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A traffic scheduling strategy based on cost function for differentiated class of service in multi-domain optical networks

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ABSTRACT

The emerging cloud computing, IoT, bulk-data store-and-forward datacenter applications are dominating the Internet traffic, which contains the commercial and business data services and behaves periodically. The traffic peak remains high during a certain time each day (known as peak traffic hours). This results in heavy load on the network, leading to higher level of connections blocking. In order to handle such a critical situation in evolving multi-vendor/multi-operator based multi-domain optical networks (MDONs), prioritization of connection requests based on the differentiated class of service (CoS) is a must. The differentiated CoS (DiffCoS) may be categorized as: CoS1-delay-tolerant, CoS2-deadline-driven, and CoS3-fixed scheduled (or hard time bounded) traffic. To avail the maximum benefit of DiffCoS traffic characteristics, proper planning and efficient resource provisioning during admission phase is essential for the network service providers. A traffic scheduling strategy based on cost function (TSSCF) for DiffCoS in MDON is proposed, in which the connection requests are arranged in decreasing order of the cost function, and the route is selected based on shortest path minimum domain criterion, as per which the shortest route traversing or passing through the minimum number of domains is chosen. The simulations are performed on three-domain ARPANET topology, and the results are evaluated for different intra and inter-domain request ratios i.e., 1:1, 3:2 and 7:3, under 1:1:1 ratio of various CoSs. The simulation results of the proposed TSSCF strategy show significant improvement on the metric of blocking probability (BP), individual CoS BP, resource utilization ratio, and a newly introduced metric called revenue index as compared to the existing strategies.

1. Introduction

Worldwide, the Internet users are growing rapidly and are expected to reach up to 58% of the global population by 2021 [1]. According to the data forecasting report by Cisco, 18 billion devices are connected to the Internet protocol (IP) networks, and the global IP traffic crossed 122 Exabyte (EB) data per month in the year 2017 and is expected to increase with the compound annual growth rate of 26% [2]. This traffic is dominated by the emerging 5G communication [3], fog and cloud computing [4,5], Internet of Thing (IoT) [6], store-and-forward (SnF) datacenter applications for bulk data [7,8] and scheduled services [9–18] which may be of business type, commercial, or both kinds. These services require large bandwidth and high-speed connectivity either at pre-defined specific time, or unspecific time, or with some time delay across the backbone optical networks. However, with every passing year, there is advancement in technology and addition of smart mobile devices, leading to increase in the number of users, connectivity and network size, manifold times. So, it is practically not possible to control, manage and share the complete global database of a large network by a single node entity. Also, the increased number of administrators, vendors, and service providers (SPs) want to manage their own part of the network. The traditional backbone single domain optical networks (SDONs) are now shifting to the multi-domain optical networks (MDONs). Hence, the MDON is a group of many SDONs which are interconnected by inter-domain links via gateway/border nodes, incorporate vastly diverse technology, and multiple administrative operators/SPs [19–23]. The internal topological details of each domain are hidden and confidential to all other domains, due to the diversities in domain management policies, routing protocols, security and privacy issues.

It has been observed from the IPv6 traffic generated at Amsterdam Internet Exchange (AMS-IX) network ports daily (see Fig. 1 of [9]) that

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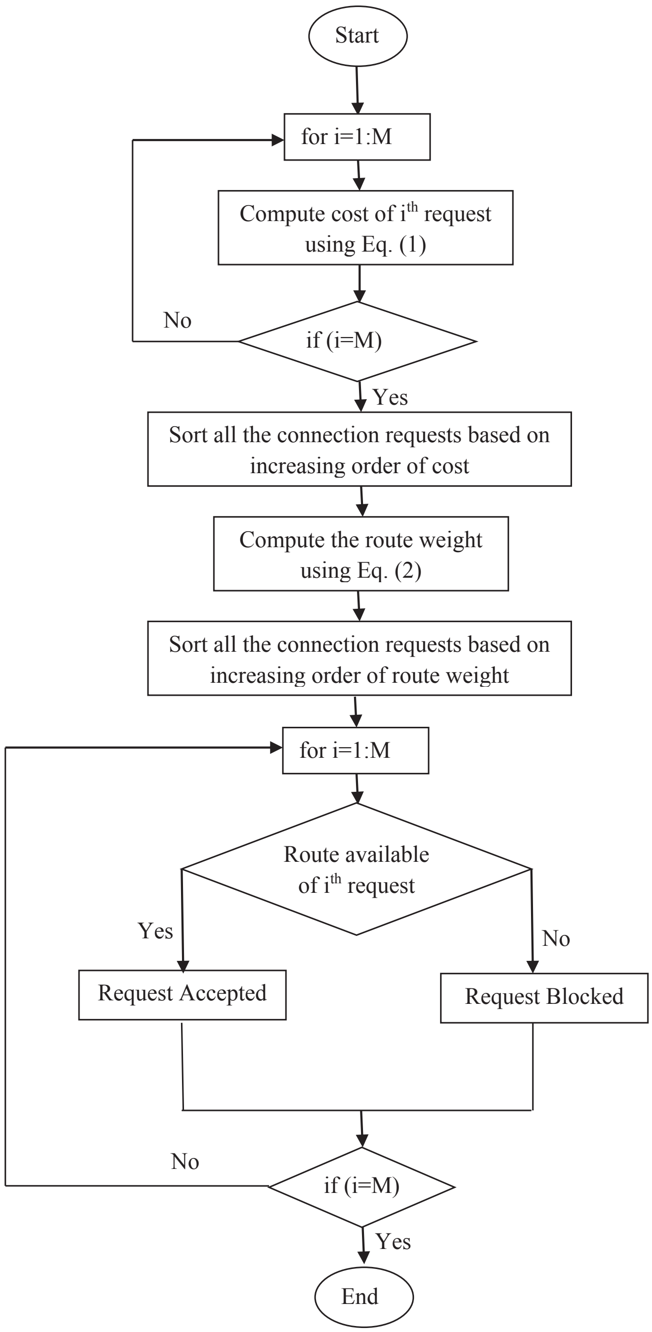


Fig. 1. Flow chart of the proposed TSSCF strategy.

the traffic achieves its peak every day, and it remain so for some specific time duration each day (which is referred as peak traffic hours or working hours). At the time of peak traffic load hours, the network is utilizing its maximum resource capacity. It is quite probable that the connection requests through which some urgent and important information is to be transferred, get blocked due to the unavailability of network resources at peak time hours. Thus, it is important to classify the network traffic into differentiated class of services (DiffCoSs) on the basis of different criterions such as delay tolerance, holding time, bandwidth requirement, customer satisfaction, and network SPs profit or revenue. The class of service (CoS) ensures that the highest CoS connection requests can be easily transported, even when the network is suffering from congestion problem. In this work, the traffic is classified into three different CoSs: delay tolerant (DT) [24–27], deadline driven (DD) [16,28] and fixed scheduled traffic (also known as hard time bound traffic) [13,14], these are abbreviated here as CoS1, CoS2, and CoS3, respectively. The requests which have zero waiting time or zero tolerance/patience time for execution and are to be served immediately, are categorized as CoS3 traffic. In CoS3, the setup (T_s) and teardown (T_e) time of connection requests are fixed. Stock exchange or share trading, e-banking, online ticket reservation, online gaming, health care monitoring, and remote surgeries/treatment requiring real time data transfer are the examples of CoS3 traffic whose priority is highest. The applications that allow a limited time delay and are less time critical, comprise CoS2 requests; these are referred as DD traffic requests [16,28] or sliding scheduled lightpath demands [11,12] in literature. Here, instead of a given fixed T_s and T_e time, the clients provide the information about the holding time (HT), starting time (w_s) and ending time (w_e) of the window during which the backup data is to be transferred. The starting time of connection requests varies between w_s and (w_e - HT). Live match telecasting, video conference, banking data backup file transfer from the branch offices to the head/central office are the examples of moderate priority traffic that comes in the category of CoS2. The DT traffic can wait for some time or a day or until the network resources get idle or free. Synchronizing datacenters across continents, video surveillance, bulk scientific data movement from remote experimental locations to laboratories/datacenters around the world, downloading the recorded or stored high-definition entertainment contents like-movies, television serials, past Olympic or cricket world cup videos [29–31] are the examples of CoS1 traffic. The priority order of CoSs is as CoS3 > CoS2 > CoS1. The network SP charges high, moderate, and relatively lesser for CoS3, CoS2, and CoS1 traffic requests, respectively.

The emergence of vast datacenter applications, SnF services for bulk data files transfer, traffic variations and DiffCoS opens new challenges and opportunities in MDONs. The routing and resource provisioning for DiffCoS in MDON is quite complicated and difficult due to the diversity in domain management policies, multiple vendors/SPs and large network size. This leads to the necessity of major planning during the admission phase, prior to actual allocation of network resources for each domain network SP. In line of these, a traffic scheduling strategy based on cost function (TSSCF) for DiffCoS in MDON is proposed. Here, the cost function is a cumulative function of CoS and holding time information of the connection requests. In TSSCF, the cost of each request is estimated first, and the requests are arranged in decreasing order of their cost. The routing and wavelength assignment (RWA) is undertaken next and the route is selected by using route weight method (RWM). According to RWM, the route having lowest value of route weight is selected as a candidate route among all pre-defined K-alternate routes. The route weight is a collective function of pathlength (hop-count), and domain-count (i.e., number of domains through which the lightpath traverses), as per which the best optimal route with minimum domain passing criterion is selected. The term “K-alternate routes” is a set of pre-defined link-disjoint routes [32]. These routes are fixed and reserved at the time of network designing and planning phase for the establishment of the connection requests. In general, the routes are estimated using shortest path routing algorithm such as Dijikistra’s algorithm, and are arranged in increasing order of their pathlength/hop-count value. However, in MDONs, this fixed sequence of the K-alternate routes is not always feasible, specially, for inter-domain requests in which the routes traversed through multiple domains. The route which traverses through larger number of domains, consume higher network resources; whereas, the route traversing through lesser number of domains, consume lesser resources. Based on the past literature, no such footprints are available that selects the minimum domain passing route criterion with DiffCoS in MDONs. In light of these, the simulation results of the proposed TSSCF strategy is evaluated on the three domain ARPANET topology with 100 simulation runs, under three different intra-domain and inter-domain request ratios (i.e., 1:1, 3:2, and 7:3) under uniform CoS distribution (i.e., CoS1:CoS2:CoS3 = 1:1:1). The proposed strategy is then compared with the existing strategies based on scheduling the connection requests on different criterions such as highest CoS with shortest path first (HCSPF) [33], highest CoS with earlier setup-time first (HCESF) [15], and highest CoS with earlier teardown-time first (HCETF) [15]. Metrics of comparison were blocking probability (BP), individual CoS BP, resource utilization ratio (RUR), and a newly introduced metric called as revenue index (RI). The research outcomes of the proposed strategy yield significantly improved performance on all metrics under investigation.

Remaining part of the article is organized in the following manner. Section 2, reviews the relevant literature with their pros and cons. Section 3, present the system model and notations used. Existing and proposed strategies are discussed in Section 4. Simulation outcomes and results analysis are reported in Section 5. Section 6, concludes the proposed investigation.

2. Related work

In the past decades, the network traffic increased manifold times. During this interval, there has been vast deployment of applications like cloud-computing, IoT, SnF datacenter services which require massive and high-speed bandwidth guaranteed services with different scheduled time. The provisioning of these DiffCoSs in SDONs is widely explored in the work of [29–31,34]. The RWA problem for MDON is extensively researched under dynamic and scheduled traffic scenario. However, the handling of DiffCoS requests and effective end-to-end provisioning of network resources is still complicated and challenging, due to the domain privacy issues in MDONs. Each domain manager may keep the complete information of network topology, routes, and resource availability confidential, and only share the limited intra-domain information to other domain managers. In this section, the existing literature related to the RWA problem is discussed first for MDONs, and a brief review of DiffCoS is reported next.

To setup an end-to-end connection across multiple domains, authors used automatically switched optical network architecture framework, and proposed a dynamic inter-domain routing algorithm in [35]. In [36], authors proposed a heuristic algorithm, namely, network virtualization weighted clustering algorithm to address the multicast RWA problem in MDONs. The proposed algorithm minimizes resource consumption and connection setup time. To minimize the routing cost, a top down routing approach was proposed in [37] for MDONs. In [38], authors presented a border node selection approach, and proposed an impairment and bandwidth aware routing algorithm for MDONs. In [39], authors proposed hybrid intra-domain and inter-domain traffic engineering scheme named egress route selection based on hot potato routing in order to improve the load balancing and minimize the time required to traverse the inter-domain lightpaths. A technology-aware inter-domain routing algorithm for finding the feasible shortest route in MDONs is suggested in [40]. The works reported in [35–40] are based on dynamic traffic. In dynamic traffic, the requests arrive randomly and the assignment of network resources is dependent on the current network state information [41–43]. The network traffic achieves its peak, every day for certain time duration. During this time, the network suffers from congestion, leading to increase in the connections blocking. This may result in poor customer satisfaction and significant loss of revenue. To solve these issues, a scheduled traffic model (STM) was proposed for MDONs in [13]. The STM has features borrowed from the static, as well as dynamic traffic model. Hence, similar to static traffic, the set of connection requests is known in advance, while like dynamic traffic, the connection requests consider the evolution of network traffic in time.

The provisioning of connection requests with fixed and flexible setup and teardown time information have been reported for MDONs in [13,14] and [9,10], respectively. The model used for traffic having fixed setup and teardown times which is known in advance, is referred as STM, [13,14] and the model incorporating flexible setup time is known as sliding scheduled traffic model (SSTM) [11,12]. In SSTM, instead of fixed setup and teardown time of connection requests, the starting and ending time of window, and the duration i.e., holding time for which the request stay in the network is known in advance. The advance reservation (AR), DD, and DT are the frequently used terminologies reported in the past literature for representing the time flexibility of the connection requests. In AR, the resources are pre-allocated or reserved in advance before actual connection setup [44]. For supporting the AR services in MDONs, a scalable and effective game theory based RWA strategy was proposed in [45]. In [28], authors presented a DD model for which the connection requests had flexible setup and known holding time. In real world, some of the data-intensive applications require transferring of data before a pre-defined deadline time. To minimize the network congestion, authors in [16] adopted a DD model for the transfer of bulk data files in grid computing. Authors in [17,18] implemented scheduling algorithms for transferring large size bulk data files among various datacenters. In [25], the term DT was first introduced which is defined as the maximum duration for which a customer is willing to wait until the connection setup. In [26], authors proposed two rerouting strategies for connection provisioning with setup delay tolerance to reduce BP and optimize resource utilization. An impairment aware routing scheme with setup delay tolerance and holding time was proposed to improve the blocking performance [27]. A new concept of traffic balancing (TB) was introduced to utilize the network resources efficiently under the scheduled traffic scenario for MDONs in the work of [9]. TB policies offer network SPs a flexibility to reschedule the connection requests in order to establish maximum connections and optimize network resource utilization. In [10], authors proposed survivable strategies for MDONs using TB and backup resource reservation. In the work of [46–53] different resource/spectrum assignment schemes have been investigated for decreasing BP and improving resource utilization efficiency in single domain elastic optical networks (EONs). However, all the reported works in [11,12,16–18,25–28,46–53] are tested for single domain networks only, and the service differentiation is not considered.

It has been observed from the past literature that the connection requests having zero waiting time, or smaller delay tolerance value face higher connections blocking problem as compared to the requests having higher delay tolerance value. This may degrade the service class performance in terms of BP, satisfaction level, and revenue. To minimize this issue, a service class differentiation strategy is proposed in which the requests are arranged in the increasing value of the delay tolerance and holding time ratio [29]. This work has been further extended and explained in details in [30]. An ILP (Integer Linear Programming) and three heuristic algorithms were proposed to solve the RMSA (Routing, Modulation, and Spectrum Assignment) and scheduling problem for survivable single domain EONs under AR and immediate reservation based multi-class traffic [34]. In [54], authors proposed a time scheduling based dynamic bandwidth on demand provisioning solution in software defined MDONs. To the best of our knowledge, no such footprints are available for DiffCoS in MDONs, specially, for the real time traffic situations, where, the traffic is classified as hard time bounded or fixed scheduled time, DD and DT type. In light of these, the traffic scheduling strategy based on cost function for DiffCoS in MDONs is proposed, and a new metric parameter known as revenue index (RI) is introduced to evaluate the profit earned by network SP from the client requests.

3. System model and notations used

Let us consider a multi-domain physical network topology $G\{D^r, L_{inter}, W\}(1 \leqslant r \leqslant R)$ where, 'L_{inter}' is a set of inter-domain links which is interconnected between the two gateway nodes of different domains, 'W' represents the number of wavelengths available per fiber link (i.e., WDM channels) and 'R' is the total number of domains in the network. The individual domain is represented by $D^r\{GN^r, IN^r, L^r_{intra}\}(1 \leqslant r \leqslant R)$ where, D^r represent the r^{th} domain of the network topology, GN^r is the set of gateway nodes, IN^r is the set of core nodes and L^r_{intra} is the set of intra-domain links of r^{th} domain.

- η denotes the set of nodes of 'G', $\forall\ \eta \in (GN^r \cup IN^r)$, $(1 \leqslant r \leqslant R)$.
- l denotes the set of links between two nodes in 'G', $\forall\ l \in (L_{inter} \cup L^r_{intra})$, $(1 \leqslant r \leqslant R)$.
- (s, d, CoS, T_s, HT) is the source node, destination nodes, CoS, setup time and holding time information, respectively, where $(s, d) \in \eta$.
- N denotes the total number of nodes in MDON.
- L denotes the total number of links in MDON.
- M denote the total number of connection requests which arrived in the network.

4. Existing and proposed strategies

This section presents the detailed description of three existing scheduled RWA strategies namely, highest CoS shortest path first (HCSPF), highest CoS earlier setup-time first (HCESF), and highest CoS earlier teardown-time first (HCETF), and the proposed TSSCF strategy with their pros and cons.

4.1. Highest CoS shortest path first (HCSPF)

In HCSPF strategy, the connection requests having highest CoS with shortest path are given priority. However, the shortest path selection is independent of the minimum domain passing criterion (i.e., independent of RWM). The shortest path requires less number of network links, thus the resource consumption is less in this strategy which leads to reduced BP. But, the value of revenue index is relatively lower, resulting to low profit for the network SPs. Also, the holding time parameter is not considered for setting priority of any connection request; only CoS is considered in this strategy. The HCSPF performs well in terms of BP for low network loads.

4.2. Highest CoS earlier setup-time first (HCESF)

In HCESF strategy, the connection requests are arranged in descending order of CoS. If the connection requests belong to the same CoS, the requests having earlier setup time will be served first. This implies that the highest CoS requests with an earlier start (or setup) time will have the highest priority. The RWA is undertaken next using K-alternate shortest path first routing without considering the RWM, and a wavelength is assigned using first fit wavelength assignment scheme. In HCESF strategy, the time duration for which the connection requests stay in the network is not considered. Therefore, the possibility of connection requests which start earlier and stay in the network for longer duration increases. Consequently, the network resource consumption increases, leading to block the future connection requests. But, at the same time the RI value increases because higher holding time requests pay high to the SP.

4.3. Highest CoS earlier teardown-time first (HCETF)

In HCETF strategy, the connection requests are sorted in decreasing order of CoS. If the connection requests belong to the same CoS, the requests having earlier teardown time get priority. This implies that the requests with highest CoS and earlier teardown time are served first. After sorting of the requests, RWA is undertaken next without considering RWM. This strategy does not consider any information regarding the holding time. It may be possible that some connection requests stay in the network for shorter time duration and utilize lesser number of network resources. As a result, BP performance improved. But, at the same time the revenue generation is less because lower holding time requests pay less to the SP.

4.4. Proposed traffic scheduling strategy based on cost function (TSSCF)

To solve the routing and resource provisioning problem for DiffCoS, and increase the SPs profit/revenue in MDONs, a TSSCF strategy is proposed. In TSSCF, first the cost of each connection request is estimated by using Eq. (1), then the requests are arranged in decreasing order of their cost, and the RWA is undertaken next using RWM. The cost function is a cumulative function of CoS and holding time which is used to set the priority of connection requests during admission phase, before the actual provisioning of network resources. For routing, the lowest weighted route is selected as a candidate route which is estimated by using Eq. (2), instead of the pre-defined sequence of K-alternate routes in which the routes are already arranged in increasing order of pathlength without considering the minimum domain passing criterion. The route weight is a collective function of pathlength (hop-count) and domain-count (i.e., number of domains through which the lightpath traverses), which selects the shortest route traversing through the least number of domains. However, in MDONs, the fixed sequence of the K-alternate routes is not always feasible, particularly, for the inter-domain requests. After route selection, wavelength is assigned to the selected candidate route using first fit wavelength assignment scheme. Here, wavelength continuity constraint (WCC) is followed, as per which the same wavelength is assigned to each link of the candidate route.

$$Cost_i = \frac{CoS_i}{CoS_{\max}} + \frac{HT_i}{HT_{\max}} \tag{1}$$

$$RW_{i,k} = \frac{PL_{i,k}}{PL_{\max}} + \frac{D_{i,k}}{D_{\max}} \tag{2}$$

where,

$Cost_i$: Cost of i^{th} connection request
CoS_i: Class of Service of i^{th} connection request
CoS_{max}: Maximum or highest value of CoS in the network (i.e., 3)
HT_i: Holding time of i^{th} connection request
HT_{max}: Maximum value of the holding time of a connection request arriving in the network
$RW_{i,k}$: Route weight of k^{th} alternate path of i^{th} connection request
$PL_{i,k}$: Path length of k^{th} route of i^{th} connection request
PL_{max}: Maximum value of path length from the K-alternate route.
$D_{i,k}$: Domain count or the number of domains through which the k^{th} route of i^{th} connection request passes or traverses
D_{max}: Maximum number of domains for which the route traverses or the number of domains in the network (i.e., 3)

Each of the individual components/terms of Eq. (1) and Eq. (2) contribute towards priority setting of connection requests, as well as, the route. The detail description of each term in cost function and route weight equation are as follows:

- **Class of Service (CoS):** The connection requests having higher CoS (i.e., CoS3) comprise of hard time bounded requests for which the client/customer pay higher to the network SP. The connection requests belonging to DD and DT i.e., CoS2 and CoS1, respectively, pay lesser as compared to the CoS3 requests. The service charges vary as per the holding time requirement of the connection requests.
- **Holding time (HT):** HT defines as the time duration for which the connection requests stay in the network. The higher HT implies that the network resources are engaged for longer time. In such a case, the client pay higher to the network SP, whereas, the connection requests which have lower HT, pay less.
- **Path length (PL):** PL is defined as the number of hops or links used by the selected route. Smaller PL means the lesser number of fiber links are used, resulting in minimization of the network resource consumption. Hence, more free resources shall be available for the

Table 1
Algorithm of the proposed TSSCF strategy.

Input	*G, M, W*, Pre-computed K- alternate routes, *(s, d, CoS, T_s, HT)*, and Intra- and Inter-domain request ratio
Output	*BP, RUR, RI*
Initialize	*ConnectionBlocked* = 0; *RUR* = 0; *RI* = 0;
Phase-1: Arrange the connection requests in descending order of *Cost* value.	
1.	**For** *i* ← *1 to M do*
2.	Compute $Cost_i$ using Eq. (1)
3.	**End**
4.	Sort all the connection requests in descending order of *Cost* value
Phase-2: RWA	
5.	**For** *i* ← *1 to M do*
6.	**For** *k* ← *1 to K do*
7.	Compute the route weight ($RW_{i,k}$) using Eq. (2)
8.	**End**
9.	Arrange the alternate routes in increasing order of route weight
10.	**For** *n* ← *1 to K do*
11.	**For** w ← *1 to W do*
12.	**If** (K^{th} route with w^{th} wavelength available)
13.	Accept the connection and allocate the resources to the connection request
14.	**Else**
15.	ConnectionBlocked = ConnectionBlocked + 1;
16.	**End**
17.	**End**
18.	**End**
19.	**End**
20.	Finally estimate *BP, RUR, RI.*
Computational Complexity: $O(M+M\times(K+(K \times W)))$	

future connection requests. PL directly affects the connection setup speed and resource consumption in the network.

- **Domain-count (D):** The domain count indicates the number of domains through which the lightpath traverses from the source domain node to the destination domain node. In MDON, the inter-domain lightpath traverses through multiple domains via gateway nodes. Each gateway node performs optical-to-electrical-to-optical (OEO) conversion, wavelength conversion, and regeneration of weak signals [32,55]. The OEO conversion increases the processing time (i.e., decrease the speed of operation) for the establishment of inter-domain lightpath. Hence, the inter-domain route which traverses through lesser number of domains (i.e., lower value of domain-count) is assigned higher priority.

4.4.1. Algorithm description and complexity analysis

The algorithm of the proposed TSSCF strategy is shown in Table 1 and the flow chart is shown in Fig. 1. The algorithm is divided in two phases. The system model and notations used in Section 3, pre-computed K-alternate routes, set of connection requests including information of *(s, d, CoS, T_s, HT),* and intra and inter-domain request ratios are treated as the input parameters for the simulation program. All the essential variables and output parameters are initialized. In Phase-1, the *Cost* of each request is estimated using Eq. (1) first, then the requests are arranged in descending order of the *Cost* value (refer Step 1 to Step 4). The computational complexity of Phase-1 is $O(M)$. The RWA is undertaken next in Phase-2. In Phase-2, route weight ($RW_{i,k}$) of all K-routes for i^{th} connection request are computed using Eq. (2); then all routes are arranged in increasing value of route weight (see, Step 6 to Step 9). The availability of wavelength for the shortest path route traversing through minimum domain is searched. If resources are available then the connection request is accepted and w^{th} wavelength is assigned to the route, otherwise the connection request is blocked (refer Step 11 to Step 17). The relevant variables are updated and the output variables computed. The algorithm complexity of Phase-2 is calculated as $O(M\times(K+(K \times W)))$, where, *M*, *K*, and *W* represent the number of connection requests, number of alternate routes, and number of wavelength per fiber links in the network, respectively. Therefore, the overall complexity of the proposed TSSCF strategy is $O(M+M\times(K+(K \times W)))$.

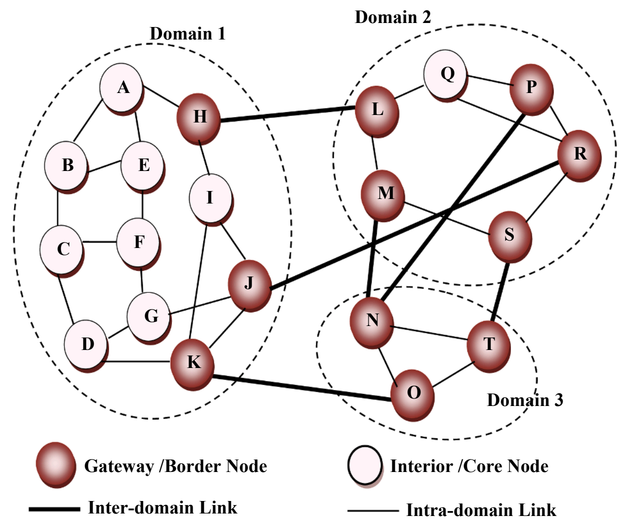


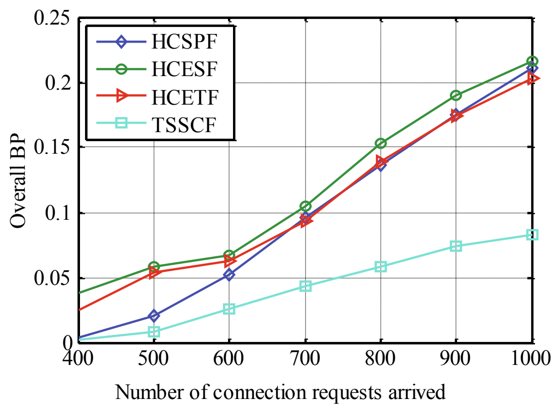
Fig. 2. Three domain ARPANET topology.

5. Simulation results and discussion

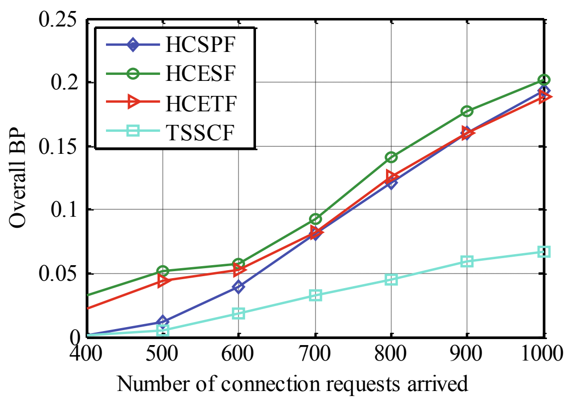
To evaluate the performance of the proposed TSSCF strategy and existing non-RWM strategies such as HCSPF, HCESF, and HCETF, a simulation program using MATLAB software was developed. The simulation was performed on three domain ARPANET topology shown in Fig. 2. The information related to the network topology (such as number of domains, interior and gateway nodes, intra and inter-domain links), K-alternate routes, wavelengths per fiber link, intra and inter-domain request ratios, setup time, teardown time, holding time, and CoS information were treated as input parameters for the simulation program. Here, each link in the network is assumed to be bidirectional, so that the data can be transmitted in both the directions of a link, and each link occupied 20 wavelengths capacity. For evaluating the performance of the proposed and existing strategies, 100 simulation runs were performed and the results reported were taken as average of simulation outcomes on the metric of BP, individual CoS BP, RUR, and RI. Different intra and inter-domain request ratios i.e., 1:1, 3:2, and 7:3 were considered for reflecting the real network traffic scenario under uniform CoS ratio (i.e., 1:1:1). The network was assumed to be non-wavelength convertible network, thus lightpaths follow WCC. The simulation results are shown in Figs. 3–6 for all strategies on different metric of interest.

5.1. Blocking probability (BP)

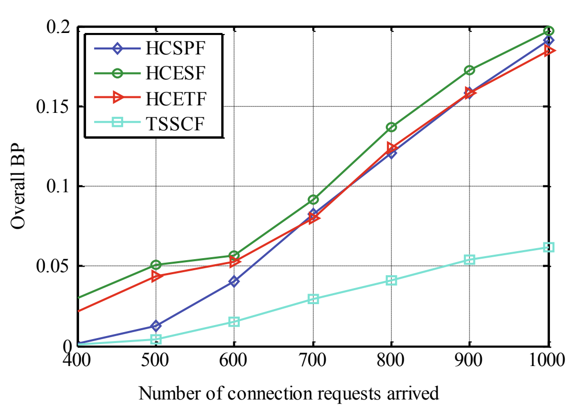
Fig. 3 shows the graph of BP versus the number of connection requests arrived in the network for (a) 1:1, (b) 3:2, and (c) 7:3 intra and inter-domain request ratios. The BP refers to the ratio of blocked connection requests to the total number of arrived connection requests [41–43,56,57]. The value of BP should be as low as possible. It has been observed from figures, as the number of connection requests increase, BP also increases. This is due to the fixed and limited resource availability in the network. As the connection requests are accepted, the network resource availability for the upcoming requests decreases, leading to increase in BP. It is also evident from the figure that the proposed TSSCF strategy shows lowest value of BP for all intra and inter-domain request ratios as compared to the existing non-RWM strategies such as HCSPF, HCESF, and HCETF. The TSSCF strategy accords priority to the requests having higher value of the cost function, and the route is selected using RWM. In RWM, the route having lowest value of route weight is selected by using route weight formula shown



(a) 1:1 Intra and Inter-domain requests ratio



(b) 3:2 Intra and Inter-domain requests ratio



(c) 7:3 Intra and Inter-domain requests ratio

Fig. 3. Graph of overall BP for (a) 1:1, (b) 3:2, and (c) 7:3 intra and inter-domain request ratios.

in Eq. (2). As per this formula, the route weight is assigned based on the pathlength and the number of domains through which the route traverses. For routing, the lowest weighted route is assigned priority. Hence, the shortest route traversing through the least number of domains is selected. This leads to lower consumption of fiber link capacity in the network. As a result, more free resources are available for accommodating the forthcoming connection requests. Hence, the proposed TSSCF strategy shows lowest value of BP as compared to other existing non-RWM strategies. Among all existing non-RWM strategies, the HCSPF strategy performs better as compared to HCESF and HCETF strategies. In HCSPF, the highest CoS requests get priority and the shortest route feature leads to utilize lesser resources. But, in this strategy, the shortest path does not consider the minimum domain passing route criterion. Hence, BP is higher as compared to TSSCF strategy. In HCESF and HCETF strategies, the connection requests are arranged based on the highest CoS with earlier setup time and earlier teardown times, respectively. These strategies do not consider any information of the holding time. It is quite possible that some connection requests stay in the network for longer duration, which leads to the increase in the network resources consumption. The average value of BP is shown in Table 2. As compared to HCSPF, HCESF, and HCETF, the percentage reduction in BP of the proposed TSSCF strategy is (57.55%, 64.45%, 61.03%) for 1:1 intra and inter-domain requests ratio, (62.17%, 69.57%, 66.07%) for 3:2 requests ratio, and (65.95%, 71.91%, 68.91%) for 7:3 intra domain: inter-domain requests ratio is noted.

Also, the inter-domain route selected by the existing non-RWM based strategies traverse through higher number of domains and encompass more inter-domain links and gateway nodes. Each gateway node performs optical-to-electrical-to-optical (OEO) conversion and regeneration of weak signals [32,55]. The OEO conversion increases the processing time (i.e., decrease the speed of operation) for the establishment of connection requests. Whereas, the inter-domain route selected through RWM consist of lesser number of inter-domain links and gateway nodes. This leads to decrease in the number of gateway nodes, resulting in decrease of OEO conversion time. Consequently, this increases the speed of data transfer (i.e., shorter connection setup time).

It has been observed from the past literature that the connection requests having zero or smaller delay tolerance value (CoS3 and CoS2) face higher connection's blocking as compared to the requests having higher delay tolerance value (CoS1). This may degrade the service class performance in terms of BP for these time and revenue critical connection requests. In order to handle such a situation in evolving multi-vendor/multi-operator based MDONs, the TSSCF strategy is proposed. Here, the blocking for real time (hard time bounded) services is minimized at the cost of delay tolerant traffic. Fig. 4 represents the graph of individual CoS blocking probability for different CoS traffic, for traffics of different intra and inter-domain request ratios. It is noteworthy that for all cases of intra and inter-domain request ratios considered, the blocking for CoS3 traffic is negligible followed by CoS2 and CoS1 traffic. Also, the simulation results verify that the proposed TSSCF strategy shows minimum BP in each of the cases when compared with respect to the existing non-RWM strategies.

5.2. Resource utilization ratio (RUR)

The RUR is defined as the ratio of network capacity used to the number of connection requests accepted in the network, which relates to how efficiently the network resources are utilized. In other words, it can be referred as the total number of wavelength links used per established connection request. The lower value of RUR indicates that the resources are utilized efficiently. Fig. 5 shows the variation in RUR with respect to the number of connection requests which arrived in the network for (a) 1:1, (b) 3:2, and (c) 7:3 intra and inter-domain request ratios. Simulation results of TSSCF strategy shows remarkable reduction in the value of RUR as compared to the existing HCSPF, HCESF, and HCETF strategies. This is because the process of optimal route selection which passes through minimum number of domains, leads to the efficient utilization of network resources; this increase the resource availability for future connection requests in the network, as compared to the existing strategies. All the existing strategies are unaware of RWM. Also, the information regarding the duration for which the requests stay in the network is not considered in the existing strategies, thus it is quite possible that the initial traffic requests utilize network resources for longer duration of time, leading to decrease the availability of free resources for the upcoming requests. This degrades the RUR performance monotonically. The average value of RUR is reported in Table 2. As compared to HCSPF, HCESF, and HCETF strategies, the proposed

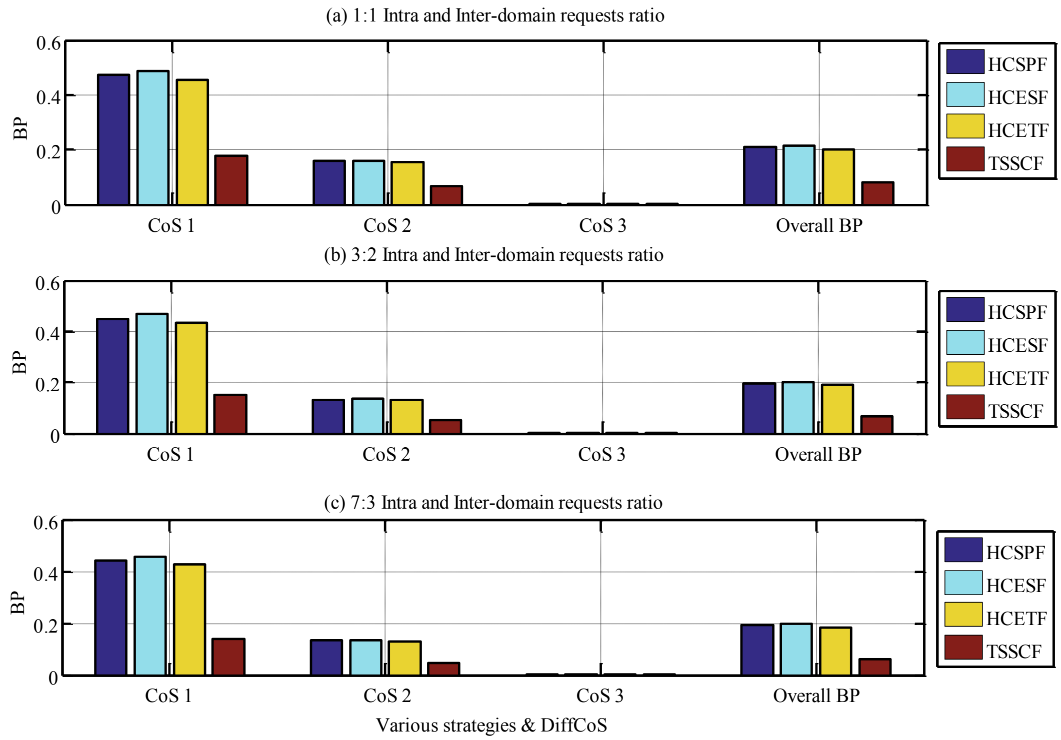


Fig. 4. Graph of individual CoS BP and overall BP for (a) 1:1, (b) 3:2, and (c) 7:3 intra and inter-domain request ratios.

TSSCF strategy shows the percentage reduction in RUR value of (15.85%, 27.83%, 25.33%) under 1:1, (17.36%, 28.98%, 27.18%) under 3:2, and (18.59%, 29.68%, 27.97%) under 7:3 intra and inter domain request ratios.

5.3. Revenue index (RI)

To highlight the strength of the proposed TSSCF strategy, we introduce a new metric named as revenue index (RI). RI is defined as the ratio of total cost of the established connection requests to the number of wavelength links used by the accepted connection requests, as represented in Eq. (3). The clients pay higher to the SP for the connection requests having higher CoS or higher holding time. The denominator part of RI (in Eq. (3)) indicates the wavelength links used by the established connection request; depends on the route length, domain-count, and time disjointness of the connection requests. In line of these, the network SP selects the best optimal candidate route by using RWM in which the routes are selected according to the shortest path which traverses through the minimum number of domains; leading to reduce the extra resources use in the network. Hence, more free resources are available for the future requests, which results to increase the earning of each domain SP and maximize the customer satisfaction. The value of RI should be as high as possible, which indicates higher profitability for the network SP.

$$RI = \sum_{i=1}^{Z} Cost_i / \sum_{i=1}^{Z} WLU \tag{3}$$

where,

RI: Revenue Index

$Cost_i$: Cost of i^{th} accepted connection request

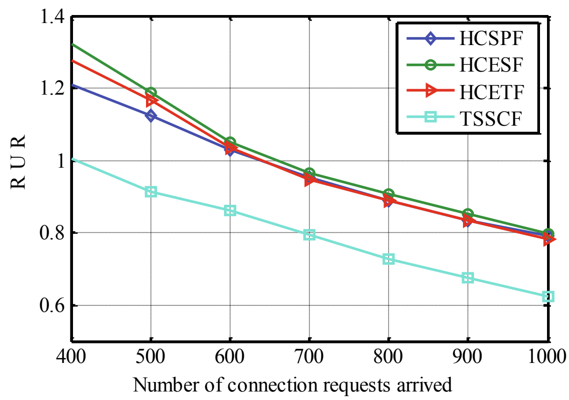
WLU: Wavelength links used

Z: Total number of established connection requests

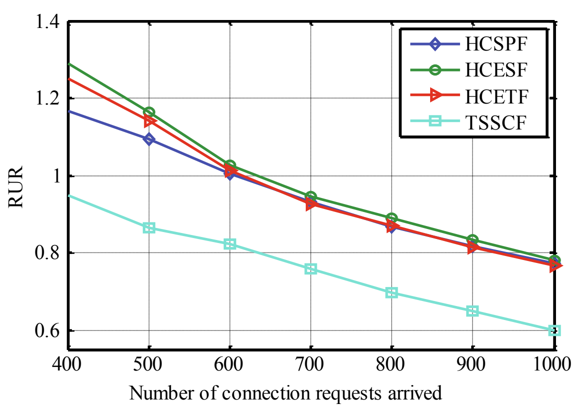
Fig. 6 shows the plot of RI for (a) 1:1, (b) 3:2, and (c) 7:3 intra and inter-domain request ratios. As the number of connection requests increase, the RI increases. It is evident from the figures that the TSSCF strategy shows highest value of RI as compared to the existing HCSPF, HCESF, and HCETF strategies. This is due to the acceptance of the connection requests which have higher cost and minimum resource utilization, leading to earning of the maximum revenue. The existing HCESF strategy shows higher value of RI as compared to the other existing strategies, i.e., HCSPF and HCETF. This is because the connection requests prioritize according to the higher CoS and earlier setup time first. Hence, the probability of incoming requests to have higher time span is higher. The cost of such requests is high due to higher holding time. The HCSPF strategy is unaware of holding time information and HCETF strategy prioritize the connection requests as per higher CoS with earlier tear-down time first. The strategy HCETF serves the connection requests having lower holding time which reflects in the form of lower value of RI. Table 2 shows the average value of RI for existing and proposed strategies. The percentage improvement in RI value of the proposed TSSCF strategy is (45.06%, 45.06%, 95.83%) in 1:1 intra and inter-domain request ratio, (50.30%, 50.30%,100.81%) in 3:2 request ratio, and (51.49%, 49.70%, 102.4%) in 7:3 ratio as compared to the existing HCSPF, HCESF and HCETF strategies, respectively.

6. Conclusion

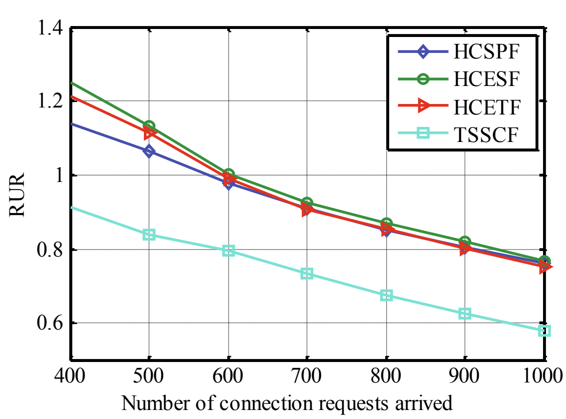
In this article, a cost based strategy, namely, TSSCF is proposed for DiffCoS in multi-domain environment. The DiffCoS is classified as CoS1, CoS2 and CoS3 which mainly comprises of DT, DD and hard real time (fixed time) traffic requests, respectively. The CoS is defined in the mutual SLA between the client and network SP. In the proposed TSSCF strategy, the connection requests are arranged in decreasing order of their cost value and routing is done by RWM in which the shortest path which traverses through the minimum number of domains is selected. The strategy is investigated for 1:1:1 CoS ratio, under 1:1, 3:2 and 7:3 intra and inter-domain request ratios. The results of the proposed TSSCF strategy are then compared with the existing HCSPF, HCESF and HCETF strategies on the metrics of BP, CoS BP, RUR, and newly introduced metric RI. It has been observed that the TSSCF shows significant improved performances on all metrics. The TSSCF strategy



(a) 1:1 Intra and Inter-domain requests ratio

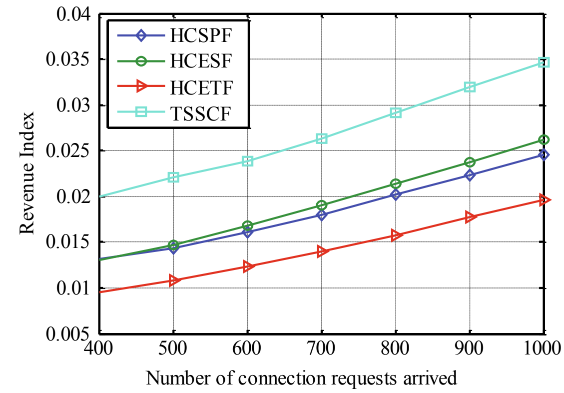


(b) 3:2 Intra and Inter-domain requests ratio

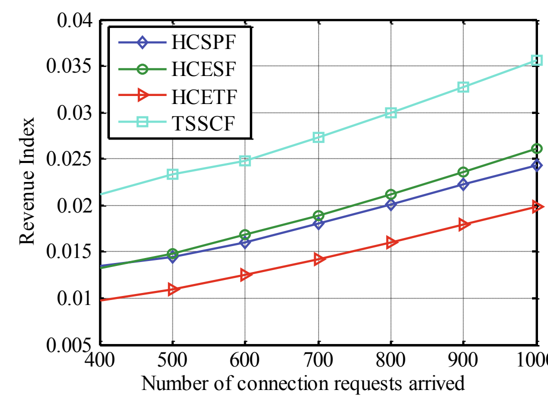


(c) 7:3 Intra and Inter-domain requests ratio

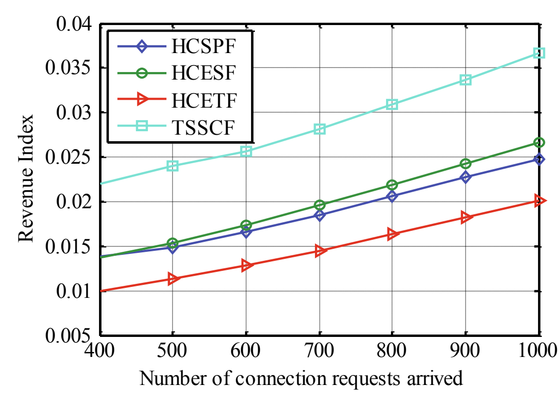
Fig. 5. Plot of RUR for (a) 1:1, (b) 3:2, and (c) 7:3 intra and inter-domain request ratios.



(a) 1:1 Intra and Inter-domain requests ratio



(b) 3:2 Intra and Inter-domain requests ratio



(c) 7:3 Intra and Inter-domain requests ratio

Fig. 6. Plot of revenue index for (a) 1:1, (b) 3:2, and (c) 7:3 intra and inter-domain request ratios.

accords priority to the connection requests based on CoS, holding time, and minimum domain traversing route. The proposed strategy shows highest value of RI which directly relates to SPs profit. Also, lower value of RUR implies that the networks resources are efficiently utilized. Following are the advantages of TSSCF strategy: (i) minimized BP, (ii) optimized resource utilization, and (iii) maximized operators/SPs revenue without any additional infrastructure or resources. In future, the traffic classification based efficient resource provisioning strategies shall be diversified for the survivable multi-domain elastic optical networks.

Table 2
Average value of network parameters for existing and proposed strategies.

Parameters	Intra and Inter-domain requests ratio	HCSPF	HCESF	HCETF	TSSCF
BP	1:1	0.0695	0.0830	0.0757	0.0295
	6:4	0.0608	0.0756	0.0678	0.0230
	7:3	0.0608	0.0737	0.0666	0.0207
RUR	1:1	1.1227	1.3091	1.2652	0.9447
	6:4	1.0894	1.2677	1.2362	0.9002
	7:3	1.0631	1.2307	1.2015	0.8654
RI	1:1	0.0162	0.0162	0.0120	0.0235
	6:4	0.0163	0.0163	0.0122	0.0245
	7:3	0.0167	0.0169	0.0125	0.0253

CRediT authorship contribution statement

Deepak Batham: Conceptualization, Methodology, Software, Validation, Writing - original draft, Writing - review & editing. **Shailendra Kumar Pathak:** Formal analysis. **Dharmendra Singh Yadav:** Visualization. **Shashi Prakash:** Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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