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RESEARCH ARTICLE

TRAFFIC MANAGEMENT IN SDN-BASED OPTICAL NETWORKS

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ABSTRACT

This paper investigates Routing and Wavelength Assignment (RWA) problem in Optical Networks. Optical Networks are critical for handling increased bandwidth demands; and it is difficult to manage lightpath requests due to the lack of network resources. To overcome this challenge, a queuing theory based framework for Optical Networks is proposed with Software-Defined Networking (SDN) paradigm. Here, traffic management is controlled by a centralized controller. More specifically, in the considered scenario, a controller is modeled with a queuing approach, and lightpath requests between source and destination node pairs are scheduled. The thorough evaluations show that the assigned lightpath can be increased with the proposed queuing based SDN model in Optical Networks.

Keywords: *Optical Networks, Traffic Management, SDN, Routing and Wavelength Assignment.*

SDN TABANLI OPTİK AĞLARDA TRAFİK YÖNETİMİ

ÖZ

Bu çalışma, optik ağlarda Yönlendirme ve Dalga Boyu Ataması (RWA) problemine odaklanmaktadır. Optik Ağlar, artan bant genişliği taleplerinin yerine getirilmesi için kritik öneme sahiptir ve kısıtlı ağ kaynakları nedeniyle gelen ışık yolu isteklerini yönetmek zordur. Bu problem çözümüne yönelik, Yazılım Tanımlı Ağ (SDN) paradigması ile optik ağlar için bir kuyruk teorisi temelli model önerilmiştir. Burada, trafik yönetimi bir denetleyici tarafından kontrol edilmektedir. Daha spesifik olarak, ele alınan senaryoda, merkezi bir kontrolör, kuyruk yaklaşımı ile modellenmiş, kaynak ve hedef düğüm çiftleri arasındaki ışık yolu talepleri planlanmıştır. Kapsamlı değerlendirmeler, ışık yolunun tesisinin optik ağlarda önerilen kuyruk teorisi yaklaşımı ve SDN paradigması ile geliştirilebileceğini göstermektedir.

Anahtar Kelimeler: *Optik Ağlar, Trafik Yönetimi, Yazılım Tabanlı Ağlar, Yönlendirme ve Dalga Boyu Ataması.*

1. INTRODUCTION

Optical Networks have a significant role in the operation of Internet, availability of the resilient and survivable communication services. Conventional optical networks assign a full wavelength to each traffic demand. This results in low utilization of the available spectrum since it is difficult to manage lightpath requests due to the lack of network resources.

Routing and Wavelength Assignment (RWA) arises as one of the fundamental designs and control problem in optical networks [1-3]. In the first step, a lightpath is set up and a route is determined. Then, a wavelength is assigned to the lightpath. If there is no available wavelength for the lightpath on the selected route, the connection request is blocked. This problem is more complicated than traditional routing problem [4-6] since routing and wavelength assignment is jointly considered. Optical networks are critical for handling increased bandwidth demands. The challenge is that the bandwidth on the lightpath is allocated for the connection until it is terminated. In addition, a wavelength is associated along the route. If there is no wavelength conversion, the lightpath occupies the same wavelength along the route. This results with inefficient utilization and increases the blocking probability.

To overcome this challenge, Software Defined Networking (SDN) is a promising solution with a programmable and flexible configuration. SDN enables to manage the topology with a centralized controller so that there is no need to change in the existing network infrastructure and the controller schedules the lightpath demands and controls the traffic.

Several works have studied the RWA problem in optical networks. For instance, based on the traffic arrivals, static and dynamic lightpath establishment [7] is considered. In static scenarios, traffic demand is fixed and known. Thus, the routes are predetermined for all lightpaths. The main objective is to manage the demands while minimizing the wavelengths. By contrast, in dynamic scenarios, the demands arrive one by one at random between source and destination node pairs and the aim is to minimize the blocking probability of demands. Although the RWA problem has been investigated, the solutions have been generally proposed to minimize the number of wavelengths [8]-[9]. SDN approach has not received the same attention.

Hence, the main objective of this paper is to set up lightpaths and then assign the wavelengths in order to minimize the amount of blocked connections and maximize the number of established connections with SDN paradigm. In the paper, a dynamic traffic pattern is considered. Here, the customers submit to the requests for lightpaths. According to the number of submitted requests at any time, network resources may not be sufficient to establish a lightpath between the corresponding source and destination node pairs. In this case, the request is blocked. To avoid the blocking scenario, the controller is modeled with a queuing model so that the requests are evaluated even if there is no available resource.

The rest of the paper is organized as follows: Section 2 describes the proposed SDN-based optical network architecture. Section 3 explains RWA scheme and queuing model. Section 4 evaluates the performance of the proposed model and finally Section 5 concludes the paper.

2. NETWORK ARCHITECTURE

The considered SDN-based optical network architecture has two main components: control plane and data plane as seen in Figure 1. OpenFlow protocol enables to communication between control plane and data plane.

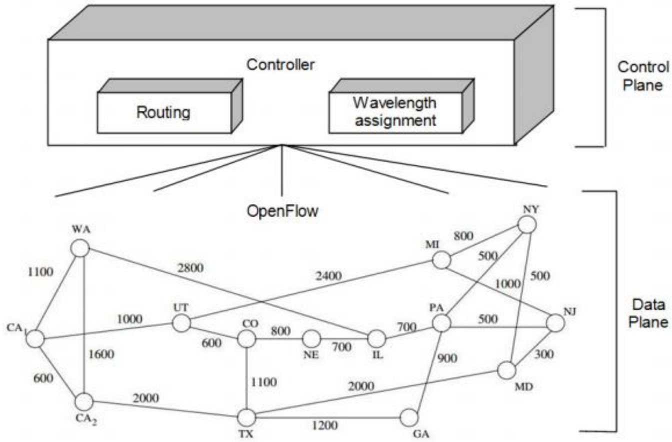


Figure 1. Proposed network architecture with SDN paradigm.

In optical networks, the amount of network resources is limited. Thus, a limited number of lightpath requests can be served at each time interval. In data plane, lighpath requests are created with a random fashion between source and destination node pairs. Control plane manages the lightpath requests between the corresponding node pairs. It enables low cost, improved operation, effective response to failures, and dynamic lightpath assignment to actual demand. The control plane executes two functions: (i) Routing and (ii) Wavelength Assignment.

Fixed and alternate paths are defined for each source-destination node pair by control plane. After the list of primary and secondary paths is created in a routing table, all wavelengths are ordered. Then, an appropriate path and wavelength for the requested lightpath are searched. Finally, if there is no available resource, the lightpath requests are waited in the queue in order to check the availability of the resources in the next time slot.

Moreover, depending on network status, two types of customers are determined.

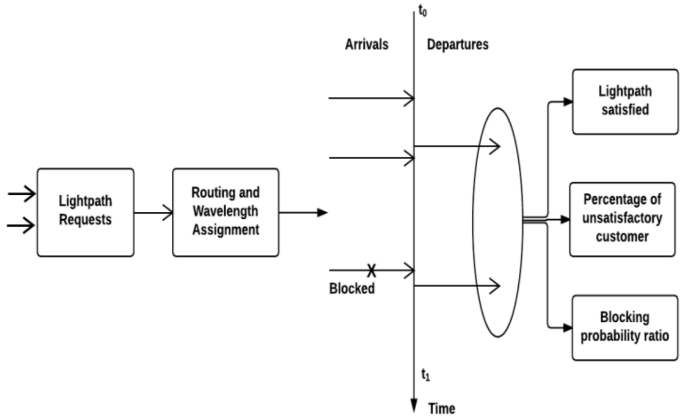
- *Unsatisfactory Customer:* According to the total number of requested lightpaths at node pairs, demands between source and destination are served with a limited manner. These customers are unsatisfactory customers. In particular, new coming demands can result with the degradation of the satisfaction of the customers due to the limited network resources.

- *Satisfied Customer:* The satisfied customers are those who can find an appropriate path and wavelength assignment between the corresponding source and destination.

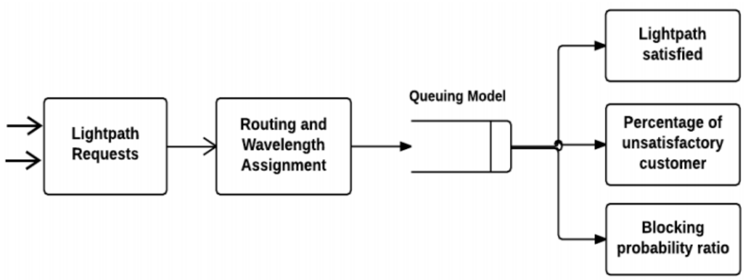
3. PROPOSED SCHEME

In the paper, two scenarios are considered to address RWA problem as seen in Figure 2.

- *Without queue:* Here, lightpath requests are considered in each time slot separately. When a request arrives at a time, available routing paths and wavelength assignments are defined spontaneously. However, if there is no available resource, the lightpath requests are dropped as seen in Figure 2(a). Moreover, when more ligthpaths are detected for the same routing path as available, one of them is randomly selected and the other ligthpaths requests are dropped.
- *With queue (with SDN paradigm):* Lightpath requests are modeled with M/M/1/K queuing model as seen in Figure 2(b). Here, at first, primary and secondary paths are checked for source and destination node pairs and then wavelengths are assigned. When the lightpath for the connection has been established, the network state is updated. However, if there is no available resource for lightpath requests, requests are waited in the queue to serve next slots by minimizing the amount of connection blocking.



(a)



(b)

Figure 2. (a) Proposed scheme without queuing approach (b) Proposed scheme with queuing model (with SDN paradigm).

3.1. Routing

Dijkstra's algorithm is a shortest path algorithm between source and destination node pairs. Each path is checked with minimum distance. Then a feasible solution is assigned to the first free wavelength with Dijkstra's algorithm. Path lengths are the sums of the link weights.

It is assumed that shortest path for each source-destination node pair is predetermined as fixed routing in the network topology. Then, a fixed alternate routing is established for each node pairs in the routing table. Note that this route does not share any links with primary route.

Moreover, it is assumed that there is link fault in the network and the wavelengths along the path are not tied up such that it will enable to prevent high blocking probabilities.

3.2. Wavelength Assignment

When lightpath requests arrive, lightpaths are assigned to the wavelengths. In the paper, it is assumed that the number of wavelengths is fixed, also assigned according to First-Fit. In this scheme, all wavelengths are numbered from 1 to W, where W is the maximum number of wavelengths supported on a fiber, and then wavelength list is ordered depending on wavelength number. Then, a free wavelength is found for the request. In every step, available lower-numbered wavelength is selected. Here, if the lightpaths share the same route, the wavelengths for these lightpaths are assigned differently.

The main objective of this scheme is to reduce the blocking probability in the network. Moreover, an advantage of this scheme is that it requires no global information so that the First-Fit does not introduce any communication overhead.

3.3. Queuing Model

M/M/1/K queuing model is considered to model the lightpath requests. K is the maximum number of lightpaths that is being waited in the system. The arrivals are independent of the number of lightpaths in the system and exponentially distributed. The service times are also assumed to be exponentially distributed and independent so that the mathematical calculations are traceable. Assigned lightpath, ψ, is determined as the ratio of total number of lightpaths that successfully served, L^B, to the number of entire requested lightpaths, L^S, at time interval t_0 and t_1, as given in Equation 1.

$$\psi = \frac{E(L^B)}{E(L^S)} 100 \qquad (1)$$

where

$$E(L^B) = 1 - \frac{1-\rho}{1-\rho^{K+1}} \tag{2}$$

and

$$E(L^S) = \sum_{i=0}^{K} nP_n \tag{3}$$

where ρ is the traffic intensity and $\rho = \lambda / \mu$. λ represents the lightpath arrival rate, and μ is service rate, n is the number of lightpaths.

$$P_n = \rho^n P_0 \tag{4}$$

where P_0 is the probability that there is a feasible path and wavelength for the requested lightpath as given in Equation 5.

$$P_0 = \frac{1-\rho}{1-\rho^{K+1}} \tag{5}$$

The number of requested lightpaths that waits in the queue is given in Equation 6.

$$E(L^q) = \sum_{i=0}^{K} (n-1)P_n \tag{6}$$

The ratio of total number the waited lightpaths in queue is as follows. Please note that this also represents to the ratio of unsatisfactory customers.

$$E(L^q) = \frac{\sum_{i=1}^{n} E(L^q)}{\sum_{i=1}^{n} n_i} 100 \tag{7}$$

The blocking probability of a customer can be expressed as follows:

$$P(n=K) = P_K = \frac{(1-\rho)\rho^K}{1-\rho^{K+1}} \tag{8}$$

4. PERFORMANCE EVALUATION

The performance of the proposed schemes, which are without queue and with queue (with SDN paradigm), is evaluated in this section. In the first approach, when a connection request arrives, if there is no available path or a wavelength assignment for a route, this request is blocked. However, in the SDN approach, the controller is responsible to manage optical network topology, establishes and schedules the lightpaths for node pairs.

Here, 14-node National Science Foundation Network (NSFNET) is employed as demonstrated in Figure 3. Each link contains 2 fibers, and each fiber supports 8 wavelengths. The capacity of a wavelength is assumed to be 10 Gbps. A dynamic traffic pattern is considered. Lightpath requests are created with a random fashion between source and destination node pairs.

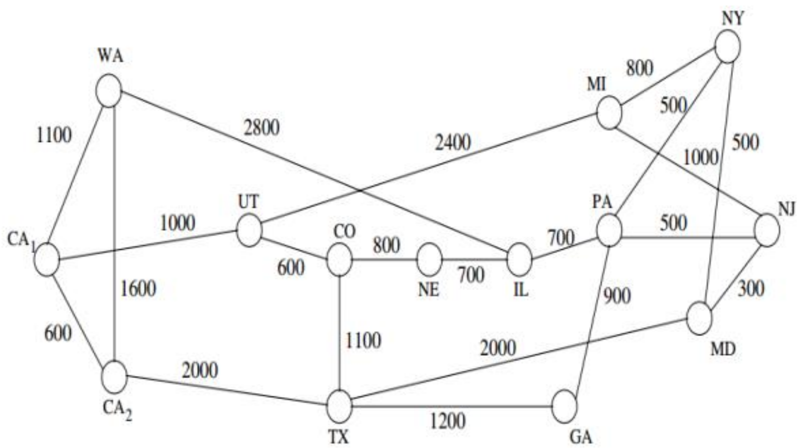


Figure 3. The 14-node NSFNET network topology showing approximate distances between the nodes in km.

In this respect, Figure 4 shows the assigned lightpath for different traffic loads. This is determined as the ratio of total number of lightpaths that successfully served to the number of all requested lightpaths.

As seen in Figure 4, SDN-based optical networks achieve more lightpath in each traffic load. The explanation for the observation is that if there is no available network resource, the requested lightpaths are waited and scheduled in the next time intervals with a centralized controller. Here, controller has the global information of the network so that it can manage the lightpaths. With SDN approach, the lightpath is approximately enhanced 6% in optical networks.

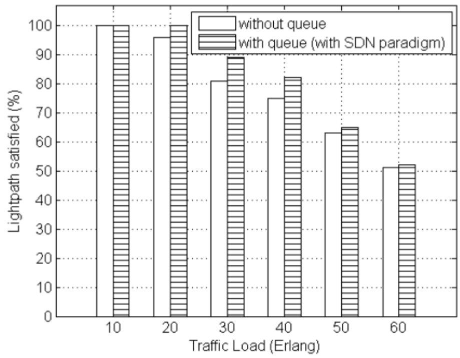


Figure 4. Lightpath satisfied w.r.t traffic load.

In addition, Figure 5 shows the ratio of total unsatisfactory customer in the optical network topology. Here, when there is no sufficient resource, lightpaths are waited in the queue to handle in the next time slots. This enables degradation in the ratio of unsatisfactory customers. Queuing model enables to serve more unsatisfactory customers when compared to without queuing model.

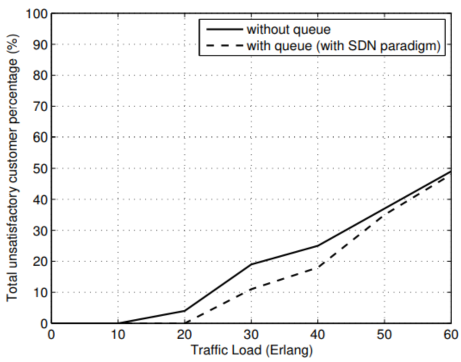


Figure 5. Total unsatisfactory customer percentage.

Figure 6 shows the blocking probability ratio. Here, unsatisfactory customers waiting in the queue are restricted in order to manage network resources. In the M/M/1/K model, K is maximum number of lightpaths that can be waited in the system. Here, SDN-based optical networks achieve better blocking probability performance under different traffic load. However, it is observed that when the traffic load increases, the performance of the SDN-based optical networks will show more slowly increase due to the high number of existing lightpaths in the topology. It can be seen that SDN-based optical networks achieve better performance when compared to conventional optical networks.

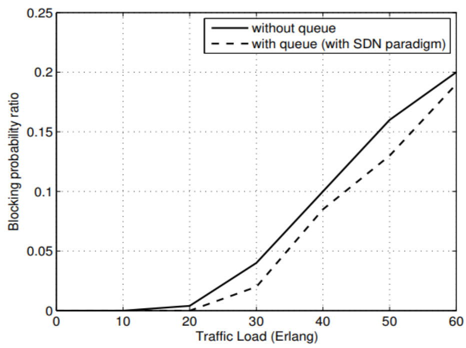


Figure 6. Blocking probability ratio w.r.t traffic load.

5. CONCLUSION

In this paper, the Routing and Wavelength Assignment problem is analyzed with SDN paradigm in optical networks. In order to enhance the assigned lightpath and decrease the blocking probability, SDN based queuing model is proposed. A centralized and programmable controller is modeled to manage all requested lightpaths in the topology. It is observed that SDN paradigm in optical networks is a suitable option to serve more customers. The ongoing work involves the effect of the dynamic traffic patterns for Optical Networks.

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