BALANCING NETWORK LOAD BY IMPLANTING LABELS TO DATA CENTERS IN DYNAMİC SDM-EONS

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Abstract
Data center placement in a network plays a vital role for different online applications like VoIP, cloud computing, etc. However, disasters can affect their functionality leading to huge disruption in service. Not only this, network load balancing is another major concern nowadays, the improper management of which can hamper the network throughput and quality of service. In this paper, a new routing, spectrum and core allocation (RSCA) heuristic has been developed to balance the network load by imposing labels to the data centers based on their usage in dynamic space division multiplexing-based elastic optical network (SDM-EON). In this context, two data center selection strategies are introduced which are tested and analysed on two well-known topologies against different parameters, proving their efficacy over each other.

Keywords:
SDM-EON, RSCA, Data Center, Dynamic, Network Load

1. INTRODUCTION

Elastic optical network (EON) due to efficient data transmission capability, has emerged as one of the backbone technologies in optical communication systems [1]. It subdivides the fiber capacity into variable sized slots called spectrum, with each slot having granularity of about 12.5 Gbps. Applications like cloud computing, video conferencing, etc. make use of this technology for swift transmission of network traffic.

The main purpose of EON is to allocate route and spectrum to any connection request-may be static or dynamic. A static or offline connection is already known by the system and is served accordingly. A dynamic or online connection request arrives randomly into the network, gets placed or blocked based on the network status [2]. The routing and spectrum allocation (RSA) problem is to assign proper route and spectrum to a connection request by trying to minimize both blocking probability as well as resource utilization of the network. Spectrum assigned to the connection should be contiguous and is placed at same position of each link of the selected route. To avoid interference between different signals, guardband slots are assigned between them [3].

The capacity of EON is further risen by technically de-signing the architecture of the network. This introduces the addition of multiple cores within a fiber route leading to an increase in the spatial capacity of the fibers. The technology is known as space division multiplexing-based elastic optical network (SDM-EON) [4]. However, allocating spectrum among adjacent core for similar signals cause hindrance, giving birth to inter-core crosstalk. Thus, routing, spectrum and core allocation (RSCA) besides considering inter-core crosstalk is a major issue in SDM-EONs.

The connection requests in SDM-EON arrive, they search for some file, receive them and then departs. They access the files from various data centers, placed in the network. A data center (DC) is physical location where around trillions of data are stored and during any need, the files are served from it [5]. However, the DCs are prone to various calamities, may be a natural disaster or any man-made activity, causing tremendous data loss. In this context, a data center is said to be active if it is not damaged due to any disaster or man-made activities. A DC can also be non-functional if it remains busy for a prolonged period of time. Thus, placement and load distribution of data centers are two important concerns to be taken care of.

Resource management also plays a vital role in the network. The more the resource utilization, the efficient is the network. To increase the throughput and quality of service, the network load needs to be balanced and this happens when the data centers are uniformly used for file access.

The proposed work defines a new heuristic, DS-RSCA which tries to balance the network load by implanting various labels to the data centers located in the dynamic SDM-EON. An RSCA has been developed whose objective is to improve network resource utilization by decreasing connection blocking probability. Two different DC-selection strategies are introduced following by a suitable route and core selection and resource allocation scheme. Extensive simulation on two large known SDM-EONs prove the competency of DS-RSCA against different benchmarks like rate of resource occupation, blocking ratio and load distribution factor of DCs.

2. LITERATURE STUDY

Khatiri et al. [6] studied the issues related to virtual network functions (VNFs) and RSA of inter-DC EONs with the objective of balancing resource utilization by reducing network cost and blocking probability. Page et al. [7] proposed various optimal and sub-optimal techniques on resource disaggregation to estimate the capacity required to support VDC demands. Lin et al. [8] introduced a software-defined networking (SDN)-based optical DC network for flexible QoS provisioning of multi-tenant applications. Khatiri et al. [9] developed a new solution called CELFA to address the problems of VNF service chain deployment in order to reduce resource cost and spectrum fragmentation by balancing the resource utilization in EONs. Yang et al. [10] proposed a multipath protection technique for DC services and experimentally demonstrated it in OpenFlow-based software defined EON to ensure reliability. Maswood et al. [11] addressed the problems related to the allocation of DC resources to cloud enterprise customers who on demand require guaranteed service.

Yang et al. [12] developed a cross stratum resilience architecture for OpenFlow-based DC interconnection with Flexi-

Grid optical networks. Tang et al. [13] focused on the flow schedule problems in optical circuit switching technology-based DC networks. A dynamic network architecture called Flat Ball is developed by Rezaei et al. [14] which has capa-bilities of bandwidth reconfiguration and energy consumption reduction in DC-based optical interconnection networks.

Chen et al. [15] developed shared path protection-based approaches in DC-based EONs for maximizing spectrum sharing. Hadi et al. [16] proposed an energy-efficient service provisioning scheme for inter-DC based EONs. Zhen et al. [4] developed a virtual optical network (VON) mapping scheme to reduce intercore crosstalk in DC-based SDM-EONs. Hao et al. [17] introduced a method on distance-adaptive traffic grooming and energy-efficiency in internet protocol over DC-based EONs. X. Li et al. [1] proposed a distributed subtree-based multicasting scheme for minimizing spectrum consumption in DC-based EONs.

Chen et al. [18] addressed various problems related to mapping of VON with DC-based SDM-EONs. Tang et al. [19] aggregated multiclass with multicast service by distributed subtree approach in elastic optical DC networks. Zhao et al. [20] developed a data retrieval process with dynamic erasure-coded in elastic optical DC networks.

3. STATE OF THE ART

Data centers or warehouses are considered as providers of billions of data to the network traffic. However, any mishap, probably a disaster or a man-made activity can cause huge data loss by affecting a data center or even its surroundings, thus making survivability of data centers a great concern. Besides this, dependence of connection requests on any specific data center for a prolonged period of time can enhance pressure thereby creating the victim data center busy and routes connecting the data center overloaded.

The impartial load balancing in the network increases blocking of connections thereby degrading the quality of service. The purpose of the proposed work is to balance the network load by implanting various labels to the data centers placed in the SDM-EON. These labels help in maintaining uniformity in the selection of data centers for file access.

Table.1. Table defining various adopted modulation formats

Modulation format, m	**Slot Capacity, ϕ_m (Gbps)**	**Optical reach (km)**
16QAM	50	1200
8QAM	37.5	2400
QPSK	25	4800
BPSK	12.5	9600

4. PROBLEM STATEMENT

The underlying network is modeled as an SDM-EON, say $S(N,L,C,D)$ where N, L, C and D are sets of nodes, links, cores and data centers, respectively placed in the network. Each data center, say d, where $d \in D$ is associated with a label, say l. A connection request R arrives randomly as (n,B) where n is the destination node, asking for some file transfer and B is the bandwidth, in Gbps, required for the transmission.

The purpose of the proposed method is to allocate route, core and spectrum to dynamic connection requests without compromising network load balance. It also tries to maintain uniform load distribution among the data centers by decreasing network resource utilization and blocking probability of the connection requests.

Assumptions:

- Minimum two data centers are within optical reach from each node present in the network to maintain protection against single-DC failure.
- Label value of each data center is directly proportional to its usage. A data center with label 0 indicates that it has not been used for file access yet.
- Core switching is not adopted in the work.
- Each DC maintains all the requisite files.

5. PROPOSED WORK

This section details the proposed heuristic, DS-RSCA which aims to balance network load by suitably selecting data centers and allocating route, cores and spectrum to the incoming connection requests in dynamic SDM-EON. The heuristic DS-RSCA is a four-steps process consisting of some prior calculations, data center selection, route / (core) selection and resource allocation steps.

5.1 PRIOR CALCULATIONS STEP

Before processing DS-RSCA, firstly, data centers are placed in the network following the DC-P algorithm [5]. Placement of data centers is such that each node in the network is connected to at-least two data center nodes ensuring protection against single-DC failure. Secondly, sets of data centers which are within optical reach from each node are generated and are stored in a super set, say A. Thirdly, Dijkstra's algorithm [21] is used to compute shortest routes amongst each node pair in the network and store them in a set, say P.

5.2 DATA CENTER SELECTION STEP

DS-RSCA is represented through algorithm 1. Before executing algorithm 1, the labels of all the data centers are set to 0 and are stored in a set, say L. When $R(n,B)$ enters into the network, the shortest routes connecting the node n and the DCs which are closer to it i.e., within optical reach are obtained from set A and are stored in a set, say D'.

DS-RSCA follows two DC selection strategies: *selDC* and *selLL*. In *selDC*, the active DC, belonging to set D', which is located nearest to the destination node n is chosen as the most suitable one. If more than one such DCs are available than the one with least label value is chosen. Whereas, in *selLL*, the active DC, belonging to set D', with least label value is considered as the most eligible one. In case of a tie, the DC which is nearest to node n is selected.

5.3 ROUTE/(CORE) SELECTION STEP

Once the eligible DC, say d is chosen for destination node n, the shortest route connecting them is assigned to p. The next step is to select suitable core for resource allocation in the selected route. But, before that DS-RSCA computes the number of subcarriers, say *s*, required to be allocated in the core to be chosen by applying Eq.(1).

$$s=\lceil B/\phi_m \rceil \quad (1)$$

where,

s = #slots required for traffic allocation,

ϕ_m = Slot capacity of m^{th} modulation format, and

m = Modulation format selected for resource allocation.

Modulation formats are chosen based on the length of the route being selected. The modulation format m with closest optical reach, equal to or greater than the selected route length, is selected and used in Eq.(1). Application of modulation formats helps in reducing resource utilization of the network as well as blocking probability of the connection requests. Table.1 defines the various modulation formats adopted in DS-RSCA. Now, for each core present in route p, one by one algorithm 1 checks whether a gap of size s is available or not. The first available resource gap is taken where the calculated crosstalk level after allocation is less than or equal to −16dB (threshold crosstalk level). The value of crosstalk level is obtained using equation adopted in [2].

5.4 RESOURCE ALLOCATION STEP

The last step of DS-RSCA is the resource allocation step. Resources are allocated based on the first fit approach i.e., the first available resource gap, in the selected core, of size $s + 1$ which after being used produces a crosstalk level $\leq -16dB$ is chosen. In this context, 1 is added to s to indicate the placement of guardband slot.

5.5 COMPLEXITY OF DS-RSCA

The complexity of DS-RSCA depends on the overall complexity of the four sub steps. The worst case complexities of DC-P algorithm [5] and Dijkstra's algorithm are $O\left((k\cdot|L|)+(|N|\cdot\log|N|)+|N|\right)$ and $O\left((|N|+|L|)\log|N|\right)$, respectively.

The DC selection step takes $O(|D|\log|D|)$ time. Core selection and resource allocation steps require $O(|C|\cdot\alpha)$ time, where α is the core slot capacity. Thus, the worst case time complexity of DS-RSCA is

$$O\begin{pmatrix}(k\cdot|L|)+(|N|\cdot\log|N|)+|N|+\\(|N|+|L|)\log|N|)+\\(|D|\log|D|)+(|C|\cdot\alpha)\end{pmatrix}.$$

Algorithm 1 : Heuristic DS-RSCA

INPUT: SDM-EON (*N,L,C,D*), *R*(*n,B*), *L*

OUTPUT: Acceptance/ Rejection of *R*

Obtain the set of DCs which are within optical reach from node *n*, from set A and assign it to set, say *D*'.

Consider a boolean variable, say *f*.

if *f*==0 then

//Method *selDC* is chosen

Obtain the shortest routes from set *P* connecting node n with each node in set *D*'.

Sort set *D′* in non-decreasing order of the above obtained shortest routes.

for each DC d ∈ *D′* do if d is active then

if the next active DCs which are also at same distance from node n as that of d then Choose the DC with lowest label value. Break.

end

Select d as the eligible DC.

Break.

end

end

end

else

//Method *selLL* is chosen

Select the active DCs, present in set *D′*, with lowest label value. if more than one DC is available with same label value then Choose the DC which is nearest to node n.

end

end

Increment the label of the selected DC by 1.

Let the DC being selected for file transfer be d.

Assign the shortest route between nodes d and n to p.

Let a variable, flg=0.

for each core c ∈ C present in route p do

Initialize a set G as empty.

if resource gap of size (s+1) is available then

Store the starting location of the gap in set G.

end

for each location present in set G do

if crosstalk level on accepting the gap is ≤ -16dB then

The gap is chosen and resources are allocated.

Update flg=1 and Break.

end

end

if flg==1 then

Break.

end

end

if flg==0 then

Request R is blocked.

end

Table.2. SDM-EONs considered in the work

SDM-EON	|*N*|	|*L*|	Mean Nodal degree	Mean path length(km)	Optical Reach of DC (km)	Set of DCs (D)
Cost 239	11	52	4.727	578.654	1889	{n7, n8}

NSFNET	14	44	3.143	1936.364	3864	{n3, n6, n9}

Table.3. Simulation Setup

Parameter	Value
Traffic load (erlangs)	100-500
Traffic demand (B)	50-500 Gbps
No. of cores in each fiber ($\|C\|$)	7
No. of slots in each core/ fiber (α)	320
Threshold crosstalk	-16dB
Guardband slots	1

6. SIMULATION ANALYSIS

The execution and analysis of DS-RSCA is explained in this section. Dynamic connection requests in the form of $R(n,B)$ arrive randomly in the underlying SDM-EON following Poisson's Distribution with mean arrival rate of μ. Upon arrival, data centers are found out for serving the requests using either *sel_SD* or *sel_LL* method. Then, routes and cores are decided before allocating network resources. If the incoming connection request fails to be served then it is blocked. DS-RSCA targets to minimize network load by distributing them through assigning labels to the data centers. The results of DS-RSCA are measured for large traffic load against various network benchmarks like load distribution factor of DCs, blocking ratio, and rate of resource occupation in the network. The simulation is performed nearly twenty times on two large known SDM-EONs namely COST239 and NSFNET, whose data are available in Table.2 and is averaged out for analysis with 95% confidence interval. The setup of simulation for DS-RSCA is given in Table.3.

6.1 VARIATION OF RATE OF RESOURCE OCCUPATION AGAINST TRAFFIC LOAD

The Fig.1(a) and Fig.1(b) show the variations of rate of resource occupation (RRO) against traffic load, in erlangs for DS-RSCA using *sel_SD* and *sel_LL* on SDM-EONs-COST239 and NSFNET, respectively. RRO of the network at any time is obtained using Eq.(2).

$$\text{RRO} = \eta'/(\eta) \quad (2)$$

where

η' = Number of utilized slots in the network

η = Number of utilized and non-utilized slots in the network

From Fig.1, it is observed that on increasing traffic load, RRO for both DS-RSCA using *sel_SD* and *sel_LL* increases because of the establishment of more number of connection requests. Initially, due to the selection of shorter routes, DS-RSCA using *sel_SD* has lower RRO values than that of DS-RSCA using *sel_LL*. However, as the load grows, both DS- RSCA using *sel_SD* and *sel_LL* gives a tough competition to each other.

Later on further incrementing the traffic load, the selected routes in DS-RSCA using *sel_SD* become stagnant due to the non-availability of resources on repetitive selection of same routes and blocking of connection request increases. Hence, RRO in case of DS-RSCA using *sel_SD* again tends to provide much lower values compared to that of DS-RSCA using *sel_LL*. When the two SDM-EONs are compared, RRO of COST239 is lower than that of NSFNET due to its higher nodal density and lower average path length (Table.2).

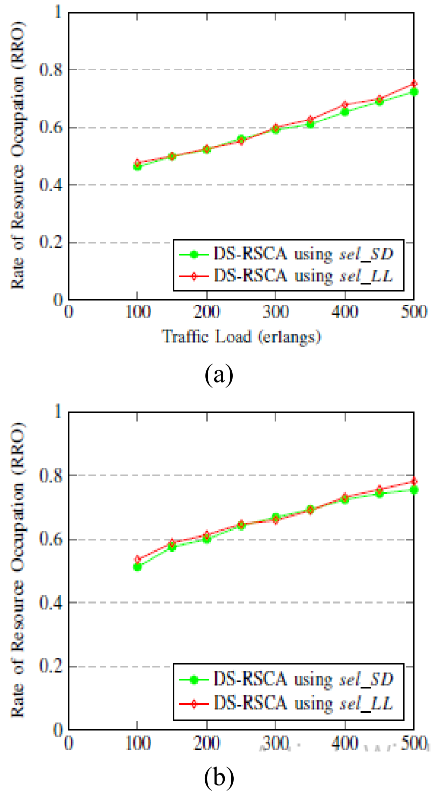
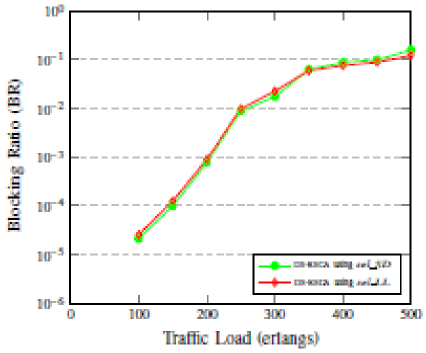


Fig.1. Variation of rate of resource occupation (RRO) against traffic load (a) COST239 (b) NSFNET

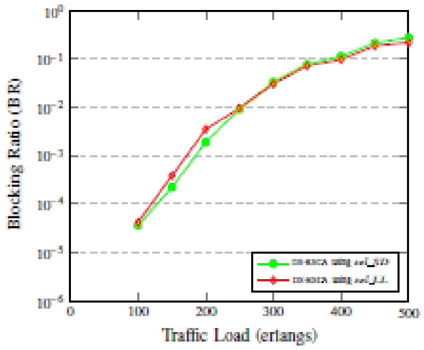
6.2 VARIATION OF BLOCKING RATIO AGAINST TRAFFIC LOAD

The Fig.2(a) and Fig.2(b) show the variations of blocking ratio (BR) against traffic load, in erlangs for DS-RSCA using *sel_SD* and *sel_LL* on SDM-EONs-COST239 and NSFNET. In this context, BR is defined as the ratio of frequency of connections blocked to total connections arrived in the SDM-EON.From Fig.2 it is observed that on increasing traffic load,BR for both DS-RSCA using *sel_SD* and *sel_LL* increases because more the number of connection arrival, more is the chance of their blockage. During the initial phase of simulation, BR of DS-RSCA using *sel_LL* tends to grow compared to that of DS-RSCA using *sel_SD* due to the former's selection of DCs based on label values. A DC with lower label value may be selected which is far away from the destination node. Hence, longer connecting route allows more spectrum allocation leading to a quick utilization of resources in the network. However, in DS-RSCA using *sel_SD*, selection of shorter routes consumes lesser resources and reduces BR value.

During the later phase of simulation, the repetitive selection of same shorter routes nearly stops the connection establishment and increases BR value in case of DS-RSCA using *sel_SD* when compared to DS-RSCA using *sel_LL*. COST239 again produces better results than NSFNET because the higher nodal density supports a variety of route selection in COST239. Also, the smaller routes in COST239 consumes lesser resources and reduces BR value to a great extent. The lower the BR value, the more efficient the network is.



(a)



(b)

Fig.2. Variation of blocking ratio (BR) against traffic load (a) COST239 (b) NSFNET

6.3 VARIATION OF LOAD DISTRIBUTION FACTOR OF DCS AGAINST TRAFFIC LOAD

The Fig.3(a) and Fig.3(b) show the variations of load distribution factor (LDF) of DCs against traffic load, in erlangs for DS-RSCA using *selSD* and *selLL* on SDM-EONs-COST239 and NSFNET, respectively. LDF of DCs, at any point of time, is computed using Eq.(3).

$$LDF = l_{low}/l_{high} \quad (3)$$

where,

l_{low} = Lowest label value

l_{high} = Highest label value

The values of LDF lies in the range $0<LDF<=1$ i.e., a greater value of LDF indicates uniformity in distribution of load among the DCs and vice versa. From both the graphs, it is observed that as the traffic load increases, LDF of DCs varies randomly for DS-RSCA using *sel_LL* i.e., sometimes it rises and sometimes it falls but the variation is very slight. On the other hand, LDF of DCs for DS-RSCA using *sel_SD* shows similar results initially and as the load increments, it tends to fall due to the repetitive selection of same DCs which are nearest to the incoming destination nodes.

The LDF of DS-RSCA using *sel_LL* is higher than that of DS-RSCA using *sel_SD* in both the network topologies. This is because DS-RSCA using *selLL* selects DCs with lowest label values which means it distributes the load uniformly among the DCs in the network. DS-RSCA using *sel_SD* tries to repetitively select the DCs which are closest to the incoming destination nodes thereby making the selected DCs overloaded. It may happen that due to this overload, DCs may get damaged and connections may be blocked although there exists some idle DCs with lower label values in the SDM-EON. The structure of NSFNET requires more resource utilization due to its longer path lengths and less nodal density than COST239 leading to quick blocking of connection requests (Table 2). The repetition in the selection of DCs in NSFNET is slightly less than that in COST239 due to the exhaustion of network resources. Hence, the value of LDF is higher in case of NSFNET for all values of traffic load.

7. CONCLUSION AND FUTURE SCOPE

Load balancing is considered as one of the major concerns to be taken care of while routing traffic in any network. In this sense, a new heuristic DS-RSCA is proposed which tries to balance network load by introducing labels to data centers besides provisioning online traffic in SDM-EONs. Two DC-selection methods are developed, namely *selSD* and *sel_LL*, and are tested against extensive simulation setup. Method *sel_SD* selects the nearest active DC which is within optical reach from the destination node. As a result, the spectrum requirement in *sel_SD* is less followed by a reduced network resource utilization. However, due to the selection of closest DCs every time can exhaust the resources of the selected routes leading to an increase in blocking ratio as the arrival of connection requests grows. Moreover, the load is not balanced within the network and burden increases in the selected DCs making the later slow.

The problem is solved by *sel_LL* which tries to select the active DC with lowest label value. Label values are updated each time a DC is used. The method not only distributes the traffic load among different DCs but also reduces blocking ratio by intelligently allocation network resources for the connection requests. Although, the rate of resource occupation is more during the initial phase of simulation due to the random selection of DCs, yet it declines when the traffic load is further increased as compared to *sel SD*. An active DC is free from any disaster in the network. Also, resources are allocated by maintaining inter-core crosstalk within a threshold limit. In future, we shall try to address various file access problems in DC-based SDM-EONs.

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