load sharing of segment routing for SDN green traffic engineering*. (2017) In: 2016 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS 2016), 24 October 2016 - 27 October 2016 (Phuket, Thailand).

Any correspondence concerning this service should be sent to the repository administrator: tech-oatao@listes-diff.inp-toulouse.fr

Mitigate the Load Sharing of Segment Routing for SDN green Traffic Engineering

Chakadkit Thaenchaikun*, Gentian Jakllari*, Beatrice Paillassa*, Wasimon Panichpattanaku†

*IRIT-ENSEEIH, University of Toulouse, France

{chakadkit.thaenchaikun, jakllari, beatrice.paillassa}@enseeih.fr

†Department of Computer Engineering, Prince of Songkla University, Thailand

wasimon@coe.phuket.psu.ac.th

Abstract—This research paper proposes IEEE802.3az incorporated green algorithmic schemes on the software defined networking-based segment routing (SDN-based SR) centralized network. The proposed schemes are the *green* (i.e. the EAGER and CARE metrics) SDN-based SR networks with and without traffic engineering (TE) tunneling. Green metrics extend the IEEE 802.3az energy saving to the whole network, while tunneling avoids the load sharing mechanism included in the segment routing that is not convenient for energy saving purpose. The findings of evaluation revealed that the energy efficiency under the EAGER-tunneling strategy is comparable to the conventional metric with TE tunneling, and the saving realized under the CARE-tunneling scheme is twofold in comparison with the LEGACY-tunneling strategy. Meanwhile, the energy saving performance achieved with all three metrics under TE non-tunneling was inferior to those with tunneling. Nonetheless, the lower end-to-end delay and lower maximum link utilization (MLU) were achievable with the non-tunneling strategy.

Keywords—SDN, Green network, Traffic engineering, Segment Routing, IEEE802.3az

I. INTRODUCTION

With the exponential growth in the cyberspace activity amid the growing concern for the environment, several attempts have been made to develop more energy-efficient communications networks. Among an array of alternatives is the “*green*” centralized network topology [1], where a controller is deployed for the centralized network control and monitoring. In the centralized topology, the controller negotiates with the routers and obtains the traffic statistics on individual routers for the efficient management of the network traffic flows. The implementation of the centralized network concept typically involves specific technologies, e.g. software defined networking (SDN). In SDN, an OpenFlow protocol is used for the exchange of control messages between the controller and a router due to the protocols enhanced performance with regard to the network control and monitoring. Nevertheless, the incorporation of traffic engineering (TE) to the network necessitates the OpenFlow protocol to undergo a complex process, by which each individual router between the source and the destination is required to communicate with the central controller for every single traffic flow.

To mitigate the SDNs shortcoming with regard to the control message overhead, we adopt Segment Routing (SR) technique

for the TE-implemented network, in which the SR controller instructs the ingress (source) router with regard to the traffic path from the source to the destination using the segment identifiers (SIDs). Once the ingress router obtains the SID instruction from the controller, the traffic flow is forwarded hop-by-hop to the egress (destination) router without the inter routers communicating with the controller (i.e. the source routing paradigm). Most importantly, the SR technology is well compatible with the green TE routing mechanism where path is chosen in order to minimize the energy consumption. Meanwhile, because SR is based on a load sharing mechanism that spreads data over many links, it can suffer from a high energy consumption. Thus the problem to solve is how to mitigate this load sharing, without changing the protocol, so that green TE can be easily deployed.

Traffic engineering to green the network is generally to enable/disable links. In this paper we consider the implementation of Ethernet links, mostly deployed technology, with low power idle mode standardized by IEEE 802.3az. When the non-utilized links in the TE-routing SR network are disabled (i.e. OFF), the controller instructs a given router to switch off certain links for energy saving. Nonetheless, this technique involves the complex mechanism in which the controller is required to instruct individual links to enter the OFF mode and also to enable (ON) those links in the event of traffic congestion. Thus, this current research has focused on the application of IEEE802.3az for automatic sleep and wakeup, whereby the energy efficiency between Ethernet links is achieved through the low power idle mode (i.e. sleep mode). In other words, in the event of no traffic, the device would enter sleep mode, with limited interruptions for transmitting refresh signals. Once a transmission is required, the link would be re-activated to awake mode.

Paper investigated the energy saving performance of the IEEE802.3az SDN-based SR network. To decrease the link utilization and thus increase the energy saving, we propose a green computation of the shortest path with two metrics (EAGER and CARE). Idea is to direct traffic on some links so that other links can enter in LPI mode. We show that this green policy improves the energy performance but even if it decreases globally the energy consumption, load sharing is still in use. So we propose a TE-scheme with tunnel configuration for energy saving improvement. Paper investigated the energy

saving performance of the SR network under two TE schemes. In the first scenario, tunneling is implemented in routing the network traffic while, in the second scheme, no tunneling policy is set for the network controller. In other words, in the latter scenario, the traffic is routed from source to destination with no pre-determined tunnel configuration.

II. RELATED PUBLICATIONS

Existing research on the energy-efficient wireline network can be classified into two solution groups: the local and global energy efficiency solutions. On the local energy-saving level, prior research has largely focused on the Adaptive Link Rate (ALR) [2] [3] and Link Sleep techniques [4] [5] for the realization of energy economy. In ALR, the energy efficiency is achievable by scaling down the link speed. This technique however is less favorable for the data transmission over an extended period due to the poor transmission performance [6]. Meanwhile, with Link Sleep, a non-utilized link is put to sleep and the extent of energy saving is positively correlated to the length of sleep interval. In [7], Gupta and Singh proposed a strategy to alter the state of network interfaces from active to dormant, which was subsequently extensively researched and established as the IEEE802.3az standard [4].

Unlike the local-level solution whose focus is on the energy saving on the link layer, the global-level solution is concerned with the total energy economy of all links or components in a network [8][9][10]. The operating principle of the global solution is either to leverage the graphical topology and individual link utilization statistics for identification of the low-load links to enter sleep mode; or to apply the traffic engineering (TE) to the traffic flow.

In [11], two energy-efficient (*green*) metrics were proposed for augmenting the energy saving of IEEE802.3az hardware, i.e. the Extremely Augmented Energy efficient eHeRnet (EAGER) and Congestion aware Augmented eneRgy efficient Ethernet (CARE) metrics. Nevertheless, in [11], the experiments were carried out on the *distributed* network scheme. On the contrary, in this current research, the assessment of the energy saving associated with the EAGER and CARE green metrics implementation is carried out on an SR centralized network.

Similar to the normal centralized network, either SDN or SR is required in the energy-efficient centralized network operation. On the *green* SDN network, Rasih et al. [12] proposed the energy-efficient SDN network in which MPLS Label Switching Paths (PLSP) was employed for pre-established paths based on the aggregate traffic load of every source-destination pair of the network to reduce the number of paths utilized while increasing the network resource utilization. In [13], an energy-saving mechanism was proposed and applied to a network to reduce the total energy cost by powering off certain links unnecessary for the traffic demand. In essence, the implementation of the *green* SDN network entails the designation of sleep links and the network traffic flow management. The notion of switching off or putting to sleep the SDN network elements for the energy economy has long been studied, e.g. [14][15].

A novel centralized network that utilizes the source routing paradigm, the Segment Routing (SR) network has been proposed in the Internet Engineering Task Force (IETF) [16]. One advantage of SR is its compatibility with TE routing in the *green* centralized network. Carpa et al. [17] proposed the STREETE framework on the energy-efficient SR network that involves three steps: the designation of OFF/ON links, identification of alternative routes, and transmission of new routing instructions to the routers. In essence, the framework simply deployed the rerouting and dynamic reconfiguration in the SR implementation. Nevertheless, no tunneling policy was set in their experimental implementation. Unlike Carpa [17], this current research has investigated the *green* SR network under two different TE schemes: tunneling and non-tunneling.

III. ENERGY-EFFICIENT SEGMENT ROUTING

The proposed global energy-efficient (*green*) SDN-based SR centralized network involves two sequential steps: the green metrics and TE implementation.

Step1 : Green Metrics Implementation

In the first step, either the Extremely Augmented Energy efficient eHeRnet (EAGER) or Congestion aware Augmented eneRgy efficient Ethernet (CARE) approach [11] is deployed to designate the dormant links for realization of the global energy economy. In the sleep links designation, the SR controller negotiates with the routers for statistic messages to establish a virtual topology using the Topology Discovery Process. The controller then generates the source-destination pairs prior to the application of either EAGER or CARE to determine the pre-established path associated with each source-destination pair and subsequently realize the global energy saving. To realize the energy economy, the traffic is aggregated for more non-utilized links which are subsequently put to sleep consistent with the IEEE802.3az standard. It differs from [12],[17], where the pre-established paths are identified and the disable/enable (OFF/ON) switching technique deployed rather than the IEEE802.3az standard.

The Extremely Augmented Energy efficient eHeRnet (EAGER) function is a straightforward *green* metric function. Given a link (i, j) with the link utilization of $L_{i,j}$, the EAGER value of the link can be computed by:

$$EAGER_{i,j} = \begin{cases} 100, & \text{if } L_{i,j} \leq 25\% \\ 1, & \text{Otherwise} \end{cases} \quad (1)$$

Under the IEEE802.3az standard, energy saving is possible for the load range of 0 - 25% while none is realized beyond the 25% threshold (i.e. the green threshold). In this research, an EAGER metric of 100 is thus assigned to a low-load link so that new incoming traffic is redirected to another link. On the hand, an EAGER metric is equal to 1 for the load utilization beyond the green threshold.

In the Congestion aware Augmented eneRgy efficient Ethernet (CARE) metric function, in addition to the green threshold (25% link utilization), the CARE *green* metric function incorporates a congestion threshold (>80% link utilization). Specifically, links with utilization beyond the congestion threshold

(>80%) are assigned a value of 100. Furthermore, for links with utilization under the green threshold ($\leq 25\%$), the CARE metric will assign the simple multiplicative inverse of the link utilization. Given a link (i, j) with the link utilization of $L_{i,j}$, the CARE value of this link can be computed by:

$$CARE - X_{i,j} = \begin{cases} \frac{100}{L_{i,j}}, & \text{if } L_{i,j} \leq 25\% \\ 1, & \text{if } 25 < L_{i,j} \leq X\% \\ 100, & \text{if } L_{i,j} > X\% \end{cases} \quad (2)$$

Interestingly, an appropriate congestion threshold for the CARE metric function varies, depending on a number of reasons, e.g. the diverse manufacturer specifications and customer requirements. This experimental research has used the congestion threshold (X) of 80%.

Step2 : TE Implementation

Once shortest path has been computed and the associated SID from controller to the ingress switch, segment routing and so load balancing is applied. As we can see in Fig. 1 more links will be used in this case compare to routing without load sharing. For the sake of comparison, we carried out experiments with the green SDN-based SR centralized network under two TE scenarios of with and without tunneling scheme, as illustrated in Fig. 2.

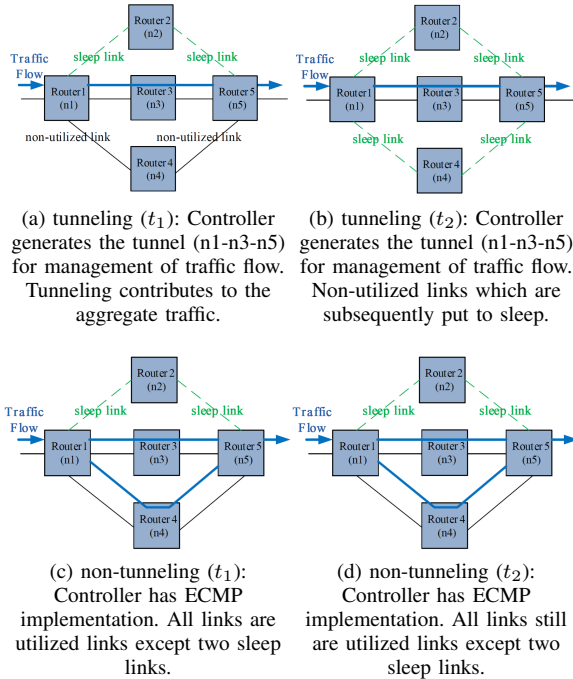


Fig. 1: The operations of the SDN-based SR centralized network at t_1 (time 1) and t_2 under the tunneling (a, b) and non-tunneling (c, d) TE schemes

In the first scheme, the pre-established paths of the source-destination pairs are “tunneled” for the management of traffic flow. Once the tunnels are configured, the controller then

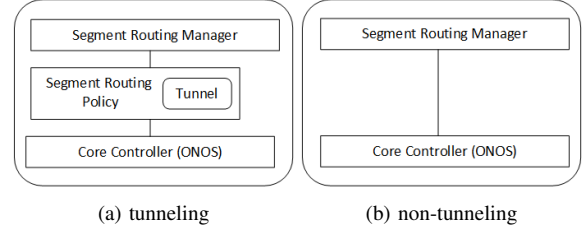


Fig. 2: The experimental traffic engineering (TE) schemes: (a) tunneling, (b) non-tunneling

orchestrates the traffic flow in accordance with the tunnel configuration. The tunneling contributes to the aggregate traffic and at the same time idle links which are subsequently put to sleep as per the IEEE802.3az standard.

The *green* SDN-based SR network with tunneling scheme is algorithmically illustrated in Algorithm 1. In the first phase of the algorithmic scheme (i.e. the green metrics and pre-established paths phase), all the links in the network are assumed to be active and the controller is aware of all the traffic flow in the network. In this phase, the controller calculates the pre-established paths using either the green EAGER or CARE metrics. In addition, the links outside of the pre-established paths (i.e. non-utilized links) are put to sleep in accordance with the IEEE802.3az standard due to no traffic flow. In the second phase (TE with tunneling), the controller generates the tunnels corresponding to the pre-established paths and instructs the segment routers in the network to direct the traffic according to the tunnel configuration.

Algorithm 1: Tunneling TE

- 1 $X = (1, 1, \dots, 1) \rightarrow$ Initially all the link are active
- 2 $F = (f_1, f_2, \dots, f_N) \rightarrow$ Total flows in Network = N
/*Phase1-Green Metrics and pre-established paths*/
- 3 **for** each flow $f_i \in F (i = 1, 2, \dots, N)$ **do**
- 4 $S(i) \leftarrow$ Pre-established Path (calculate with EAGER or CARE metrics)
- 5 $P_{xy}(i) \leftarrow$ Select Path (x, y) (denote Path between source (x) and destination (y))
- 6 $P \leftarrow P_{xy}(i)$
- 7 **end**
/*Phase2-Traffic Engineer with Tunneling*/
- 8 **for** each flow $f_i \in F (i = 1, 2, \dots, N)$ **do**
- 9 Tunnels are set follow Pre-established Path $P_{xy}(i)$
- 10 Controller tells every Segment Routers
- 11 Segment Router update and use tunnel table for transfer traffic f_i
- 12 **end**

In the second scheme, no tunneling policy is set for the traffic management of the *green* network. Under this condition, the controller designates the links to enter sleep mode from the non-pre-established paths and then computes the shortest equal

Algorithm 2: Non-tunneling TE

```
1  $X = (1, 1, \dots, 1) \rightarrow$  Initially all the link are active
2  $F = (f_1, f_2, \dots, f_N) \rightarrow$  Total flows in Network =  $N$ 
   /*Phase1-Green Metrics and Selecting links to sleep*/
3 for each flow  $f_i \in F (i = 1, 2, \dots, N)$  do
4    $S(i) \leftarrow$  Pre-established Path (calculate with EAGER
   or CARE metrics)
5    $P_{xy}(i) \leftarrow$  Select Path  $(x, y)$  (denote Path between
   source  $(x)$  and destination  $(y)$ )
6    $P \leftarrow P_{xy}(i)$ 
7   for each link  $l_k \in L (k = 1, 2, \dots, N)$  do
8      $X_k \leftarrow \delta(P_{xy}(i), l_k)$ 
     \\ Sleep links are selected by Kronecker delta
     function  $(\delta)$ .
     \\ Kronecker delta function returns 1 if the link  $k$ 
     belong to  $P_{xy}(i)$  and 0 otherwise.
     \\ keep active link = 1 and sleep link = 0 at
      $X_k \in X (k = 1, 2, \dots, L)$ 
9   end
10  Update( $X$ )
11 end
   /*Phase2-Traffic Engineer with Non-Tunneling*/
12 Green Virtual Topology is set with sleep links
13 Controller use green virtual topology and controller tells
   every SR routers
14 Every router change the forwarding table to routing over
   the new paths
```

cost multiple paths (ECMP) of the source-destination pairs, without taking into account the designated sleep links. The sleep links become non-utilized links as per the IEEE802.3az standard and thereby consume little energy.

The *green* SDN-based SR network without tunneling is algorithmically depicted in Algorithm 2. In the first phase of the scheme (i.e. the green metrics and sleep link selection), all the links are active and the controller is aware of all the traffic flow in the network. The controller calculates the pre-established paths of source-destination pairs using the green EAGER and CARE metrics. The Kronecker delta function is used to determine the links outside of the pre-established paths (i.e. non-utilized links). The sleep links are subsequently selected from the non-utilized links prior to the application of the IEEE802.3az standard. In the second phase (TE without tunneling), unlike the SR network with the tunneling TE implementation, no tunneling is generated and thus the sleep links are directly applied to the virtual topology. The controller then computes the shortest ECMP of the source-destination pairs, without taking into account the sleep links.

IV. EXPERIMENTAL EVALUATION

This section deals with the experimental setup of the *green* SDN-based SR network with and without tunneling schemes and the evaluation of both algorithmic schemes on an Abilene network topology and its traffic matrices. Fig. 3 illustrates

the 11-core node SR Abilene topology utilized in the global energy saving evaluation of both algorithmic schemes. The nodes (routers) are connected by 10Gbps links. In [18], the traffic matrices were the five-minute average traffic for a period of several months. In this experiment, the traffic matrices (TM) are the averages of the final five minutes of the hour [18] for a period of 24 hours.

In the experimental network, the 11 source-nodes generate the traffic and transmit to the 10 destination-nodes, resulting in a total TM size of 110 (11x10). Each individual router node of the 11-node SR Abilene topology network is connected to an ONOS controller [19]. To achieve the global energy saving, the green metrics (EAGER and CARE) are first integrated into the ONOS controller prior to the application of the tunneling and non-tunneling TE schemes.

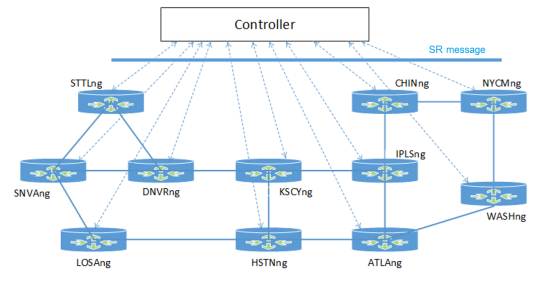
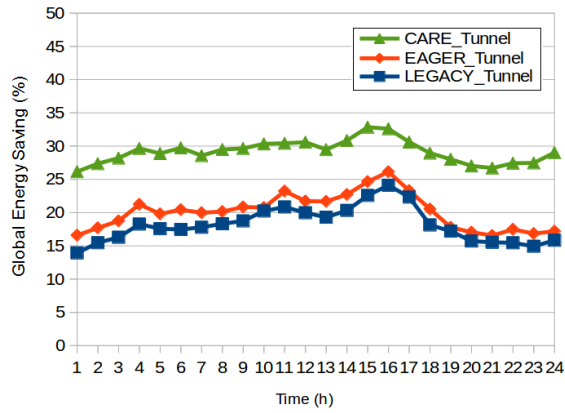


Fig. 3: A depiction of the experimental SDN-based SR Abilene topology network

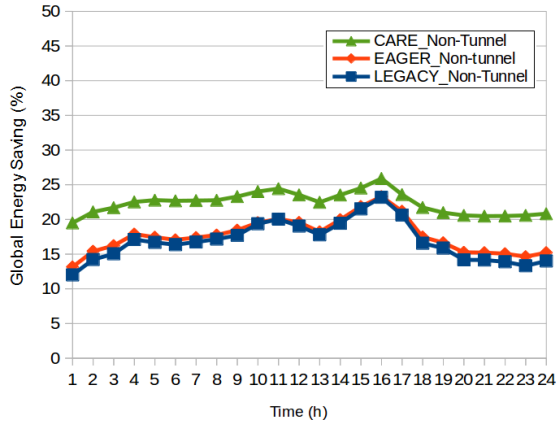
To obtain the energy consumption for subsequent calculation of energy saving associated with the network links, the 10GBASE-T power consumption against load curve [20] was utilized by applying the Poisson traffic to the IEEE802.3az standard. In [20], simulations were carried out on a 10Gbps link and it was reported that the energy consumption increased with the traffic load and reached the full energy consumption (100%) with a mere 24% link utilization. As previously mentioned, since all router nodes are linked to the controller, the controller negotiates the router statistics for their respective link load. The link load is algorithmically compared against the consumption-load curve for the energy consumption of each link. The energy consumption is converted into the link-level energy *saving* and subsequently the network-level (global) energy saving.

Figs. 4(a)-(b) illustrate the global energy saving of the Abilene SR topology network using three different metrics under the tunneling and non-tunneling TE schemes, respectively. The three metrics are the LEGACY, EAGER and CARE metrics. In LEGACY, the pre-established paths are determined by the conventional metric and the IEEE802.3az standard applied to the low-traffic links. EAGER and CARE have been previously discussed.

Under the tunneling scheme (Algorithm 1), CARE could achieve a higher overall energy saving than EAGER and LEGACY. The largest energy saving gain (i.e. the differences between energy saving) of two times (2X) was achieved with



(a) tunneling



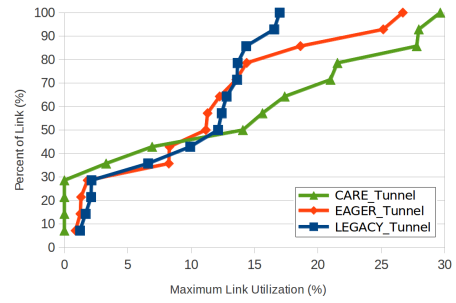
(b) non-tunneling

Fig. 4: The global energy saving of the SDN-based SR Abilene topology: (a) tunneling, (b) non-tunneling

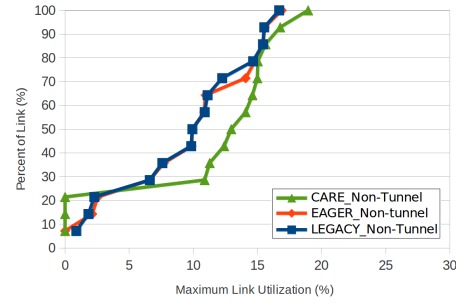
the CARE metric (relative to LEGACY) at termination (at the 24th hour). The low global energy saving under LEGACY was attributable to the absence of green metrics other than the IEEE802.3az standard. The nonexistence of green metrics in LEGACY contributed to non-aggregate traffic and few sleep links. In this research, the traffic matrices (TM) were observed hourly for a period of 24 hours since the energy saving levels are correlated to the traffic matrices (TM) on the network.

By comparison, under the non-tunneling scheme (Algorithm 2), the algorithm would resort to the shortest equal cost multiple paths (ECMP) and the subsequent traffic dissipation. Under this TE scheme, the largest energy saving gain achieved under the CARE metric was 1.6X at the end of the 1st hour.

Fig. 5 compares the cumulative distribution functions (CDF) of maximum link utilization (MLU) of the first hour between the three metrics under the two TE schemes. Under the tunneling TE scheme (Algorithm 1), the MLU increased nearly 30% with the CARE metric vis-à-vis the 17% with LEGACY. The greater MLU was attributable to the more aggregate traffic and greater numbers of non-utilized links. The increase (13%) was nonetheless small, suggesting the minimal impact

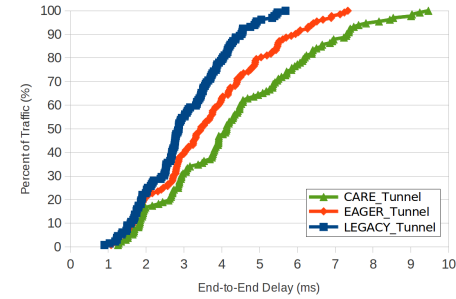


(a) tunneling

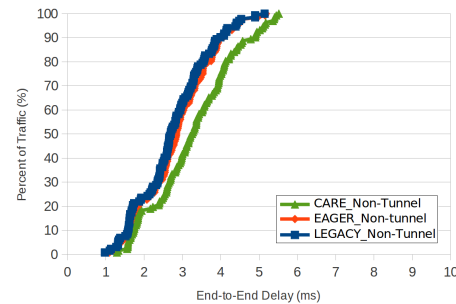


(b) non-tunneling

Fig. 5: CDF of maximum link utilization on the SDN-based SR Abilene network: (a) tunneling, (b) non-tunneling



(a) tunneling



(b) non-tunneling

Fig. 6: The CDF of end-to-end delay on the SDN-based SR Abilene network: (a) tunneling, (b) non-tunneling

of the CARE-tunneling scheme (Algorithm 1) on the MLU. Meanwhile, under the non-tunneling TE (Algorithm 2), the

increase in MLU under CARE was significantly less (19%) and that belonging to LEGACY was similar to that under the tunneling scheme (17%).

Fig. 6 compares the CDF of end-to-end delay between the three metrics under the two TE schemes. Under the tunneling scheme with the CARE and EAGER metrics, the end-to-end delay became lengthier. On the other hand, under the non-tunneling TE, the end-to-end delays with the three metrics (LEGACY, EAGER and CARE) were essentially similar. In short, the experimental findings revealed that the higher global energy saving on the Abilene segment routing (SR) network could be achieved with the CARE-tunneling TE scheme.

V. CONCLUSION

The paper studies green traffic engineering in centralized SDN environment through segment routing. This experimental research has evaluated the global energy saving performance on SDN-based SR centralized network under two IEEE802.3az-incorporated algorithmic schemes, i.e. the green (EAGER and CARE metrics) SDN-based SR networks with and without TE tunneling. Results put forward on real internet topology the advantage of the green metrics and the inconvenience of load sharing policy, i.e. the non-tunneling policy, for energy saving purpose. The experimental results showed that the overall (global) energy saving realized under the CARE-tunneling strategy was twice that of the conventional metric with TE tunneling (LEGACY tunneling strategy). Meanwhile, the global energy efficiency under the EAGER-tunneling scheme was comparable to the LEGACY tunneling strategy. On the other hand, the energy saving performance achieved under TE non-tunneling (all three metrics) was inferior to those with tunneling. Nevertheless, the non-tunneling course exhibited the lower end-to-end delay and lower maximum link utilization (MLU).

REFERENCES

- [1] A. Amokrane, R. Langar, R. Boutaba, and G. Pujolle, "Flow-based management for energy efficient campus networks," *IEEE Transactions on Network and Service Management*, vol. 12, no. 4, pp. 565–579, Dec 2015.
- [2] C. Lange, D. Kosiankowski, A. Betker, H. Simon, N. Bayer, D. von Hugo, H. Lehmann, and A. Gladisch, "Energy efficiency of load-adaptively operated telecommunication networks," *Journal of Lightwave Technology*, vol. 32, no. 4, pp. 571–590, Feb 2014.
- [3] C. Gunaratne, K. Christensen, B. Nordman, and S. Suen, "Reducing the energy consumption of ethernet with adaptive link rate (alr)," *IEEE Transactions on Computers*, vol. 57, no. 4, pp. 448–461, April 2008.
- [4] "Ieee standard for information technology-local and metropolitan area networks-specific requirements-part 3: Csma/cd access method and physical layer specifications amendment 5: Media access control parameters, physical layers, and management parameters for energy-efficient ethernet," *IEEE Std 802.3az-2010 (Amendment to IEEE Std 802.3-2008)*, pp. 1–302, Oct 2010.
- [5] M. Gupta and S. Singh, "Greening of the internet," in *Proceedings of the 2003 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications*, ser. SIGCOMM '03, 2003, pp. 19–26.
- [6] S. Nedeveschi, L. Popa, G. Iannaccone, S. Ratnasamy, and D. Wetherall, "Reducing network energy consumption via sleeping and rate-adaptation," in *Proceedings of the 5th USENIX Symposium on Networked Systems Design and Implementation*, ser. NSDI'08, 2008, pp. 323–336.

- [7] M. Gupta and S. Singh, "Using low-power modes for energy conservation in ethernet lans," in *IEEE INFOCOM 2007 - 26th IEEE International Conference on Computer Communications*, May 2007, pp. 2451–2455.
- [8] E. Amaldi, A. Capone, L. G. Gianoli, and L. Mascetti, "Energy management in ip traffic engineering with shortest path routing," in *World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2011 IEEE International Symposium on a*, June 2011, pp. 1–6.
- [9] A. Ruiz-Rivera, K. W. Chin, R. Raad, and S. Soh, "Hotpluz: A bgp-aware green traffic engineering approach," in *2014 IEEE International Conference on Communications (ICC)*, June 2014, pp. 3721–3726.
- [10] J. Chabarek, J. Sommers, P. Barford, C. Estan, D. Tsang, and S. Wright, "Power awareness in network design and routing," in *INFOCOM 2008. The 27th Conference on Computer Communications. IEEE*, April 2008.
- [11] C. Thaenchaikun, G. Jakllari, and B. Paillassa, "Augmenting the energy-saving impact of ieee 802.3az via the control plane," in *2015 IEEE International Conference on Communication Workshop (ICCW)*, June 2015, pp. 2843–2849.
- [12] M. R. Celenioglu, S. B. Goger, and H. A. Mantar, "An sdn-based energy-aware routing model for intra-domain networks," in *Software, Telecommunications and Computer Networks (SoftCOM), 2014 22nd International Conference on*, Sept 2014, pp. 61–66.
- [13] M. Rahnamay-Naeini, S. S. Baidya, E. Siavashi, and N. Ghani, "A traffic and resource-aware energy-saving mechanism in software defined networks," in *2016 International Conference on Computing, Networking and Communications (ICNC)*, Feb 2016, pp. 1–5.
- [14] R. Wang, Z. Jiang, S. Gao, W. Yang, Y. Xia, and M. Zhu, "Energy-aware routing algorithms in software-defined networks," in *World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2014 IEEE 15th International Symposium on a*, June 2014, pp. 1–6.
- [15] B. Heller, S. Seetharaman, P. Mahadevan, Y. Yiakoumis, P. Sharma, S. Banerjee, and N. McKeown, "Elastictree: Saving energy in data center networks," in *Proceedings of the 7th USENIX Conference on Networked Systems Design and Implementation*, ser. NSDI'10, 2010, pp. 17–17.
- [16] Segment routing architecture. [Online]. Available: <http://tools.ietf.org/html/draft-filsfils-rtgwg-segment-routing-01>
- [17] R. Carpa, O. Glck, and L. Lefevre, "Segment routing based traffic engineering for energy efficient backbone networks," in *2014 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, Dec 2014, pp. 1–6.
- [18] Yin zhang's abilene traffic matrix. [Online]. Available: <http://www.cs.utexas.edu/~yzhang/research/AbileneTM>
- [19] The open network operating system (onos). [Online]. Available: <http://onosproject.org/>
- [20] D. Larrabeiti, P. Reviriego, J. A. HernáNdez, J. A. Maestro, and M. UruñA, "Towards an energy efficient 10 gb/s optical ethernet: Performance analysis and viability," *Opt. Switch. Netw.*, vol. 8, no. 3, pp. 131–138, Jul. 2011.