Grenze International Journal of Engineering and Technology, June Issue

ML based Intelligent Wavelength Assignments in all Optical Networks

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***Abstract*—For the past several years, Internet traffic has been increased tremendously and this growth demands fora high-speed communication network such as optical network. The RWA is one of the key tasks for the optical network, due to its information transparency and wavelength reuse characteristics.**

If multiple required wavelengths are available on the entire route between a source-destination pair, a wavelength selection mechanism is used to select the best wavelength. The wavelength selection may be performed either after a path has been determined, or in parallel during the path selection. It is also important that wavelengths should be selected in such way that the performance of the network should be optimal.

In this direction, a number of heuristics have been proposed. Among them, some significant heuristics such as First-Fit, Least Used, Most Used, and Random WA. In the First-fit (FF) scheme, a list of available and used indexed wavelengths is maintained. This scheme always chooses the lowest indexed wavelength from the list of available wavelengths and assigns it to the connection request. When the call is completed, the wavelength is added back to the available wavelength list. To implement this scheme, any global information of the network is not needed. FF performs better in terms of BP and fairness because of its low computational overhead and complexity. Least used (LU) scheme assigns the connection request to the available wavelength which is already used on the minimum number of other fiber links in the network. If several available wavelengths share the same number of usages, FF scheme is used to select the wavelength. In the Most used (MU) scheme, the available wavelength that is already used on the maximum number of other fiber links in the network is assigned to the connection request. Similar as LU, if several available wavelengths share the same maximum usage, FF scheme is used to break the tie.

In the Random WA scheme, a list of available wavelengths is maintained. Whenever a connection request arrives in the network, this scheme randomly selects a wavelength from the set of available wavelengths and assigns it to the connection request. Then, the list of available wavelengths is updated by removing the used wavelength from the free list. When the call is completed, the wavelength is again added to the list of free wavelengths. The wavelength assignment plays an important role in further enhancing the network performance; two schemes mainly ARWA and FT-ARWA are developed. The dynamic wavelength assignment is carried out in ARWA algorithm on immediate and intermediate assignments. The blocking probability, throughput and the bandwidth utilization is improved when more flows are combined together for ARWA algorithm.

Grenze ID: 01.GIJET.12.2.350_24

***Index Terms*— Routing and wavelength assignment (RWA), Convolutional neural network (CNN), Machine learning (ML), deep learning (DL) Wavelength division Multiplexing. Routing and wavelength assignment problem.**

I. INTRODUCTION

Telecommunications makes wide use of optical techniques in which the carrier wave belongs to the classical optical domain. The bit rate can be increased further, using several carrier waves that are propagating without significant interaction on the same fiber. The ever-growing complexity of optical communication systems and networks demands sophisticated methodologies

[1] to extract meaningful insights from vast amounts of heterogeneous data. Machine learning (ML) and deep learning (DL) have emerged as frontrunners in this domain, offering a transformative approach to data analysis and enabling automated self-configuration in optical communication systems. The adoption of ML and DL in optical communication is driven by the exponential increase in system and link complexity, stemming from the introduction of numerous adjustable and interdependent parameters.

ML techniques [2] have been used as enablers of intelligence, adaptability, and efficiency in the functioning and operation of optical networks. The Supervised machine learning techniques are used for resource management, network monitoring, fault management, and traffic classification and prediction of an optical network. Using a well-trained ML technique involves only linear and pseudo- linear computing, which enables complex task results with great time efficiency, thus optimizing the optical network's operation.

The RWA problem [3] takes two forms: static and dynamic. In the static case, all connection requested at network are known in advance, thus a routing decision can be made based on the full information of the traffic to be served by the network. In the dynamic case, a connection request has to be routed and wavelengths assigned independently of other connections, which either have already been assigned. The load balancing problem is defined as given a physical network with the link costs and the traffic requirements between every pair of source- destination find a routing of the light. P. Gurzi et al [4] have proposed a dynamic RWA algorithm based on maximum flow computation. The max-flow RWA algorithm runs on a transformed version of the physical topology which allows solving the two problems of routing and wavelength assignment simultaneously while misusing Kolmogrov's algorithm for a faster communication paths for the network with the least congestion. Jorge Crichigno et al [5] have proposed a multi-objective integer linear program (ILP) for the joint throughput optimization and traffic engineering problem. By simultaneously maximizing the throughput, minimizing the resource consumption and balancing the traffic load, it is demonstrated that better solutions than those of mono-objective approaches are obtained. Zhizhong Zhang et al [6] have introduced an algorithm to accomplish integrated dynamic routing of guaranteed paths in IP over WDM networks. Their approach has considered the information of topology and resource usage at the IP and WDM layers. Further, the routing procedure utilizes the statistical information of bandwidth requirement of users, routing cost and according length of routing path. Therefore, their approach provides link load balancing and network usage. M.Sumathi et al [7] have presented a new approach for load balancing in WDM network with single and multiple light path additions. Their approach has considered the light paths with less traffic for deletion while setup a new light path. This deletion approach decreases the value of objective function namely congestion. Thus, the deletion of light paths to make free the resources largely improves the congestion of the network. Addition of one or two light paths for slow varying traffic patterns minimizes the congestion significantly.

II. MACHINE LEARNING ALGORITHMS AND ANALYSIS

The applications of ML are classified in to two classes, namely optical network control and resource management, and optical networks monitoring and survivability. The use cases are analyzed and compared according to the used ML techniques.[10] In general, there are mainly three challenges faced by development and operation of optical networks:

- Network complexity: The number and complexity of optical network devices increase with the scale of optical networks extend. Additionally, the optical network acts as the bearer network in communication systems, which may carry multiple heterogeneous networks, such as 5G mobile networks, IoT, vehicle networking, and cloud computing. How to adapt the traffic from these different networks is becoming the first challenge for optical network operation and management.
- Service complexity: Different Quality of Service (QoS) agreements require optical networks to provide differentiated services. And the novel techniques and applications, such as network slicing, ask the service

provision to be implemented in real time. Then, the optical networks should furnish a flexible service providing mechanism to provide different levels of QoS to different services in the physical domain

- Resource management complexity: The optical network is the bridge between upper layer traffic and underlying physical layer resources. So, it is responsible for physical layer resources allocation for traffic provision. However, there are multiple dimensional physical resources to be allocated, such as fiber, wavelength, spectrum, modulation format, and time slots. The joint assignment of multiple resources is time-consuming with high computational complexity. Applying ML for intelligent optical networks has achieved better efficiency and accuracy than many conventional methods.

III. Routing and wavelength assignment problem.

The RWA is basically an optimization problem using integer programming formulations. The objective of the formulation is to minimize the maximum congestion level in the network subject to network resource constraints. While other objective functions are possible, such as minimizing the average weighted number of hops or minimizing the average packet delay, minimizing network congestion is preferable since it can lead to ILP formulations [8]. The performance of a dynamic RWA algorithm is generally measured in terms of the call blocking probability, that is, the probability that a light path cannot be established in the network due to lack of resources such as link capacity or free wavelengths [9]. The NSF Model is used for testing the algorithms. The developed algorithms for RWA namely Max flow LB, and ABSRLB are tested for their performance. Network simulator (NS-2) platform is used for describing the effectiveness of the developed algorithms. Various simulation parameters setting as given in Table 1

Table I: Simulation Parameters

Topology	Mesh	Traffic Holding Time	0.2
Total no. of nodes	14	Packet Size	200
Link Wavelength Number	8	No. of Session-traffics	5
Link Delay	10 m sec	Max Requests Number	50
Wavelength Conversion Factor	1	Link Utilization sample Interval	0.5
Wavelength Conversion Distance	8	Traffic Arrival Rate	0.5
Wavelength Conversion Time	0.024 sec		

A. Performance of Max flow LB algorithm [8].

An efficient routing protocol for optical WDM network is proposed based on maximum flow algorithm along with load balancing. It considers the unbalanced status of the network in the routing strategies. Initially, the original physical topology is transformed into new topology, to reflect the number of wavelength along each link. Then max flow paths are determined using Kolmogorov's algorithm which builds search trees for detecting augmenting paths. Two search trees are built, one from the source and the other from the sink. Among the determined max flow paths, the current traffic load of each path is calculated using the load balancing algorithm. The path with the minimum load is chosen as the best path.

Effects of Varying Traffic Rate.
The traffic rate is varied from 5 Mbps to 25 Mbps, in the steps of 5Mbps and the corresponding of E2E is recorded. The E2E performance of the proposed Max-flow-LB algorithm is measured for various data rates. It is observed that the E2E is reduced substantially. Average reduction in delay is observed as 64 % as compared to Max flow algorithm. Thus the performance improves more, at all higher data rates.

Effect of Varying Traffic Sources.
The number of traffic sources (flows) is varied from 1through 5 and end to end delay is recorded. It is observed that there is a noticeable fluctuation in Max flow algorithm as the number of flows is combined. For Max Flow LB there is a steady decrease in E2E is observed as the number of flows is increased. An average reduction in E2E is observed as 94 % as compared to Max flow algorithm. The performance of Max flow LB improves due to fact that load balancing with max flow a feature is incorporated in the proposed solution.

B. Performance throughput (Tp) of proposed Max flow LB algorithm.

Effects of varying traffic rate.
The traffic rate is varied from 5Mbps to 25 Mbps, in the steps of 5Mbps and the corresponding of throughput is measured. It is observed that the 〖T〗_p, in terms of packets received is more in the case of Max-flow-LB Algorithm when compared to Max-flow algorithm. The Tp is substantial in the case of Max flow-LB when

compared to Max-flow for all data rates. Average increase in throughput is observed as 76% as compared to Max flow algorithm. It is seen that, when traffic rate is higher Max-flow-LB gives steep rise in the throughput than the Max-flow algorithm.

Effect of varying traffic sources.

The number of traffic sources (flows) is varied from 1through 5 and the Tp received is recorded. It is observed from the Tp is more in the case of Max-flow- LB when compared to Max-flow algorithm for all values of the data rates. An average increase in Tp is observed in Max flow LB as 71 % as compared to Max flow algorithm. Thus Tp increases as the traffic rate is varied for both algorithms but, in the case of Max-flow-LB about 40552 more number of packets is received than the Max-flow algorithm for the highest data rate.

C. Performance Bandwidth utilization BU of proposed Max flow LB algorithm.

Effects of varying traffic rate.

The traffic rate is varied from 5Mbps to 25 Mbps, in the steps of 5Mbps and the corresponding of BU is computed. It is found that the BU is more in the case of Max-flow-LB when compared to Max-flow algorithm. An average increase in utilization is observed as 146 % as compared to Max flow algorithm

Effect of varying traffic Sources.

The number of traffic sources (flows) is varied from 1 through 5 and BU is calculated. It is observed that the BU is more in the case of Max-flow-LB when compared to Max-flow algorithm. An average increase in BU is observed as 41% as compared to Max flow algorithm. Thus BU obtained for all the flows is increased linearly for Max-flow-LB and is better than the Max-flow scheme.

D. Performance of ABSRLB algorithm [8].

The ABSRLB discovers survivable and load balanced feasible paths by means of ant optimization technique. Ant agents are launched in the network to gather essential information such as available bandwidth, route length and number of free wavelength. A combined feasible value is generated from these factors for each path. Similarly, load values are updated and maintained in the network. While transmitting data to the destination, the source selects the path with high feasible value and low load value, other paths are termed as backup paths. During congestion and failures backup paths are made used for transmission. This algorithm is tested with higher data rates and two classes of the traffic Constant bit rate (CBR) and Exponential bit rate (EXPO), which is variable bit rate. In order to minimize cost standard Dijkshtra's shortest path algorithm is used. This ABSRLB algorithm is compared with the shortest path Dijkshtra's algorithm.

E. Performance of blocking probability (BP) of proposed ABSRLB algorithm.

Case 1: Constant bit rate (CBR) traffic with rates.

The traffic rate is varied from 10 Mbps to 50 Mbps, in the steps of 10 Mbps and the BP is computed. It is found that the BP is less in the case of ABSRLB when compared to shortest path Dijkshtra's' algorithm. An average decrease in Blocking Probability is observed as 49% as compared to Dijkshtra's' algorithm. Since ant pheromones can detect in advance unhealthy condition of links and divert the route, the blocking is less, which proves the novelty of ABSRLB algorithm.

Case 2: Exponential bit rate (EXPO) traffic with rates (Ta The traffic rate is varied from 10 Mbps through 50 Mbps, in the steps of 10 Mbps and the BP is computed. It is found that the BP is less in the case of ABSRLB when compared to Dijkshtra's algorithm. The BP of ABSRLB Algorithm is less than the Shortest Path Dijkshtra's algorithm for all data rates. For burst traffic the algorithm works well, which indicate that in the dynamic environment also the algorithm works well.

Case 3: Constant bit rate (CBR) traffic with flows.

The number of flow is varied from 2 to 8, in the steps of 2 and blocking probability is computed. It is found from that the blocking probability is less in the case of ABSRLB when compared to Dijkshtra's algorithm. Average decrease in blocking probability is observed as 89 % as compared to Dijkshtra's algorithm. The blocking probability of ABSRLB algorithm is less than the shortest path Dijkshtra's algorithm.

Case 4: Exponential bit rate (EXPO) traffic with flows.

The number of flow is varied from 2 to 8, in the steps of 2 and BP is computed. It is found that the BP is less in the case of ABSRLB when compared to Dijkshtra's algorithm. An average decrease in BP is observed as 119 % as compared to Dijkshtra's algorithm. The BP of ABSRLB algorithm is less than the Shortest Path Dijkshtra's algorithm.

F. Performance of end to end delay (E2E) of proposed ABSRLB algorithm.

Case 1: Constant bit rate (CBR) traffic with rates
The traffic rate is varied from 10 Mbps to 50 Mbps, in the steps of 10 Mbps and the End to end delay is measured. It is found that the end to end delay is less in the case of ABSRLB when compared to Dijkshtra's algorithm. The delay of ABSRLB algorithm is less than the shortest path Dijkshtra's algorithm. There is decrease in end to end delay when the data rate is high.
Case 2: Exponential bit rate (EXPO) traffic with rates The traffic rate is varied from 10 Mbps to 50 Mbps, in the steps of 10 Mbps and the end to end delay is computed. It is found that the end to end delay is less in the case of ABSRLB when compared to Dijkshtra's algorithm. Decrease in average end to end delay is observed as 65% as compared to Dijkshtra's algorithm. The end to end delay of ABSRLB algorithm is less than the shortest path Dijkshtra's algorithm.
Case 3: Constant bit rate (CBR) traffic with flows.
The no of flow is varied from 2 to 8, in the steps of 2 and the end to end delay is computed. It is found that the end to end delay is less in the case of ABSRLB when compared to Dijkshtra's algorithm. The end to end is decreased by 24 % as compared to Dijkshtra's' algorithm. The end to end delay of ABSRLB Algorithm is less than the shortest path Dijkshtra's algorithm.
Case 4- Exponential bit rate (EXPO) traffic with flows The no of flow is varied from 2 to 8, in the steps of 2 and the end to end delay is computed. It is found that the end to end delay is less in the case of ABSRLB when compared to Dijkshtra's algorithm. The end to end delay is observed as 78 % as compared to Dijkshtra's algorithm. The delay of ABSRLB algorithm is less than the shortest path Dijkshtra's algorithm.

G. Performance of throughput (Tp) of proposed ABSRLB Algorithm.

Case 1: Constant bit rate (CBR) traffic with rates.
The traffic rate is varied from 10 Mbps to 50 Mbps, in the steps of 10 Mbps and the throughput is measured. It is found that the throughput is more in the case of ABSRLB when compared to Dijkshtra's algorithm. Throughput is increased as 12 % as compared to Dijkshtra's algorithm.
Case 2: Exponential bit rate (EXPO) traffic with rates. The traffic rate is varied from 10 Mbps to 50 Mbps, in the steps of 10 Mbps and the throughput is computed. It is found that the throughput is more, in the case of ABSRLB when compared to Dijkshtra's algorithm. Increase in average throughput is observed as 64 % as compared to Dijkshtra's algorithm. The throughput of ABSRLB algorithm is more than the shortest path Dijkshtra's algorithm.
Case 3: Constant bit rate (CBR) traffic with flows.
The no of flow is varied from 2 to 8, in the steps of 2 and the throughput is computed. It is found that the throughput is more in the case of ABSRLB when compared to Dijkshtra's algorithm. Average increase in throughput is observed as 30 % as compared to Dijkshtra's algorithm. Thus throughput of ABSRLB Algorithm is more than the shortest path Dijkshtra's algorithm.
Case 4: Exponential bit rate (EXPO) traffic with flows. The no of flow is varied from 2 to 8, in the steps of 2 and the throughput is computed. It is found that the throughput is more in the case of ABSRLB when compared to Dijkshtra's' algorithm. Average increase in the throughput is observed as 77 % as compared to Dijkshtra's algorithm. Thus throughput of ABSRLB algorithm is more than the shortest path Dijkshtra's algorithm.

H. Performance of bandwidth utilization (BU) of proposed ABSRLB algorithm.

Case 1: Constant bit rate (CBR) traffic with rates
The traffic rate is varied from 10 Mbps to 50 Mbps, in the steps of 10 Mbps and the bandwidth utilization is computed. It is found that the bandwidth utilization (BU) is more in the case of ABSRLB when compared to Dijkshtra's algorithm. The average bandwidth utilization is increased observed as 37 % as compared to Dijkshtra's algorithm. Thus the bandwidth utilization of ABSRLB algorithm is more than the shortest path Dijkshtra's algorithm.
Case 2: Exponential bit rate (EXPO) traffic with rates. (T The traffic rate is varied from 10 Mbps to 50 Mbps, in the steps of 10 Mbps and the bandwidth utilization is computed. It is found that bandwidth utilization is more in the case of ABSRLB when compared to Dijkshtra's algorithm. Increase in average bandwidth utilization is observed as 42 % as compared to Dijkshtra's algorithm. The bandwidth utilization of ABSRLB algorithm is less than the shortest path Dijkshtra's algorithm.
Case 3: Constant bit rate (CBR) traffic with flows.
The number of flow is varied from 2 to 8, in the steps of 2 and the bandwidth utilization is computed. It is found that the bandwidth utilization is more in the case of ABSRLB when compared to Dijkshtra's algorithm. Average

increase in bandwidth utilization is observed as 22 % as compared to Dijkshtra's algorithm. The bandwidth utilization (BU) of ABSRLB Algorithm is more than the shortest path Dijkshtra's algorithm.

Case 4: Exponential bit rate (EXPO) traffic with flows. The number of flow is varied from 2 to 8, in the steps of 2 and the bandwidth utilization is computed. It is found that the channel utilization is more in the case of ABSRLB when compared to Dijkshtra's algorithm. The average bandwidth utilization is increased by 62% as compared to Dijkshtra's algorithm. The bandwidth utilization of ABSRLB algorithm is more than the shortest path Dijkshtra's algorithm.

IV. RESULT

The developed algorithms can be used in dynamic practical environment in the optical networks so that performance is better. The performance of the algorithms is summarized as follows 1.Max flow LB [8] algorithm is compared with Max flow[4]:

- For varying traffic rate: Average reduction in delay is observed as 64 % as compared to Max flow. Average increase in throughput is observed as 69 % as compared to Max flow. Average increase in utilization is observed as 146% as compared to Max flow.
- For varying number of flows: Average reduction in delay is observed as 94 % as compared to Max flow. Average increase in throughput is observed as 71 % as compared to Max flow. Average increase in utilization is observed as 41 % as compared to Max flow.

A. ABSRLB [9] algorithm is compared with Dijkshtra's [4] shortest path algorithm

- For varying traffic rate (CBR): Average reduction in delay is observed as 7.8 % as compared to Dijkshtra's algorithm. Average increase in throughput is observed as 12% as compared to Dijkshtra's algorithm. Average increase in utilization is observed as 37% as compared to Dijkshtra's algorithm.
- For varying number of flows (CBR): Average reduction in delay is observed as 24 % as compared to Dijkshtra's algorithm. Average increase in throughput is observed as 30% as compared to Dijkshtra's algorithm. Average increase in utilization is observed as 22% as compared to Dijkshtra's algorithm.

V. CONCLUSION

From the routing algorithms developed, it is concluded that the Max flow LB algorithm is suitable for offline processing, while the ant based survivable routing (ABSRLB) along with load balancing algorithm is suitable for dynamic environment, in which the link failures, link restoration and load balancing features are incorporated together so that the routing is done efficiently. The results of simulation proved that the blocking probability is reduced for both of these algorithms. The throughput is observed more for both algorithms, the path which is based on Dijkstra's shortest path algorithm indicating that the data transfer takes through the minimum number of hops resulting in more throughput is more. The ant pheromone is the packets send in advance at each node to check whether there is any path, which unhealthy and needs immediate outage. Introduction of this feature is found to be more effective for reducing the down time. The performance of the data transfer in terms of packets delivery, packets resend, packets acknowledgement and resource management is achieved satisfactory.

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