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Impairment Aware RWA based on a K-Shuffle Edge-Disjoint Path Solution (IA-KS-EDP)

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Abstract: We propose an IA-RWA algorithm called IA-KS-EDP, which evaluates multiple routing combinations considering the effects of OSNR, CD, PMD and using edge-disjoint paths to satisfy multi-line-rate traffic demands with minimum wavelengths.

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1. Introduction

With the advancements in optical switching technologies and multi-degree ROADM architectures, the transport networks are moving towards all-optical (i.e., transparent) networks. However, due to non-ideal properties of optical components, the Physical Layer Impairments (PLIs) accumulate along an optical-path in the absence of OEO regeneration. Optical amplifiers introduce Amplified Spontaneous Emission (ASE) noise, which degrades the OSNR of the signal. Higher line-rate channels also suffer from Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD) leading to Inter Symbol Interference (ISI). These PLIs degrade the signal quality leading to high BER. Hence, we need to consider the effects of PLIs in the Routing and Wavelength Assignment (RWA) solution.

In this paper, we propose an RWA algorithm called as Impairment Aware K-Shuffle Edge-Disjoint Path (*IA-KS-EDP*) where routing is based on our earlier *K*-shuffle Edge-Disjoint Path (EDP) pool approach (*KS-EDP*) [2]. In KS-EDP, we consider edge-disjoint paths for routing different connections, which significantly reduces the total number of wavelengths required to satisfy the given set of connections. We consider *K* different EDP routing combinations by shuffling the connection-list *K* times, each time picking up the random sequence of connections. This increases the chance of selecting an optimal routing combination. The wavelength assignment algorithm is a variation of First-Fit approach [3], which considers the possible sharing of Add-Drop Multiplexing (ADM) cards and transponders at a node. This leads to efficient usage of the network equipment. In this paper, we extend our work on KS-EDP algorithm [2] and *consider PMD and OSNR limits in the routing decision on multi-line-rate demands*. The connections that are unable to satisfy these limits are blocked. The routing combination is selected based on the least blocking probability.

2. Problem Statement and High Level Solution

We consider the RWA problem in mesh topologies with limited number of available wavelengths and no converters and assume that the static traffic demands are given a-priori. The problem statement is as follows: a network graph *G (V, E, T)* is given; where *V* is the set of nodes, *E* is the set of bidirectional optical links, and *T* is a traffic matrix. Every T_{ij} is a connection between source *i* and destination *j*, which can have multiple traffic demands of different line-rates. $T_{ij}^{k} (\geq 0)$ is the number of traffic demands of granularity *k* for the connection T_{ij}. Each traffic demand of granularity *k* requires equivalent capacity wavelength along the route. We let *k* be one of the different granularities amongst 1Gbps, 2.5Gbps, 10Gbps, and 40Gbps, selected based on a given traffic distribution. The objective is to minimize the blocking probability and the number of wavelengths required to satisfy all the traffic demands.

The classical RWA problem does not assume any power loss at the optical components such as fiber loss, insertion and pass-through loss of the nodes as well as neglects ASE noise and dispersion. In our Impairment Aware RWA solution, we consider the ASE noise effects to the OSNR, as the predominant contributor to OSNR degradation. The OSNR for an amplifier stage is calculated as: $OSNR_{stage} = \frac{P_{in}}{NF \times h \times \nu \times \nabla f}$ and the OSNR at the receiver node is calculated as: $\frac{1}{OSNR_{final}} = \frac{1}{OSNR_{stage\,1}} + \frac{1}{OSNR_{stage\,2}} + \cdots + \frac{1}{OSNR_{stage\,n}}$[4].

In addition, we also consider Chromatic dispersion (CD) and Polarization Mode Dispersion (PMD) introduced in signals of line-rate $\geq$ 10 Gbps. CD is calculated as: $CD = CD_{constant} \times L_{link}$ and PMD for a link is calculated as $PMD_{link} = PMD_{constant} \times \sqrt{L_{link}}$. PMD of the lightpath is calculated as $\sqrt{\sum (PMD_{link})^2}$ [1]. We assume the same link model as considered in [1] for OSNR, CD and PMD calculation. The in-line amplifiers and DCUs are placed on the fiber links to fully compensate for the power loss and CD. However, due to the absence of efficient in-line PMD compensation techniques, lightpaths that do not satisfy the PMD thresholds are blocked, though some electronic compensation is assumed at the receiver. Every demand has a line-rate dependent threshold for OSNR and PMD (Table 1). The demands that do not satisfy either OSNR or PMD threshold are blocked and considered as the *impairment blocked* (I_b). The number of demands blocked due to the unavailability of wavelength is counted as *wavelength blocking* (W_b). The *total blocking probability* (*Bp*) for a routing combination is the sum of the *impairment blocking* and *wavelength blocking*. The optimal routing combination is selected based on the least *Bp.*

3. Algorithms and Explanation

In this Section, we present a primer on the K-shuffle EDP (KS-EDP) algorithm and then present two Impairment Aware RWA algorithms called IA-RWA-Simple and IA-KS-EDP. The IA-RWA-Simple is a greedy algorithm and IA-KS-EDP algorithm is based on our KS-EDP algorithm [2] which performs better than IA-RWA-Simple.

***K-Shuffle Edge-Disjoint Path Algorithm (KS-EDP)*:** This algorithm takes the list of connections and set of all paths for each connection as input. We maintain a data structure called *EDP Pool* to store the selected routes for each connection. For the first connection c_1, since the *EDP pool* is empty, a shortest path p_1 is picked from the set of paths of c_1 and is added to the *EDP pool*. If c_1 requires protection, then another shortest path is added to the EDP pool such that it is completely edge disjoint from p_1. The other connections are chosen in random sequence and a shortest path is picked, such that it is maximum edge disjoint with all the paths in the *EDP pool*. The chosen path is added to the *EDP pool*. Thus, the *EDP pool* contains all the maximum edge-disjoint paths which satisfy all the connection demands. Each EDP pool is a complete routing combination. We then shuffle the connection list and repeat the above procedure *K* times to generate *K* different routing combinations. Shuffling the connection list and generating K routing combinations, increases the chance of getting the optimal routing combination.

IA-RWA-Simple Algorithm:
```
for each C_i in connections
    allpaths = findAllpaths(C_i)
    for each P_j in allpaths
        find impairment blocking (P_j)
    endfor
    P_i = shortest path with the least impairment blocking
endfor
R = {P_1,P_2,...,P_n}
perform wavelength assignment for R
Bp(R) =calculate blocking probability for R
return R
```

Algorithm 1: IA-RWA-Simple

IA-KS-EDP Algorithm:
```
for each C_i in connections
    allpaths = findAllpaths(C_i)
    for each p_j in allpaths
        find impairment blocking(p_j)
    endfor
    P_i = all paths having the same least impairment blocking
endfor
path_sets = {P_1,P_2,P_3,.....,P_n}
R = KS-EDP(path_sets)
for each R_i in R
    perform wavelength assignment for R_i
    Bp(R_i) = calculate blocking probability for R_i
    if (Bp(R_i) < Min_Bp)
        Min_Bp = Bp(R_i)
        final_R = R_i
    endif
endfor
return final_R
```

Algorithm 2: IA-KS-EDP

***IA-RWA Algorithm 1 (IA-RWA-Simple)*:** This algorithm (shown in Algorithm 1 above), finds all the paths for each connection in the given list of connections. This path vector of each connection is then passed to the *impairment blocking* estimator function. This function calculates the *impairment blocking* (I_b) for each path. The path with the least I_b is selected for routing the connection. For more than one path having the same least I_b, the shortest path amongst them is selected. The routing combination with selected paths is then processed by wavelength assignment algorithm which blocks the demands due to unavailability of wavelengths. Finally, the *total blocking probability (Bp)* is calculated.

***IA-RWA Algorithm 2 (IA-KS-EDP)*:** This algorithm (shown in Algorithm 2 above) is similar to IA-RWA-Simple algorithm but instead of selecting only one path with least I_b, we select all the paths with the same least I_b for that connection. We construct a set called *path_sets* which contains the set of paths for each connection. The *path_sets* along with the list of connections is then passed to our KS-EDP algorithm. The KS-EDP algorithm then finds *K* different routing combinations with each combination having the maximum edge-disjoint paths. Each routing combination is then processed by the wavelength assignment algorithm and the *total blocking probability* (*Bp*) is calculated. The best routing combination is chosen based on the least *Bp* as shown in Algorithm 2.

4. Simulations and Results

We now compare the performance results of IA-KS-EDP algorithm with the IA-RWA-Simple. The standard NSFNET (14 nodes, 21 edges) topology (Fig. 1) is considered for the simulation with modified distances as shown in Fig. 1. Using this topology, we can have a maximum of 182 unidirectional connections.

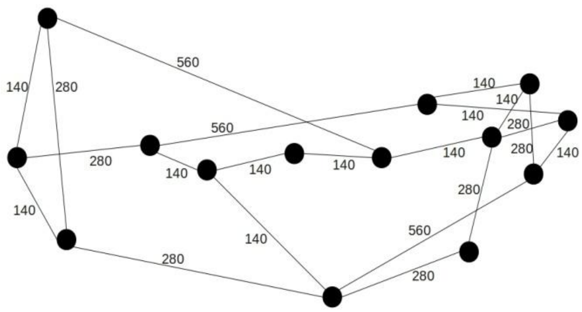

Fig. 1: Standard NSFNET topology (scaled down by 1:5)

Amplifier gain Amplifier NF	30 dB 4 dB
Node Insertion Loss Node Pass-through Loss Node Drop Loss DCU Loss	8 dB 12 dB 5.5 dB 6 dB
SMF Attenuation Factor SMF CD Constant SMF PMD Constant	0.2 dB/Km 17 ps/nm-km (0.06 or 0.08 or 0.1) ps/$\sqrt{km}$
CD Thresholds	40 Gbps:320 ps/nm , 10 GBps:1700 ps/nm, < 10Gbps: not considered
OSNR Thresholds	40 Gbps: 29 dB, 10 Gbps:26 dB, 2.5 Gbps: 19 dB, 1 Gbps: 15 dB
PMD Thresholds	40 Gbps: 2.5 ps , 10 Gbps:10 ps, < 10Gbps: not considered

Table 1: Equipment Parameters

The static connections are randomly generated based on the connection probability (*Cp*). Each connection has 3-demands which are randomly chosen from the set of granularities: 1Gbps, 2.5Gbps, 10Gbps, and 40Gbps. The overall distribution of demands across the network is as follows: 10% of the total demands are at 40Gbps, 40% at 10Gbps, 20% at 2.5Gbps, and the rest are at 1Gbps line-rates. This kind of multi-line-rate traffic distribution resembles the traffic scenario in contemporary networks. The number of wavelengths available per link is assumed to be 40. The demands that require wavelength beyond this number are blocked. However, we still count the number of wavelengths required for zero-*wavelength blocking* (W_b). Table 1 shows the values of various equipment parameters and thresholds considered in the simulation. The CD constant is assumed to be the same for all the fiber links, but the PMD constant is randomly chosen for each link, (see Table 1). An average over 200 experiments for each *Cp* value was considered.

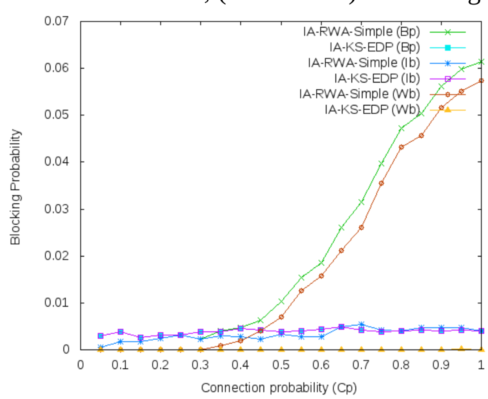

Fig 2: Comparison of Blocking Probability (*Bp*)

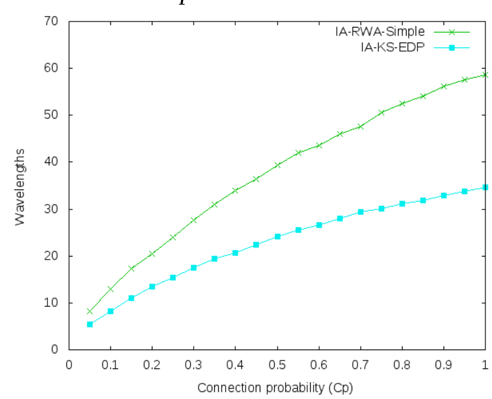

Fig3: Comparison of Wavelengths required for $W_b = 0$

The IA-KS-EDP and IA-RWA-Simple performs almost similar in terms of *impairment blocking* as shown in Fig. 2. *However, the total blocking probability of IA-RWA-Simple is significantly more than IA-KS-EDP for higher load which is due to the wavelength blocking*. IA-RWA-Simple requires significantly more wavelengths than IA-KS-EDP for W_b= 0 as shown in Fig. 3. This is because IA-RWA-Simple is a greedy solution and does not consider the efficient utilization of wavelengths while KS-EDP (within IA-KS-EDP) helps reducing the wavelengths required. The IA-KS-EDP is better than IA-RWA-Simple in terms of total blocking and the number of wavelengths.

4. Conclusion

A solution to Impairment Aware RWA problem is presented. The important PLIs such as ASE noise, CD, and PMD are considered during the routing decision subject to OSNR thresholds. The proposed IA-KS-EDP algorithm is shown to perform better than that of IA-RWA-Simple through extensive simulations.

5. References

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