N Hop a Kind Resource Assignment Method for Optical WDM Networks

Yashar Fazili^{a*}, Bill Robertson^b, William Phillips^c

a, b and c Dalhousie University, Halifax, Canada, B3H 4R2

Abstract

This paper introduces a new resource allocation mechanism for Wavelength Division Multiplexing (WDM) networks. The simple yet effective method introduced in this paper assigns the resources of a dynamically calculated route without needing an optimization solver. By minimizing the number of Lambda conversions at each node using this method, up to 8% more success rate can be achieved compared to assigning the resources using First Fit (FF) with continuity constraint. This method also results in up to 35% less energy usage compared to assigning the resources using First Fit without continuity constraint. The name of N Hop A Kind is after a winning combination of the game of Poker in which a hand with “n of a kind” wins.

Keywords: Resource assignment, WDM, GMPLS, Lambda assignment, Forwarding Plane, Optical

---

1. Introduction

Per information in [1,2], the Internet is using about 6 % of the global energy produced. The amount of emission emitted to the atmosphere because of power generation is becoming more important these days because of severe global warming. A study in [3] shows that the amount of CO₂ emitting to the atmosphere is increasing rapidly. Therefore green mechanisms and energy efficient methods must be used in the industry to reduce the CO₂ emissions. IT and networking industry has also introduced many methods such as approaches in [3-7] to reduce the energy and emission of the networks, especially in the backbone networks such as the Internet. This paper introduces a new energy efficient resource assignment method for optical networks governed by Generalized Multiprotocol Label Switching Mechanism (GMPLS). The introduced method aims at reducing the energy usage at nodes of the optical network by reducing the number of Lambda conversions. The assignment method introduced in this paper can be an “add-on” to any routing mechanism. We will add our new assignment method to the process of serving a connection requests using Shortest Path (SP) Routing mechanism. In this paper, we will refer to Lambda and resource interchangeably. There are four additional sections in this paper. Section 2 is detailing the related work in this field. Section 3 is introducing the new resource assignment method, followed by the section 4 that introduces the performance metrics and provides the analysis on the results. Chapter 5 provides the summary and states the future work. Related work in this field comes next.

2. Related work

Our previous work in [8] shows the effectiveness of Continuity Constraint (CC) with First Fit (FF) resource assignment method in emission reduction. However, the effect of the higher intensity of the traffic has not been studied on the main performance metrics of the network. In this paper, we have two scenarios for the intensity of traffic and its effect on the performance metrics detailed in section 4. In our paper, we will use the term “Continuous assignment” and “Continuous” interchangeably. The authors of the paper in [9] have proposed a Linear Programming mechanism to assign the Lambdas of a “batch” job. Multiple Lambdas for more than one route are assigned at the same time. In this paper, we use the same approach for Lambda conversion in the nodes. Therefore, at each node, if a Lambda conversion is performed, the Lambda is dropped using a transponder and is added back, by using another transponder. The conversion process uses the energy needed to power ON two transponders. There is no energy associated with Lambdas transparently transiting through a node to the destination node in the optical layer. The paper in [10] has proposed a mixed Integer linear programming mechanism that considers the node energies and performs the routing and wavelength assignment in one “shot”. However, since the routing and assignment are combined, there is no way to compare the performance of routing and assignment methods separately and use different methods for resource allocation (after computing the route). The lightpaths established from a source node to a destination node are signaled with Resource Reservation Protocol (RSVP) detailed in [11]. The forwarding elements of the network that have no

---

* Corresponding author. Tel.: +1(902) 2232144

E-mail: yashar.fazili@dal.ca

© 2019 International Association for Sharing Knowledge and Sustainability.

DOI: 10.5383/JUSPN.11.01.004

role in directing any lightpath may be placed in the OFF State, and unlike the approaches of papers in [12,13], no sleeping state is considered. Sleeping mode reduces the lifetime of equipment and is economically infeasible as also discussed in [9]. Unlike the two-phase First Fit method introduced in [4], with the dynamic network, when the resources of a link are exhausted, the link is taken out from the dynamic topology, and the routing phase does not route any more lightpath through that link. The blocking of the route with Continuous assignment can happen with higher intensity of traffic when there is no continuous lightpath from the source node to the destination node. The authors of paper in [14] have proposed an approach that provides faster resources assignment compared to mixed integer programming. This approach consists of two parts of routing and resource assignment. In contrast to method of paper in [14] our method provides resource assignment to a route that can be calculated by any mechanism. In this paper we consider the resource, resource conversion energy and link energy separately as also experimented in paper referenced in [15]. In this paper, we use the same energy model of the paper in [8] and will reduce the variable part of the energy of the lightpath. The variable portion of the node energy is the energy due to performing Lambda conversion. Therefore the lower the number of Lambda Conversion, the Lower the power consumption of the nodes. Equation (1) shows the simplified version of the energy model in the paper of [8]. Moreover, Equation (2) shows the energy associated with the Lambda conversion.

$$M_{SD} = \sum_{\forall i,j \in R} E_{ij} + \{\delta_S + \delta_D + 2 \cdot \delta_{j \in (S,D)}\} \quad (1)$$

$$2 \cdot \delta_{j \in (S,D)} \quad (2)$$

In which $\sum_{\forall i,j \in R} E_{ij}$ is the sum of the energy used by the optical links of the lightpath and is fixed since the inline amplifiers and signal leveling amplifiers regenerate the entire spectrum and have no intermediate values when they are turned ON. δ_S and δ_D are the energy needed to add and drop a Lambda in source and destination node respectively and are fixed. $2 \cdot \delta_{j \in (S,D)}$ is the amount of energy needed by two transponders in every transit node per each Lambda conversion performed. In our setup, each transponder uses 85W of energy based on information in [16] Therefore 170 W of power is needed to perform each Lambda conversion. In this paper, we reduce the energy associated with the optical or forwarding layer of each node. Per information given in papers in [9,17], the power consumption in an electronic layer of the core nodes changes by only 3% at 100% utilization and therefore can be considered as constant.

3. NHopAKind Resource Assignment

In this section, we introduce our new proposed method for resource assignment called “N Hop A Kind”, after a winning combination in the game of Poker. This method tries to find a lightpath that has zero or a minimum number of Lambda conversion(s) when no continuous lightpath to the destination is available. When establishing a lightpath with Lambda conversion, each group of Lambdas of the route is “N Hop A Kind” before each conversion. The upcoming figures explain the process with an example. In Fig. 1, S is the source node, and D is the destination node. Each Intermediate Node or (IN)

is followed by a number that shows the place of the IN in the route. Therefore, the first intermediate node in the path from S to D is IN1. The next hop is IN2 in the route and so on. NHopAKind assignment method consists of two major steps. The first step tries to find a direct and continues lightpath from S to D which is called “Advancing”. Advancing will check each available to assign Lambda in the first hop between S and IN1 in a hope to find a Lambda which will be able to “Advance” to D. If there is such a Lambda number, the lightpath is established and no Lambda conversion is needed. If there is a continuous Lambda, then NHopAkind assignment is stopped, and the process finishes. This condition is shown in Fig. 1. However, if there isn’t a continuous Lambda number, the NHopAkind initiates the second step. The second step of NHopAkind gathers the (Lambda, End-Point) pairs as demonstrated in Fig. 2, and sorts them based on highest IN. An End-Point of a Lambda is a point or hop at which advancing to D was blocked or stopped, as the Lambda was not available in the next link of the route. After sorting, the combinations with repeated IN as the End-Point are purged from the list. The second step, therefore, is called “Sorting and Purging”. The Purging sub-step significantly reduces the number of combinations to try out in the next “Round”. At the end of this process NHopAkind has finished the first Round of the attempt in finding a minimum conversion lightpath from S to D. The second Round is started with the Advancing, from the End-Point with the highest IN which is (40, IN4) in example of Fig. 3, which is closer to D and has a lower chance of needing another conversion. If the Advancing with the first (Lambda, End-Point) pair results in a direct lightpath with no conversion, the process is stopped and the overall lightpath of (40,40,40,40,23) is obtained, which has 1 conversion only. In our Figure 3, the IN4 is the last hop to D, and if there is such an End-Point, the entire lightpath will have only 1 conversion. The reason is, the routing process is decoupled from the assignment method, and there would be no hop from IN4 to D if no resource were available in the dynamic network. In other words, if there were no available to assign Lambda from IN4 to D, then the hop from IN4 to D would not exist for the assignment and the route from S to D would not transit through the node of IN4. Now let us imagine that the combination pair (40, IN4) does not exist. Therefore, the “Advancing” step would start from the (15, IN3) combination pair. If the Advancing results in a direct lightpath from IN3 to D, then the process is stopped, and the overall lightpath combination of (15,15,15,44,44) is obtained as seen in Fig. 4. This combination has only 1 conversion as well, and therefore, uses the same amount of energy in conversion. If there is no direct lightpath to D at the end of Round 2, then the process of Sorting and Purging is performed for each End-Point of Round 2 and the NHopAkind method enters the Round 3. In Round 3 at each End-Point of Round 2, the highest End-Point or IN is selected for Advancing to D and finding a direct lightpath. Advancing continues to find a direct lightpath as we will see in Fig. 5. To explain the process in Round 3 and later Rounds, let us number each End-Point. For example, Lambda 20 from S is stopped at IN3 and gets R1E1 denoting Round 1 End-Point 1. R2E3, therefore, is the 3rd End-Point in Round 2. As we can see in Fig. 5, Advancing is started from End-Points of the last Round to find a continuous lightpath. When a continuous lightpath is found, the Lambda numbers of the entire route can be found by “Reversing” to S by knowing the “Parent” of the End-Point that resulted in the continuous lightpath. For example, in Figure 5 Lambda number 3 with End-Point of R3E2 reached to D and to find the Lambdas for the entire route we need to “Reverse” back to S. The Parent of the End-Point R3E2 is R2E2, whose parent is R1E1. By knowing the Parents

of the Endpoints Lambdas of the path can be “Compiled”, as we can see in Fig 5. As soon as finding a direct lightpath in Round 3 or any Round, in general, the process is stopped, and there is no need to check the other combinations. This significantly improves the resolution time of NHopAkind method. We can conclude that at the end of each round R, a lightpath with R-1 conversions may be found. The network of our testbed has an average route length of around 2.5 hops (as we will see in the results section). Therefore NHopAkind may do up to 3 Rounds on an average, and the level of complexity becomes O^3 .

Fig. 1. Advancing step

Fig. 2. Sorting and Purging step

Fig.6 demonstrate the process of serving a connection request. When a connection request arrives, first a route using the SP method is computed. With SPCont the assignment process attempts to assign the resource of Route continuously, and if it succeeds, the lightpath is established. If the assignment is not successful, the connection request is blocked. With SP and SPNHK the resources of the Route are assigned by corresponding assignment methods which give the Lambdas of the route and the number and place (INs) of the Lambda conversions. Regardless of the assignment method, after assigning the resource, the dynamic topology table is updated, and if a link is in the OFF State it is turned ON. If a link just

Fig. 3. Single Conversion only in last IN

Fig. 4. Equivalent alternate lightpath with 1 conversion

Fig. 5. Advancing step in Round 3

assigned its last resource and cannot take any more lightpaths, it is taken out from the dynamic topology. As the last step the transponders of S, D, and INs (if Lambda conversion is needed) are allocated, and the lightpath is established. This concludes the serving a connection request. Fig. 7 shows the workflow of releasing and terminating a lightpath. When releasing a lightpath, Lambdas are given back to the links and transponders of the lightpath are deallocated. If a link becomes available for routing because it got back one of its Lambdas, it is added back to the Dynamic Topology. If a link has no used Lambda, it is turned OFF.

Fig. 6. Serving connection request

Fig. 7. Releasing a connection

4. Analysis

4.1. Testbed Network

The network of this paper is the NSFnet in Fig. 8 with 14 nodes and 21 bidirectional links in papers of [5,18,19]. Numbers on the links represent the node distances in units of km. The behavior of the traffic is simulated with a Poisson process with an arrival rate of 20 and 80 connection requests per hour, for scenario 1 (Light Traffic) and scenario 2 (Moderate to Heavy Traffic), respectively. The duration of the connections or lightpaths also follows an exponential distribution with a mean duration of 30 mins. Each link has 16 available to assign Lambdas. The inline amplifiers amplify the entire spectrum (all 16 Lambdas) and are placed every 100 km. Signal leveling amplifiers also level the entire spectrum and are placed every 500 km per information in [16]. The simulation to obtain the results of each routing and assignment

pair is performed in parallel and independently using MATLAB and MATLAB Parallel Computing Toolbox [20]. Introduction to the performance metrics used in this paper comes next.

Fig. 8. NSFnet Topology

4.2. Performance Metrics

4.2.1. Number of Conversions

This metric simply shows the total number of current Lambda conversions at each time of the day. Depending on the traffic scenario and the assignment method used, this number can be different for each routing-assignment pair. Obviously, a lower value is preferred for this metric. It is expected that continuous and NHopAkind methods have zero Lambda conversion in scenario 1, since there is enough resources to establish the lightpaths “continuously”.

4.2.2. Node Power

This performance metric shows the total sum of energy being used by the optical layer of nodes. This includes the power needed for adding or dropping the Lambdas and the power needed for Lambda conversion when nodes are transit nodes.

4.2.3. Success Rate

This metric is a ratio of the total number of connection requests that were served with a route, over the total number of the connection requests. Connection requests may not receive any route when no resources are remaining for establishing the lightpath. The success rate can also be decreased when no direct or continuous lightpaths are available when continuity constraint is enforced. This condition is more likely to happen in scenario 2. A higher value for this metric is desired.

4.2.4. Lambda per connection

This metric shows the average length of lightpaths in the network. The lower the number for this metric, the better the resource efficiency. Routes can become longer, to bypass the congested sections of the network and to reach the destination node when the traffic intensity is high.

4.2.5. Lambda per Edge

This metric is the average number of the connections per each link of the network. This metric shows how congested the network links are on average.

4.3. Results

The results section has two subsections. The first section provides the results of our analysis with graphs. The second subsection of the results are “text-based” results and are our analysis on the 95 % confidence interval of our four important performance metrics.

4.3.1. Analysis for Scenario 1: The Light Traffic

As we can see in Fig. 9, The success rate of the network for all routing mechanism of SP, SPCont and SPNHK is the same. The reason is there are enough resources to establish the lightpaths regardless of assignment mechanism used. As we can see in Fig. 10, the average utilization of the links of the network is 2.5 out of 16 available to assign Lambdas and network is not congested at all with the light traffic of scenario 1. As we can see in Fig. 11, since there is no congestion on the links due to the light traffic, SP, SPNHK and SPCont give the same route length on an average. Figure 12, for this scenario, shows that the Continuous and NHopAkind become the same, as NHopAkind assigns the resources with minimum Lambda conversion, which is zero for this scenario. This fact is shown with overlapping SPCont and SPNHK in Fig. 12. SP with FF in this case assigns the resources of the lightpaths with a total of 16 Lambda conversions. With a lower number of conversions, the total node energy is about 50% less for SPNHK and SPCont compared to SP as we can see in Fig. 13. The results of the analysis for scenario 1 concludes that Continuous assignment and NHopAkind assignment are the same when the traffic intensity and congestion of the links are low. We will perform the same analysis for scenario 2.

Fig. 9. Success rate

Fig. 10. Lambda per edge

Fig. 11. Lambda per connection

Fig. 12. Lambda conversions count

Fig. 13. Total node power

4.3.2. Analysis for Scenario 2: The Moderate to Heavy Traffic

As we can see in Fig. 14, the success rate of SPCont drops by 6%, as there is no Continuous lightpath to the destination. SPNHK and SP still provide almost 100% success rate and are overlapping in this figure, therefore, the 6% drop in the success rate of SPCont is due to lack of continuous lightpaths and not lack of available resources. Results of Fig. 15, shows that the average congestion of the links of the network is around 50% of the 16 available to assign Lambdas per each link or edge. In Fig. 15, SPNHK and SP have higher link utilization, first, because they have a higher success rate, and also because they assign the resources to the routes that bypass the congested links and are longer on an average. The fact that the routes

assigned by SP and SPNHK are longer than SPCont is clearly shown in Fig. 16. As we can see in Fig. 16, the overlapping value of average route length for SP and SPNHK is about 8% higher compared to SPCont. Therefore, routes are 8% longer on an average trying to establish the lightpath through the links that still have the resources (Lambdas to assign). With the results of Fig. 17 for Lambda conversion count, we can see that SPNHK is minimizing the Lambda conversion by 72%. Therefore, SPNHK performs 72% less Lambda conversions and gives the same route length to provide a 100% success rate compared to SP. SPCont (not surprisingly) gives zero Lambda conversion count. The lower Lambda conversion number with SPNHK compared to SP is also reflected in the results of Fig. 18 for node power consumption, and SPNHK consumes about 44% percent less energy compared to SP.

Fig. 14. Success rate

Fig. 15. Lambda per edge

Fig. 16. Lambda per connection

Fig. 17. Lambda conversion count

Fig. 18. Node power

4.4. Confidence Interval Analysis

We understand that the reader of this paper may argue that many aspects of the simulation section are random and there may be no guarantee to observe the same results by repeating the simulation. Therefore, we present this text-based unique section of our analysis on Confidence Intervals (CIs). Using MINITAB® in [21], we computed the mean and the 95% CI over the average of the mean of our four important performance metrics for 70 independent and parallel runs of our simulation, equivalent to processing and analyzing 5.6 million connection requests. The traffic intensity chosen for this analysis is the arrival rate of 100 connections per hour with the same 30-minute average duration. We chose 100 connections per hour to push the network to even more congestion level of scenario 2. Our analysis for an average of mean success rate in Table 1 shows about 8% more success rate for SPNHK compared to SPCont in the “busy time”. It is also important to notice that the 95% CIs of SPNHK and SPCont do not overlap at all which means SPNHK will defiantly have a higher success rate at 100 connections per hour. Our analysis for Route length average in Table 2 shows that SPNHK will increase the length of the routes on an average to use all available resources and ensure a higher success rate of the network. The CI of the SPNHK for average route length confirms that resources of longer routes will be assigned. The results of CI analysis for node power in Table 3 shows that SPNHK is about 35% more energy efficient compared to SP. There is no overlapping between CIs of the SP and SPNHK. Finally, for the number of Lambda Conversion in Table 4, we can see that SPNHK has about 33%

less number of conversions compared to SP. The CIs of SPNHK and SP do not overlap.

Table 1. 95% Confidence interval over the mean of success rate

Variable	Mean	StDev	SE Mean	95% CI
SP	0.938834	0.002763	0.00033	(0.938175, 0.939492)
SPCont	0.864415	0.002121	0.000254	(0.863909, 0.864921)
SPNHK	0.938834	0.002763	0.00033	(0.938175, 0.939492)

Table 2. 95% Confidence interval over the mean of route length

Variable	Mean	StDev	Mean	95% CI
SP	4.98931	0.02615	0.00313	(4.98308, 4.99554)
SPCont	4.13763	0.00996	0.00119	(4.13526, 4.14001)
SPNHK	4.98931	0.02615	0.00313	(4.98308, 4.99554)

Table 3. 95% Confidence interval over the mean of node power (kW)

Variable	Mean	StDev	Mean	95% CI
SP	37.6009	0.2301	0.0275	(37.5460, 37.6557)
SPCont	14.533	0.0527	0.0063	(14.5205, 14.5456)
SPNHK	24.2334	0.2444	0.0292	(24.1751, 24.2917)

Table 4. 95% Confidence interval over the mean of the number of Lambda conversions

Variable	Mean	StDev	Mean	95% CI
SP	128.494	1.186	0.142	(128.211, 128.776)
SPCont	0	0	0	(0.000000, 0.000000)
SPNHK	86.678	2.067	0.247	(86.185, 87.171)

5. Summary and Future Work

Based on results obtained in this paper, we can conclude that NHopAking is as good as a Continuous method regarding the success rate and resource utilization when traffic intensity is light. With higher traffic intensity NHopAking uses more resources to keep the success rate higher, compared to the continuous method. Although NHopAkind is using longer routes to establish the lightpaths, it uses (35-50)% less energy to give the same success rate of the First Fit method. In any case number of Lambda conversions performed by NHopAkind is lower than the First Fit for the same success rate. In the busy times of the network, NHopAkind gives up to 8% more success rate compared to the continuous method which can be considered as 8% more income for the service provider. We will test the NHopAkind method with different average durations of the lightpaths and a higher number of the available resources per link, in the future. We are expecting to have a better lightpath for data and other applications such video streaming and video conferencing using NHopAkind (in terms of less overall delay as less number of node transit delays are occurred) compared to FF without CC. However, we will perform a similar QoS analysis detailed in the paper of [22] in future work. In future we will also analyse the effect of adopting service parameters for selecting and dedicating a wavelength for a certain application as a constraint, when interconnecting different data centers. The service parameters and architecture of these services are defined in paper of reference [23].

References

- [1] Strickland J. How much energy does the Internet use?. 2012; Available at: <http://computer.howstuffworks.com/internet/basics/how-much-energy-does-internet-use2.htm>. Accessed September, 8, 2016.
- [2] Renzenbrink T. How Much Electricity Does the Internet Use? 2013; Available at: <http://www.techthefuture.com/technology/how-much-electricity-does-the-internet-use/>, 2015.
- [3] Blasing TJ. Recent Greenhouse Gas Concentrations. Recent Greenhouse Gas Concentrations 2015, U.S. Department of Energy.2015, From http://cdiac.ornl.gov/pns/current_ghg.html; DOI: 10.3334/CDIAC/atg.032 <https://doi.org/10.3334/CDIAC/atg.032>
- [4] Coiro,A. et all. Dynamic Power-Aware Routing and Wavelength Assignment for Green WDM Optical Networks. Communications (ICC), 2011 IEEE International Conference on; 2011. <https://doi.org/10.1109/icc.2011.5962431>
- [5] Fazili Y, Nafarieh A, Raza MH, Robertson B, Philips W. The effect of adopting green SLA on key parameters of optical WDM networks. Journal of Ambient Intelligence and Humanized Computing 2016;7(3):371-384. <https://doi.org/10.1007/s12652-016-0364-5>
- [6] Fazili Y, Nafarieh A, Robertson W. Forward Looking Emission Aware and SLA based Routing Mechanism. Procedia Computer Science; The 5th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN-2014) 2014;37:80-84. <https://doi.org/10.1016/j.procs.2014.08.015>
- [7] Haque,M.E., Kien Le, Goiri,I., Bianchini,R., Nguyen,T.D. Providing green SLAs in High Performance Computing clouds. Green Computing Conference (IGCC), 2013 International; 2013. DOI: 10.1109/IGCC.2013.6604503 <https://doi.org/10.1109/IGCC.2013.6604503>
- [8] Fazili Y, Nafarieh A, Robertson B. Multi SLA Aware Green Provisioning Mechanism for WDM Networks. Procedia Computer Science 2016;94:129. <https://doi.org/10.1016/j.procs.2016.08.021>
- [9] Ricciardi, S, et all. Energy-Aware RWA for WDM Networks with Dual Power Sources. 2011 IEEE International Conference on Communications (ICC); 2011. <https://doi.org/10.1109/icc.2011.5962432>
- [10] Rami D, Mamoori SA, Jaekel A. Energy Aware Scheduling and Routing of Periodic Lightpath Demands in Optical Grid Networks. Procedia Computer Science 2016;94:256. <https://doi.org/10.1016/j.procs.2016.08.039>
- [11] Farrel A, Ayyangar A, Vasseur J. Inter-Domain MPLS and GMPLS Traffic Engineering -- Resource Reservation Protocol-Traffic Engineering (RSVP-TE) Extensions. 2008;RFC5151. <https://doi.org/10.17487/rfc5151>
- [12] Musumeci F, Tornatore M, Lopez Vizcaino J, Ye Y, Pattavina A. Energy-efficiency of Protected IP-over-WDM Networks with Sleep-mode Devices. J.High Speed Netw. 2013 jan;19(1):19-32.
- [13] Muhammad, A, et all. Energy-Efficient WDM Network Planning with Dedicated Protection Resources in Sleep Mode. Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE; 2010. <https://doi.org/10.1109/GLOCOM.2010.5683205>
- [14] M. Hadi and M. R. Pakravan, "Resource allocation for elastic optical networks using geometric optimization," in *IEEE/OSA Journal of Optical Communications and Networking*, vol. 9, no. 10, pp. 889-899, Oct. 2017.doi: 10.1364/JOCN.9.000889 <https://doi.org/10.1364/JOCN.9.000889>
- [15] Gao W, Cvijetic M. Allocation of spectral and spatial modes in multidimensional metro-access optical networks, Optics Communications,Volume 413,2018, Pages 80-86, ISSN 0030-4018, <https://doi.org/10.1016/j.optcom.2017.12.042>.
- [16] ADVA. Scalable Optical Transport. 2016; Available at: <http://www.advaoptical.com/en/products/scalable-optical-transport.aspx>. Accessed Apr, 10, 2016.
- [17] Aleksić. S. Analysis of Power Consumption in Future High-Capacity Network Nodes. IEEE/OSA Journal of Optical Communications and Networking 2009;1(3):245-258. <https://doi.org/10.1364/JOCN.1.000245>
- [18] Song, Y.et all. Energy-aware path selection for scheduled lightpaths in IP-over-WDM networks. 2011 18th IEEE Symposium on Communications and Vehicular Technology in the Benelux (SCVT); 2011.
- [19] Charbonneau N, Vokkarane VM. Performance modeling of HS-RR-TCP over load-balanced optical burst-switched (OBS) networks. Optical Switching and Networking 2011 4;8(2):116-128. <https://doi.org/10.1016/j.osn.2010.10.002>
- [20] The MathWorks. MATLAB and Parallel Computing Toolbox Release 2017. 2017.
- [21] MINITAB ® Statistical Software. 2017.
- [22] Al Mamun A., Sheltami T.R, Ali H., Anwar S. Performance Evaluation of Routing Protocols for Video Conference over MPLS VPN Network. Journal of Ubiquitous Systems & Pervasive Networks Volume 7, No. 1 (2016) pp. 01-06
- [23] Abdelaziz J., Addab A., Mcheick H. An architecture model for fog computing. Journal of Ubiquitous Systems & Pervasive Networks, Volume 10, No. 1 (2018) pp. 21-25, DOI: 10.5383/JUSPN.10.01.003 <https://doi.org/10.5383/JUSPN.10.01.003>

"MINITAB® and all other trademarks and logos for the Company's products and services are the exclusive property of Minitab Inc. All other marks referenced remain the property of their respective owners. See minitab.com for more information."