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Fragmentation aware heuristic algorithm for routing and wavelength assignment in optical networks

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ABSTRACT

Wavelength division multiplexing (WDM) is one of the dominating technologies with high-capacity back bone networks. The cost associated with the high-capacity networks given more importance. The major issue is allocating and managing the available resources. To achieve this most efficient algorithms has to be used. We are considering the routing of lightpath and wavelength assignment problem, called as the routing and wavelength assignment (RWA) problem. The optimization of wavelength fragmentation in the WDM network is very much important in resource utilization. Wavelength fragmentation is one of the most important challenges in the area of the WDM network. Where it leads to some serious issues for the operators, such as the rejection of new requests. We are using integer linear program (ILP), here the problem is based on the node link formation. It is based on the multilayer concept and the original WDM network consists of several layers. We propose an efficient heuristic approach to solve this problem of finding the shortest path and assigning a wavelength without wavelength conversion. The model achieves better performance with fragmentation aware wavelength allocation strategy that minimizes fragmentation.

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1. INTRODUCTION

In todays scenario the popularity of data intensive applications and real time applications are increasing tremendously over the entire globe. We can see that for each and every work what we do with the electronic gadgets requires an internet connection with high speed data transmission. The technology what we are using demands a high speed internet for processing the data, for using live applications, live streaming, smart home, and smart city. Due to which there is a huge demand for high speed internet for communication. As the global data demand is growing the bandwidth requirement is also increasing. Approximately 5.3 billion internet users, that is 66% of the population in the entire globe access internet for the year 2023 [1]. We can see that smart devices, electronic gadgets, smart city, and smart house. Which needs internet connection for there functioning has been increasing day by day which demands a high network speed. To fulfil the increasing bandwidth demand, optical networks are one of the best solution for these issues. In optical wavelength division multiplexing (WDM) wavelength and division multiplexing the data is transmitted using light beams. Optical networks with WDM technology are more essential because of their seamless characteristics, huge bandwidth capability, low signal attenuation, signal distortion, low cost and low power requirement. The range of bandwidth in WDM network range high which enables the various frequencies to carry data on the same medium. This reduces the loss of data compared to the wired transmission.

In WDM network the data is transmitted on many wavelength in an optical fiber. The end users communicate via channels known as lightpaths [2], [3]. The lightpath has to reach the links using the same channel which it traverse, that is without wavelength converters [4], [5]. The established path between the end users exist for some finite amount of time, later it is released. In a any network, if the data has to be transmitted, it must be scheduled prior to prevent the data loss. The two types of traffic in the network is static and dynamic. In static traffic the routes are predefined, stored in the table [6]-[10]. The prior knowledge of network and the path to be setup is know in advance this concept. Several heuristic algorithms are investigated regarding the lightpath set up in optical network using static traffic and to solve routing and wavelength assignment (RWA) problem [11]-[17]. In dynamic traffic the establishment of the lightpath is established as soon as the request arrives dynamically in real time, where there is no knowledge of predetermined paths and the future lightpath. In the dynamic lightpath assignment the network topology is formed virtualy by a dynamic lightpath approach. In this approach after some time the connection has to be removed, once the data transferred is done. To solve the difficult problems in dynamic lightpath establishment many heuristic methods have been proposed in the literature [18]-[22]. There are several methods have been proposed, we have taken few methods for routing and wavelength assignement and compare the proposed model.

2. METHOD

In this section, we proposed a new cost-effective and efficient heuristic-based algorithm for solving dynamic routing and wavelength allocation problem in symmetric optical network operating at high traffic intensity. Our objective is achieved by minimizing the fragmentation in wavelength allocation matrix for assigning wavelength, hence It is important to understand the problem of fragmentation and its influence in the WDM context. The WDM network as shown in Figure 1 is deemed to be a stacked multi-layer virtual networks with the corresponding topologies T_1, T_2, T_3, … $T\omega$ that of the base network shown in Figure 1(a). The network topologies T_1 and T_2 as depicted in Figure 1(b) for two virtual layers with different colours correspond to wavelengths λ_1 and λ_2 respectively. The modelling of the network as independent isolated virtual network has yield benefits for the implementation of RWA task. One of the key inherent benefits is the selection of route is indeed the selection of the respective wavelength, hence search for an optimal wavelength for a call go hand in hand with selection of optimal route.

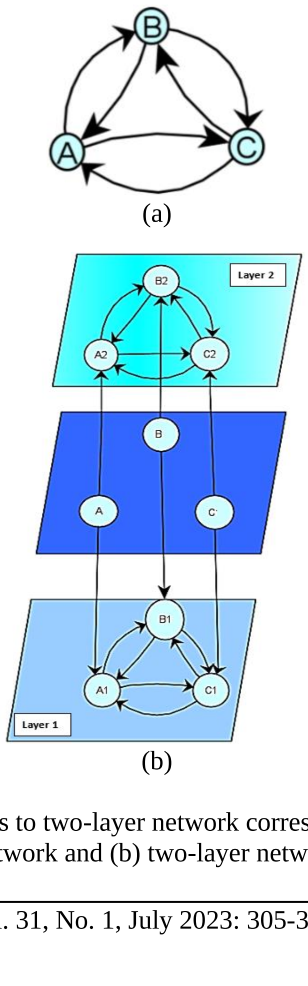
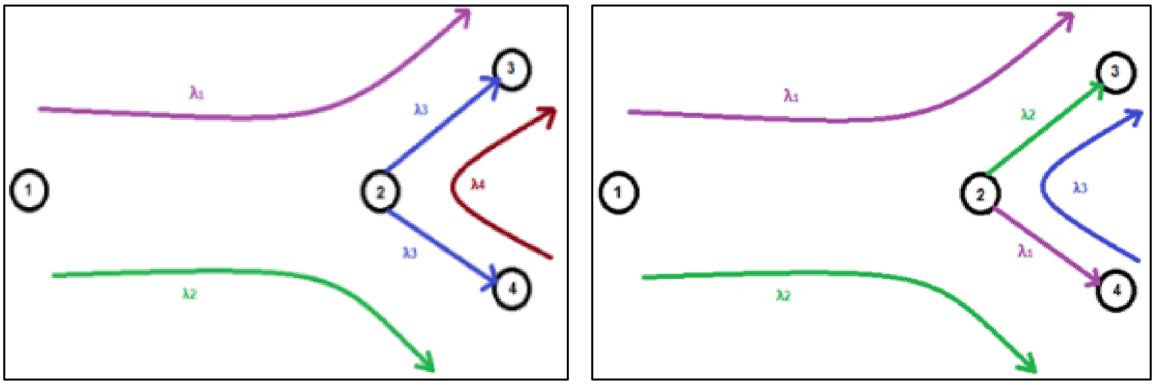


Figure 1. A base network modelled as to two-layer network corresponding to two wavelengths: (a) base network and (b) two-layer network

2.1. Wavelength fragmentation problem

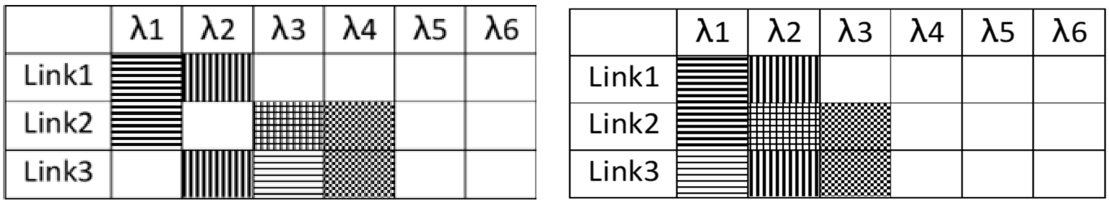
Fragmentation problem is a known issue which should be minimized, across different resource management and allocation systems such as memory storage allocation system, and spectrum allocation system. Fragmentation in wavelength allocation matrix in WDM network poses a challenge which needs to be addressed for efficient wavelength utilization [23]-[25]. The impact of fragmentation is illustrated with dense wavelength division multiplexing (DWDM) networks as shown in Figure 2 and their correspoinding wavelength allocation matrices shown in Figure 3. Consider the networks as shown in Figure 2(a) and Figure 2(b) and their corresponding wavelength allocation matrices as shown in Figure 3(a) and Figure 3(b) respectively are characterized by rows representing the number of links {Link1, Link2, Link3} and columns representing the number of available wavelengths {λ1, λ2…. λ6}.

The former referring to feasible allocation for the network considered causes fragments along the vertical directions corresponding to different wavelengths due to allocation policy that end up leaving only two wavelengths λ5 and λ6 for serving subsequent connection requests as compared to optimal allocation as shown in Figure 3(b) that has three free wavelengths λ4, λ5, and λ6 for future requests. However, fragmentation could not be avoided and is bound to happen even with the implementation of sophisticated wavelength allocation mechanism. To illustrate our point of view, consider the same network as shown in Figure 3(a). Assume Link1 (L1) between nodes 1-2, Link2 (L2) between nodes 2-3, Link3 (L3) between nodes 2-4 and dynamic connection request C1= {L1, L2} (light path using links L1 and L2 in order), C2= {L3}, C3= {L1, L3}, C4= {L2, L3} and C5={L2}. If the connection requests arrive in the order {C1, C2, C3, C4, C5}, optimal allocation of wavelength as shown in Figure 3(b) could be realized with an efficient allocation policy. However, with the same set of connections, if the order of connection requests is {C5, C4, C1, C3, C2}, the corresponding wavelength allocation matrix as depicted in Figure 4 is induced with fragmentation. It is evident that dynamic requests influence fragmentation that could not be eliminated completely but could be minimized with the implementation of fragmentation-aware wavelength allocation policy to accommodate maximum number of dynamic connections thereby reducing blocking probability.



(a) (b)

Figure 2. Two different wavelength allocation configurations: (a) feasible allocation of wavelengths and (b) optimal allocation of wavelengths



(a) (b)

Figure 3. Wavelength allocation matrix for feasible and optimal allocation: (a) feasible wavelength allocation matrix and (b) optimal wavelength allocation matrix

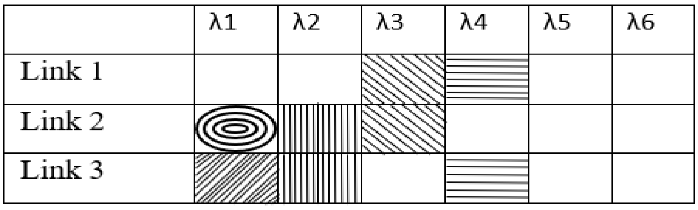


Figure 4. Wavelength allocation matrix for connection requests in order {C5, C4, C1, C3, C2}

2.2. Minimum hop count on maximum load wavelength model

Fragmentation in wavelength allocation in WDM network poses a challenge which needs to be addressed for efficient wavelength utilization. The proposed mode minimum hop count on maximum load wavelength (MHCMLW) attempts to alleviate fragmentation problem by reusing the already in use wavelengths to maximum extent before activating a new wavelength. For an incoming connection request between source and destination, the MHCMLW finds all the minimum hop count routes in first phase of the task and in the second phase, selects the wavelength having the highest allocation indicating maximum load. The notion of the model is to patch the fragmentation slots that are readily available in a wavelength already in use enabling maximum utilization of the respective wavelength without redundancy. During the operation, the free slots corresponding to a wavelength are allocated to serve the incoming requests leaving relatively fewer fragmentation slots. The wavelengths with scattered fragmentation slots would imply maximum load meaning highest allocation on the respective wavelengths therefore the probability of finding wavelengths with fewer fragmentation slots is high, thereby computing minimum hop count path for a connection request obviously would minimum slots for wavelength allocation thus complimenting the wavelength selection phase. Due to the multi-layer network architecture in which each layer corresponding to a wavelength, routing from source to destination in each of the layers can be parallelized and selection of a route in a network layer would mean the selection of the respective wavelength. The outcome of routing phase is a set of shortest distance routes in the respective network layers which are filtered out to retain minimum hop count routes. The selection of the wavelength among the minimum hop count routes depends on the maximum utilization of the wavelength. This method of allocation reduces fragmentation in wavelength allocation matrix, which in turn minimizes the future blocking or demand rejection. Consider a network topology T as shown in Figure 5 network topology. Let T(N, L) be a network topology, where each node $N_i \in N$, $\forall i, 1 \le i \le n$ and each link $L_i \in L$, $\forall i, 1 \le i \le l$. Let $\boldsymbol{\omega}$ be the number of wavelengths and λ_i is i[th] wavelength, $\forall i, 1 \le i \le \omega$, the selection of wavelength $\boldsymbol{\lambda_i}$ as show in (1) is a twostep process:

$$\lambda_i = \max_{\lambda_i} \delta(\min_{h}(h_{\lambda_i}^{(s,d)})), \forall i, 1 \le i \le \omega \quad (1)$$

where h_(λ_i)^((s,d))is hop count of a route from s to d in the topology corresponding to λ_i, δ function selects a wavelength with the maximum number of allocations indicating maximum load.

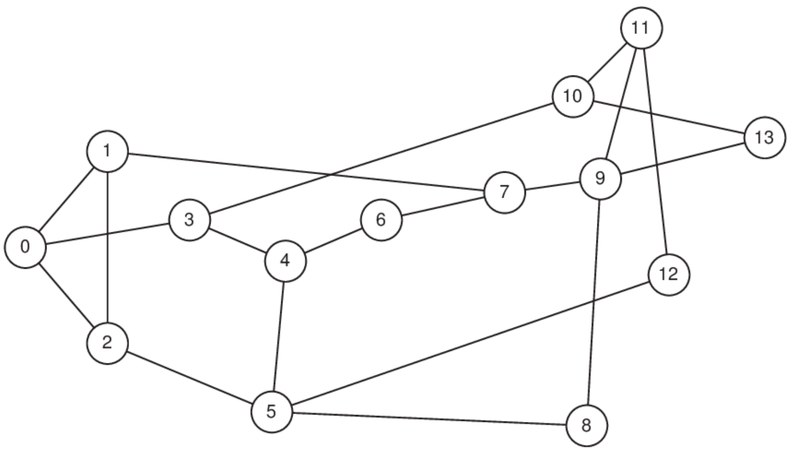


Figure 5. Network topology

2.3. Implementation

The implementation of proposed model MHCMLW and variants for evaluation is as shown in Figure 6 is based on multi-process and threading on multiprocessor/multicore architecture. The tasks for dynamic routing and wavelength assignment (DRWA) require dynamic route computations and wavelength assignment that are parallelized to emulate real world scenario. It is a centralized computation control for servicing connection requests whose arrival and releasing time are independent. The traffic generation and holding time for connections for the simulation comply with the distibutions to mimic the real-world scenario are as ploted in Figure 7. The rating of request arrival follows passion distribution at rate λ=125 requests/20 secs and releasing time that depends on connection holding time which is exponentially distributed at rate λ=0.05 are as shown in Figures 7(a) and 7(b) respectively.

Inter-process communications for connection request packets and release request packets are facilitated by message queues between request generator, processor, and releasor processes executing independently on different processor cores. On arrival of a connection request, shortest light path between the source and destination for the connection is computed in all the network layers corresponding to wavelengths using threads. Second level of heuristic-based policies are applied to find the bestter path and wavelength for the request. The links along the selected route of the network layer corresponding to the selected wavelength Special timer threads have been implemented for injecting request packets and connection release packets into queues. Various heuristic models with two different wavelength configurations (number of wavelengths ω=8 and ω=16) are evaluated on same set of network traffic requests.

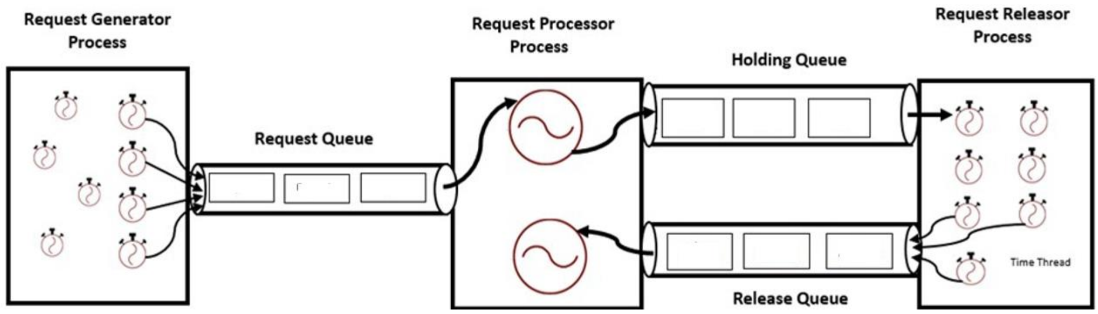
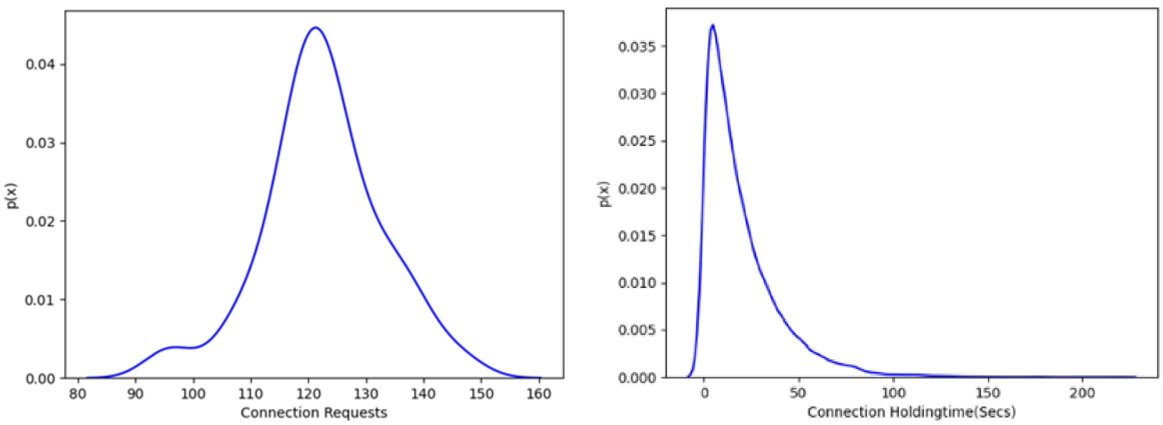


Figure 6. Multiprocessing model for serving dynamic connection request in DWDM network



(a) (b)

Figure 7. Distribution of connection requests and connection holding time: (a) connection request arrival distribution and (b) connection holding time requests

3. RESULTS AND DISCUSSION

The results of network simulations of the proposed heuristic based models and other baseline models on two different configurations of wavelength=16 and wavelength=8 are shown in Figures 8 and 9 respectively. The proposed model on minimum hop count on maximum load wavelength outperforms other heuristic models by margin of 1% to 20% reduction in packet drop which is directly proportional to the blocking probability.

The minimum hop count heuristic models perform better than other baseline models such as random wavelength selection, maximum hop count selection and first come first selection of wavelength. The improvement in the performance is due to the minimum number of links meaning optimal resource utilization leading to reduction in packet drop. However, there is a slight drawback with the selection of available wavelengths due to which the performance is downgraded.

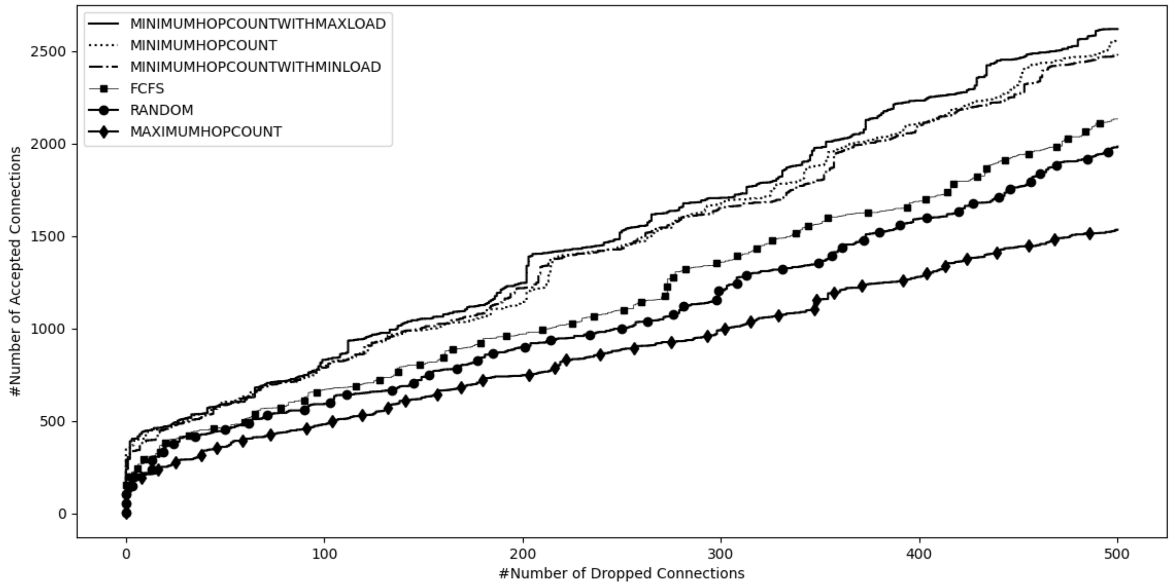


Figure 8. Responses of models w.r.t connection drops for number of wavelengths(ω=16)

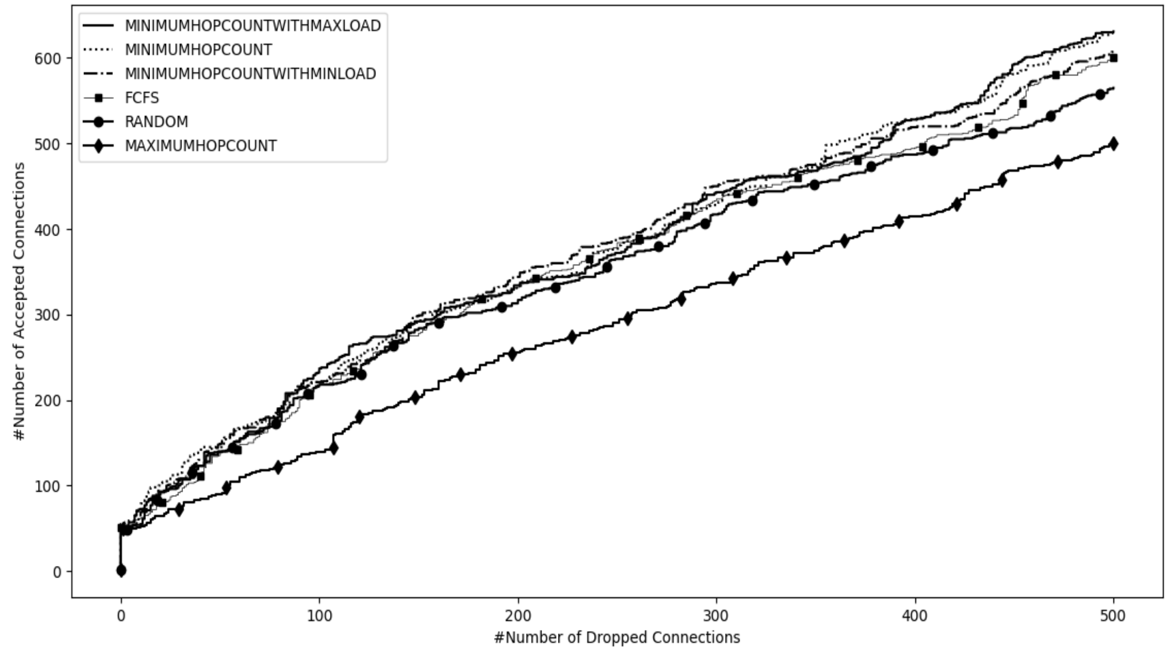


Figure 9. Responses of models w.r.t connection drops for number of wavelengths (ω=8)

4. CONCLUSION

The proposed model for solving DRWA is decomposed into two stage pipelined tasks namely routing and wavelength allocation. The execution of which could be parallelized on multiple process architecture. The perception of WDM network as layers of network corresponding to the wavelengths has advantage over other unified network models for parallel implementation of the pipelined tasks. Routing between source and destination in layers corresponding to the wavelengths and wavelength allocation out of available wavelengths based on some policy is parallelized. Determining the shortest path routes corresponding to different layers leads to the optimal selection of wavelength reducing fragmentation in the wavelength allocation matrix. The model achieves better performance with fragmentation aware wavelength allocation strategy that minimizes fragmentation along vertical direction corresponding to links and eventually along horizontal direction corresponding to wavelengths. This is achieved using heuristic method based on minimum hop count strategy for route selection among available routes and selecting wavelength that minimizes the utility of resources. The proposed model is simple, cost effective and practically feasible for DRWA task. As a part of future work, developing integrated heuristics and machine learning based strategies for routing and wavelength allocation to improve the performance could be undertaken. Strategies that predict future traffic patterns to assess wavelength allocation for current request need to be evaluated.

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