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Review and Performance Analysis on Routing and Wavelength Assignment Approaches for Optical Networks

Babeta Rawat, Ashish Kumar Gupta, Vartika Yadav

Abstract- This study focuses on the performance analysis on routing and wavelength assignment approaches for optical networks. In today's life Internet traffic is being increasing tremendously so, routing &wavelength assignment is the most challenging job in wavelength routed optical networks to provide end-users best facilities in lesser time. Another most important issue in optical networks is callblocking & it is directly proportional to the number of connection requests i.e. callblocking increases with the increase in number of connection requests due to the limited number of wavelength channels in each fiber link. Different conventional RWA approaches in the wavelength routed optical networks and there comparison with the proposed priority-based RWA (PRWA) scheme under wavelength continuity constraint in terms of blocking probability is been discussed in this paper.

Keywords- Blocking Probability**,** callblocking, Lightpath, optical network, priority order, routing, wavelength assignment

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1 INTRODUCTION

IN optical fiber networks Wavelength division multiplexing (WDM) technology has been improving rapidly in recent past years to serve as many as end users by effective utilization of bandwidth available on the network. End users communication with each other through all optical WDM channels which are known as lightpaths. If no wavelength conversion is available, then a light path must be assigned the same wavelength on all the links in its route; this property is known as wavelength continuity constraint. Fig. 1[1] shows the establishment of lightpaths between source-destination (s-d) pairs on different wavelengths in a wavelength-routed optical network. In the fig.1 each lightpath uses the same wavelength on all hops in the end-to-end path due to its wavelength continuity constraint. The connection requests (A-C) and (B-F) use different wavelength λ_1 and λ_2 because they use the common fiber link 6-7; this property is known as Distinct Channel Constant. The connection requests (H-G) and (D-E) use the same wavelength λ_1 that is already used by the connection request (A-C) due to a wavelength reuse characteristic.

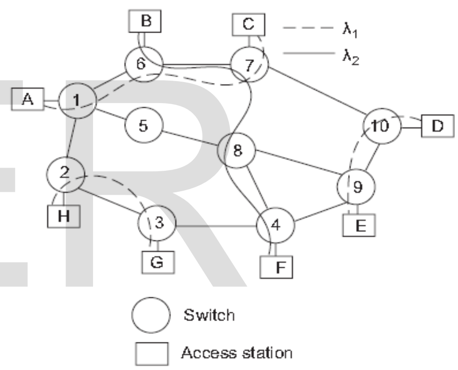


Fig1: A wavelength routed optical network [1]

Given a set of connection requests, the establishment of lightpaths by routing and assigning a wavelength to each connection is called Routing and Wavelength Assignment (RWA) problem. In the following section we discussed some of the important issues of RWA problem [1].

Rest of the paper covers the following sections.

Section2 discusses the routing and wavelength assignment (RWA) problem. The routing problems are presented in section3 and section4 focuses on various existing WA approaches. The proposed priority-based RWA (PRWA) scheme is presented in section 5. And finally, section 6 concludes the paper.

2. THE ROUTING AND WAVELENGTH ASSIGNMENT (RWA) PROBLEM

In the RWA problem, we consider a lightpath topology and a set of end-to-end light path requests. Then we determine route and wavelengths for the request using minimum number of wavelengths. There are mainly three types of traffic are considered in RWA problem, namely: (i) static traffic, (ii) incremental traffic and (iii) dynamic traffic [1]. These RWA problems are discussed in the following subsections.

2.1 Static Lightpath Establishment

Static routing and wavelength assignment problem is also known as the Static Lightpath Establishment (SLE) problem. In it a route is selected for each source destination pair of nodes in the network. The route are fixed they may only change if there is a change in the topology of the network. In other words, in the static traffic it is assumed that the entire traffic connection requests are known in advance and the lightpaths are established to satisfy the maximum numbers of traffic requests. Again, the SLE problem can be classified into two sub problems namely (i) routing and (ii) WA [1].

2.2 Dynamic Lightpath Establishment (DLE)

In DLE, light path are established (dynamically) in real time without the knowledge of future lightpath provisioning events & predetermined routes. After certain time the connection is not required & the lightpath is removed. Similar as SLE, the DLE problem can also be decomposed into two sub problems, namely (i) Routing and (ii) WA [1].

3. Routing

In most of the situation packet will require multiple hops to make journey towards the destination station for that we use routing. To find the routes between source and destination is known as routing. In other words, routing refers to the way routing tables are created to help in forwarding. Generally routing are of four types, namely (i) Fixed Routing (FR) (ii) Fixed Alternate Routing (FAR), (iii) Adaptive Routing (AR) and (iv) Least Congested Routing (LCR). Among these approaches, FR is the simplest but AR gives the best performance [1].

3.1 Fixed Routing (FR)

A route is selected for each source destination pair of nodes in the network. The route are fixed they may only change if there is a change in the topology of the network. Fixed routing is implemented using routing table. A cost is associated with each link. The simplest criterion is to choose the minimum hops through the network. A generalization is least cost routing. Several well known algorithms exist to obtain the optimum path such as, Dijkstras's algorithm and Bellman ford algorithm.

3.2 Fixed Alternate Routing

A form of routing that considers multiple routes is fixed-alternate routing. It is an updated version of the FR algorithm. Like, fixed routing there is requirement of routing table at each node. Fixed alternated routing has an advantage that it improves the blocking performance of the networks.

3.3 Adaptive Routing

The performance of Adaptive Routing (AR) algorithm is best among routing algorithms in terms of BP. In it routing decision change as conditions on the network changed. Two principle conditions that affect routing decision are: (i) Failure; when a node or trunk fails it can no longer be used as a part of the route and (ii) Congestion; when a particular portion of the network become heavily congested it is desirable to route packets around the area of congestion.

For adaptive routing to be possible network state information must be exchanged among the nodes.

More information exchange $\Rightarrow$ better routing $\Rightarrow$ more over head.

3.4 Least Congested Routing

In Least Congested Routing (LCR), sequence of routes is predetermined for each source-destination pair. Depending upon the arrival of a connection request the least-congested route is selected among the predetermined routes. The congestion on a link is measured by the number of wavelengths available on the link. If the link has fewer available wavelengths, it is considered to be more congested. The disadvantage of LCR is higher computation complexity and its BP is almost same as FAR [1].

4. Wavelength Assignment

A wavelength selection mechanism is used to select the best wavelength if multiple required wavelengths are available on the entire route between a source-destination pair. The wavelength selection may be performed either after a path has been determined, or in parallel during the path selection [1]. For optimal performance of the network it is important to select the best wavelength.

The wavelength assignment must obey two constraints: (1) Two light paths must not be assigned to the same wavelength on a given link. (2) If no wavelength conversion is available, then a light path must be assigned the same wavelength on all the links in its route. A number of heuristics have been proposed for optimal performance of the network. Some significant heuristics such as First-Fit, Least used and Most Used wavelength assignment, are discussed in the following subsections [1].

4.1 First-Fit

In first-fit, all the wavelengths are indexed, and a lightpath is used to select the wavelength with the lowest index before attempting to select a wavelength with a higher index. By selecting wavelengths in this manner, existing connections will be packed into a smaller number of total wavelengths, leaving a larger number of wavelengths available for longer ligthspaths [4].

4.2 Least-Used (LU)/SPREAD

As the name implies in Least-Used scheme it spread the traffic evenly to all the wavelengths by selecting the wavelength which is least-used, thus it balances the load among all the wavelengths. The major disadvantages of this scheme is that its performance is poor than Random, require global knowledge, additional storage & computation cost [3, 4].

4.3 Most-Used (MU)

In MU wavelength assignment, the wavelength which is the most used in the rest of the network is selected. In other words we can say that it is the opposite of LU. It outperforms LU significantly. Like LU requirement of global knowledge, additional storage & computation cost are also some major disadvantages of it [4].

5. Proposed Priority-based Routing and Wavelength Assignment [1]

For reducing the Blocking Probability in the network, a proposed PRWA scheme is used to serve the connection requests for RWA approach according to their priority order. The priority order of each connection request is estimated based on the following two criteria: (i) types of path and (ii) volume of traffic. Using these criteria direct or indirect link (type of path) is ordered in the descending order of their traffic volume. The main objective is to reduce the overall BP & hence enhance the capacity of optical network. For this, we consider type of path and traffic volume as the criteria for priority ordering of connection requests, which is required due to the wavelength continuity constraint of the network. The main requirement of the wavelength continuity constraint is to use the same wavelength on all hops in the end to end path of a connection. If we use conventional RWA approach under the wavelength continuity constrain may lead to a situation where wavelengths may be available, but connection requests cannot be established due to unavailability to the required wavelengths. Therefore, if the priority order of connection requests is estimated using these criteria, blocking of connection requests due to the wavelength continuity constraint can be reduced to a great extent, which will in turn lead to better performance of the network in terms of lower BP.

The overall concept of proposed PRWA scheme is shown in Fig. 3. Randomly connection requests arrive at the system based on Poisson process. Then, all the connection requests are en-queued into the Priority Queue to estimate their priority order. Finally, connection requests are served for RWA approach according to their priority order. If the connection request is not sewed within the holding time (t_H), it is treated as a blocked connection. The details procedures of the proposed scheme are given in Algorithm 1 and the functionality of the algorithm is explained with the following example.

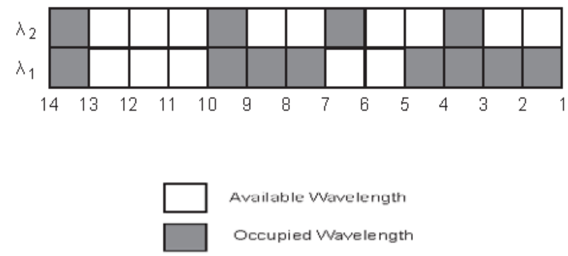


Fig2. Wavelength-usage pattern for a network segment [1]

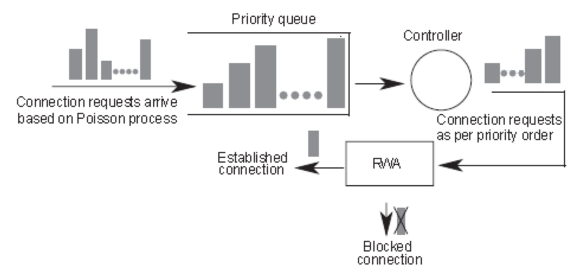


Fig3. Concept of proposed scheme [1]

Table 1 Details of different wavelength assignment schemes [1]

Problem	Approach	Performance analysis		Applicable network
		Blocking probability	Time complexity	
WA+FR	MAX SUM	In multi-fiber, MS outperforms when load is high	0(L1 W N3 Z)	Single/multi-fiber networks
	Relative capacity loss	In single fiber, RCL performs well when load is high	0(L1 W N3 Z)	Single/multi-fiber networks
	Min product	MP performs well under low load	0(L1 M N W Z)	Normally used in multi-fiber networks
	Least loaded	LL performs well under high load	0(L1 M N W Z)	Normally used in multi-fiber networks
	Least used	LU perform well under high load	0(L1 M N W Z)	Single/multi-fiber networks
	Most used	MU perform well under low load	0(L1 L2 W Z)	Single/multi-fiber networks
	Random	More BP than FF but almost close	0(L1 W Z)	Single/multi-fiber networks
	First fit	Less BP among LU, MU, R	0(L1 W Z)	Single/multi-fiber networks

L1, L2, M. N. W and Z are the length of the longest fiexed route for any node pair, total number of links in the network, total number of fibers in the network, total numbers of nodes in the network, number of wavelengths per fiber link, and *total number of connection requests, respectively; WA+FR- wavelength assignment +fixed routing; MS- Max sum; RCL- Relative capacity loss; MP- Min product; LL- Least loaded; LU- Least used; MU- Most used; R- Random; BP- Blocking probability; FF- First fit*

5.1 Example [1]

For the example purpose, we consider the NSFNFT [Fig. 4] and also assume a few connection requests that are shown in Table 2. According to Algorithm 1, two clustered order sets of connect ion re requests (R′ and R″) are estimated such that R′={ rWA,CA2, rWA,CA1, rWA,IL } and R″={ rWA,NY, rWA,NE, rWA,GA, rWA,UT, rWA,NJ, rWA,PA, rWA,MI, rWA,TX, rWA,CO }. Then, the priority order of each connection request is estimated and is given in Table 3. Finally, connection requests are served for RWA approach according to their priority order.

Algorithm 1: Priority-based RWA (PRWA) [1]

Input Network configuration and set of connection requests Output Wavelengths assignment with total number of successful and unsuccessful connections in the network

Step1 En-queue all the connection requests in the priority queue to estimate their priority order

Step2 Cluster all the connection requests into two categories, such as direct physical link connection requests and indirect physical link connection request.

R′= $\{r_{D,1}^{s_1,d_1}, r_{D,2}^{s_2,d_2}, \cdots, r_{D,X}^{s_X,d_X}\}$

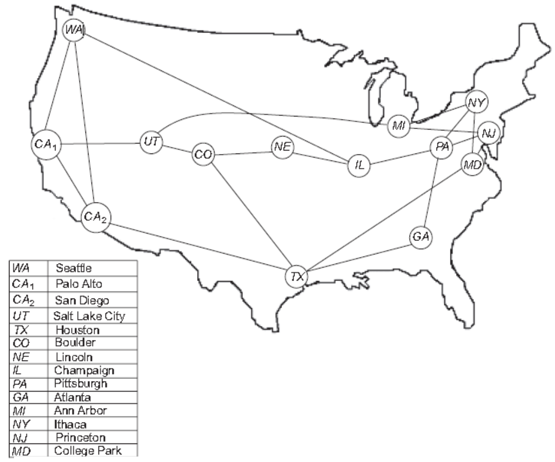
R″= $\{r_{I,1}^{s_1,d_1}, r_{I,2}^{s_2,d_2}, \cdots, r_{I,Y}^{s_Y,d_Y}\}$

Such that

$$Vol(r_{D,1}^{s_1,d_1}) \geq Vol(r_{D,2}^{s_2,d_2}) \geq \cdots \geq Vol(r_{D,X}^{s_X,d_X})$$

$$Vol(r_{I,1}^{s_1,d_1}) \geq Vol(r_{I,2}^{s_2,d_2}) \geq \cdots \geq Vol(r_{I,Y}^{s_Y,d_Y})$$

where, R′ and R″ are the two ordered set of connection requests having direct and indirect physical link, respectively X and Y are the total number of connection



Distance matrix

	WA	CA1	CA2	UT	CO	TX	NE	IL	PA	GA	MI	NY	NJ	MD
WA	0	1350	2021	0	0	0	0	3482	0	0	0	0	0	0
CA1	1350	0	766	1229	0	0	0	0	0	0	0	0	0	0
CA2	2021	766	0	0	0	2364	0	0	0	0	0	0	0	0
UT	0	1229	0	0	862	0	0	0	0	0	2613	0	0	0
CO	0	0	0	862	0	1712	736	0	0	0	2000	0	0	0
TX	0	0	2364	0	1712	0	0	0	0	1276	0	0	0	2286
NE	0	0	0	0	736	0	0	719	0	0	0	0	0	0
IL	3482	0	0	0	0	0	719	0	787	0	0	0	0	0
PA	0	0	0	0	0	0	0	787	0	1101	0	571	542	0
GA	0	0	0	0	0	1276	0	0	1101	0	0	0	0	0
MI	0	0	0	2613	2000	0	0	0	0	0	0	798	988	0
NY	0	0	0	0	0	0	0	0	571	0	798	0	0	549
NJ	0	0	0	0	0	0	0	0	542	0	988	0	0	282
MD	0	0	0	0	0	2286	0	0	0	0	0	549	282	0

Fig4. NSFNET and its distance matrix [1]

TABLE 2 CONNECTION REQUESTS WITH THEIR TRAFFIC VOLUME [1]

Connection requests	Traffic (Kbps)	Connection requests	Traffic (Kbps)	Connection requests	Traffic (Kbps)
$r_{WA,CA1}$	2,000	$r_{WA,CA2}$	3,000	$r_{WA,UT}$	40,000
$r_{WA,CO}$	20,000	$r_{WA,TX}$	22,000	$r_{WA,NE}$	48,000
$r_{WA,IL}$	300	$r_{WA,PA}$	25,000	$r_{WA,GA}$	45,000
$r_{WA,MI}$	24,000	$r_{WA,NY}$	70,000	$r_{WA,NJ}$	30,000

TABLE 3 CONNECTION REQUESTS WITH THEIR PRIORITY ORDER [1]

Connection requests	Priority order	Connection requests	Priority order	Connection requests	Priority order
$r_{WA,CA2}$	1st	$r_{WA,CA1}$	2nd	$r_{WA,IL}$	3rd
$r_{WA,NY}$	4th	$r_{WA,NE}$	5th	$r_{WA,GA}$	6th
$r_{WA,UT}$	7th	$r_{WA,NJ}$	8th	$r_{WA,PA}$	9th
$r_{WA,MT}$	10th	$r_{WA,TX}$	11th	$r_{WA,CO}$	12th

requests having direct and indirect physical link, respectively. The priority order of each connection request is assigned according to their positions either in R′ or R″. Connection requests in R′ have higher priorities compared to connection in R″. $Vol(r_{D,i}^{S_i,d_i})$ and $Vol(r_{I,i}^{S_i,d_i})$ indicate the volume of traffic for the connection request of $r_{D,i}^{S_i,d_i}$ and $r_{I,i}^{S_i,d_i}$, respectively.

Step 3: Compute K numbers of shortest paths (including primary path) using Dijkstra's algorithm for each of the connection request on the basis of link state information.

Step 4: For each of the connection request in R′ and R″, selected based on their priority order, perform the following in the given sequence:

- First, try to assign a wavelength according to wavelength constraints to the primary path based on First-Fit method.
- If no WA is possible in step 4(a), consider the alternate paths in the ascending order of their lightpath distance for assigning a wavelength (with similar constraint on wavelength like in step 4(a)) till one alternate path is assigned a wavelength.
- If no WA is possible either in step 4(a) or step 4(b) within t_H, the connection request is treated as blocked one. Otherwise, add the established connection to the total number of established connections in the network.
- Drop the connection request from the network.

5.2 Assumptions [1]

1. Equal number of wavelengths are carried b each fiber link and the network is without wavelength conversion capabilities
2. Distinct wavelengths are allocated to all the lightpaths using the same fiber link
3. Each node can work as both an access node and a routing node
4. A fixed number of tunable transceivers are equipped with each node
5. All the channels have the same bandwidth
6. The connection requests arrive in the system randomly based on a Poisson process
7. The holding time of the connection requests is exponentially distributed and we assume the same holding time for all the connection requests having the same s-d pairs for the sake of simplicity. However, differences in holding times for connection requests can be handled by taking their maximum as the holding line for all the traffic with the same s-d pairs.

6. CONCLUSION

In this paper, we have discussed different types of traffics in the RWA problem & different types of conventional routing & wavelength assignment approaches in wavelength routed optical networks. The proper PRWA scheme is then compared with conventional RWA approaches in the wavelength routed optical networks with the help of an example & algorithm. PRWA scheme trade-off between BP and average setup time gives the better performance in terms of BP and average setup time [1].

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- *Babeta Rawat and Ashish Kumar Gupta are currently pursuing Bachelor degree program in Electronics and Communication Engineering in Naraina College Of Engineering & Technology (Gautam Buddh Technical University), India, PH-05122261402, E-mail: babitarawat.jan@gmail.com, ashishkg.jan@gmail.com*
- *Vartika Yadav is also currently pursuing Bachelor degree program in Electronics and Communication Engineering in Naraina College Of Engineering & Technology(Gautam Buddh Technical University), India, E-mail: vartikayadav.in@gmail.com*

Babeta Rawat

Ashish Kumar Gupta

Vartika Yadav