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Performance Comparison of Two-Step Dynamic RSAApproachesin Elastic Optical Networks

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***Abstract*— In recent years, with introduction of elasticity (flexibility) in optical networks, bandwidth utilization can be adjusted as per the requests and also, longer transmission reach and higher spectral-efficiency can be provisioned. In view of optical transmission, elastic optical networks (EONs) resort to the use of elastic frequency grids and advanced modulation formats which necessitate solutions to the novel routing and spectrum allocation (RSA) approaches. In the current work, we compare various dynamic dual step RSA approaches applicable to the EONs. Specifically, we analyze and compare various (i) k-shortest path based approaches for the routing step, and (ii) approaches for the spectrum allocation step. Our simulation results demonstrate (i) effectiveness of the RSA approaches in regard to the considered network topologies which utilize the connections' demanded bandwidth, and (ii) improvement in the shortest path first approach's performance with an increase in candidate route's numbers for a network with higher numbers of nodes and links.**

***Index Terms*—Elastic optical network, dynamic dual step RSA approach, bandwidth blocking probability, spectrum utilization ratio.**

I. INTRODUCTION

In recent years, with the emergence of elasticity (flexibility) in optical networks, the next-generation elastic optical networks (EONs) are able to (i) provision an increased capacity allocation flexibility to the heterogeneous demands by using multiple subcarriers, and (ii) create wider channels based on the demand(s) owing to the aggregation of spectrum units which are referred to as 'frequency slots (FSs)' [1, 2]. Another important feature of the EONs includes the use of various modulation formats (MFs) which differ in both, spectral-efficiency (SE) and transmission reach (TR) [3].

To accomplish elasticity, Orthogonal Frequency Division Multiplexing (OFDM) technique based EONs [4] (i) divide optical spectrum resources into units or FSs, (ii) use several orthogonal carriers (with an individual carrier being referred to as a subcarrier [5]) which are modulated, and the composite signal is then carried over an individual wavelength, via an optical fiber, with many such wavelengths being multiplexed within the fiber, and (iii) follow the ITU-T standardization [6] with a slot granularity of 12.5 GHz wherein, width of a slot corresponds to the bandwidth of an OFDM subcarrier.

In view of the EON's planning and for setting up the optical connection(s) between the node(s) pair(s), the routing and spectrum allocation (RSA) problem is required to be solved [7, 8]. The RSA approaches are subjected to the following constraints: (i) Spectrum contiguity constraint: a block of conterminous FSs are to be assigned to a request as spectrum, (ii) Spectrum continuity constraint: sequential links over an end to end route of any demand is to be allocated the same contiguous FSs, and (iii) Non-overlapping spectrum constraint: at same instant, at maximum, only one connection can occupy spectrum of the links, (iv) Transmission distance constraint: length of an end to end route, using a specific MF cannot exceed maximum transmission distance of this specific MF, and (v) Guard band constraint: two neighbouring connections are to be separated by a guard band (GB).

In literature, to satisfy the aforementioned constraints, several RSA approaches have been proposed in regard to both, static [7, 8] and dynamic scenarios [9, 10]. Of the two scenarios, considering the internet traffic's dynamic nature, the dynamic RSA approaches are of greater importance. However, the dynamic varied sized resource(s) allocation and de-allocation results in an unusable separation(s) (or gap(s)) between the FSs that are occupied. As a worst case scenario, the non-conterminous and zoned spectral resources results in connection blocking, and hence, even though the resource(s) exists, the network is unable to handle any further demands. Therefore, according to the dynamic dual step RSA approach, improperly chosen routing techniques and spectrum allocation methods lead to an increase in bandwidth blocking probability (BWBP), and hence, the aim of the dynamic RSA approaches must be to reduce the BWBP. Of the many existing dynamic solutions, the most widely used type is the dual step RSA approach [11, 12], in which, as an initial step, for a demand, search and selection for permissible connection route is conducted. In the next step, optical resource(s) are assigned to this specific route. Details of the dual step RSA approach and various simulation results obtained through its employment can be found in [11-14].

In few of the existing studies, the simulation results are presented considering only the individual steps of the dual step RSA approach. For example, the authors in [13] have proposed a routing technique for choosing a route with lowest utilization of the links, and in [15]; the authors have presented a summary of four spectrum allocation techniques, and further, have also compared the techniques. In the current study, as a novelty, we compare the various dynamic dual step RSA approaches which are applicable to the EONs. As the main contribution, we present simulation results for both steps of the dual step main contribution, we present simulation results for both steps of the dual step RSA approach. The results are presented (i) in terms of SE of the routing methods, and (ii) considering the spectrum allocation rules for considered network topologies which utilize the connections' demanded bandwidth. The rest of the paper is structured as follows: Chosen implementation approaches are detailed in Section II. In
Section III, the simulation setup is described.
Section IV presents and discusses the various obtained simulation results.Finally,
Section V concludes the study.

II. DUAL STEP RSA APPROACH

In this section, the dual step RSA approaches are described which are used for performance comparisons. The k-shortest path based approaches are used for the routing step, and for every node(s) pair(s), the candidate path(s) set is fixed and evaluated in the initial phase. In the routing step, on the arrival of a new connection demand ***BWreq*** , candidate routes are sorted and organized on the basis of a route choosing rule. Then, beginning from the top of grouped (i.e., ordered) routes, every route is examined. In order to provision connection along a route, N numbers of FSs are needed as per BWreq , and the MF which is applied. Thus, route examination extends to the evaluation and search for NFSs available set. Further, for allocation, if an available route is found, the routing step is terminated, and then, the spectrum allocation step is initialized for this specific route. In the spectrum allocation step, a spectrum allocation rule chooses NFSs available set, and also allots demand along the route. It must be noted that in the case when the routing step is unable to find the resource(s) for a given demand, this specific demand is blocked. Since a specific k-shortest path based approach is defined by a specific route choosing rule, we focus on investigation of the route choosing rules. The following sub-sections detail schemes which are chosen for the routing, and the spectrum allocation steps, respectively.

A. Routing

When In this sub-section, we describe the route choosing rules briefly. Initially, we present the approaches which have been proposed in the literature, and then we introduce a method that re-orders the route(s). In our study, we have investigated the following approaches: (i) *Shortest Path First (SHPF)* approach [9, 13] which sorts the routes in an ascending order which is based on the physical length, and then, the routes are checked one by one. (ii) *Most Slots First (MOSF)* approach [9, 13] which introduces a metricthat is defined as the total numbers of free FSs along the route links. For every route,is evaluated, and then on the basis of , the routes are sorted in a descending order. Hence, the *MOSF* approach considers utilization of the link which leads to the network load being distributed in a load balanced manner; however, assignment along the chosen route may consume more resources compared to the other candidate routes. (iii) *Largest Slots over Hops First (LSOHOF)* approach [9, 13] MOSF metricMOSF metricMOSF metric which evaluates a metric that is defined as the ratio of free resources along a route to the included links hops numbers. After the evaluation of for every route, all the candidates are sorted in terms of the decreasing value of . It must also be noted that , and hence, the chosen route has reduced hop(s) number(s), and also consumes lesser resource compared to the *MOSF* approach. (iv) *MOSF with route re-ordering (re-MOSF)* approach in which a new metric is introduced which denotes the alterations in the route(s) order(s). The considers the ratio of and the highest MF in terms of the bit per symbolwhich is supported by the route, and hence, for every route is evaluated. Then, the routes are sorted in an increasing order based on . Overall, the main aim of the *re-MOSF* approach is to guarantee the reduced use of spectrum compared to the *MOSF* approach, which is accomplished by the allocation of (a) lesser congested route(s) compared to the *SHPF* approach, and (b) shorter route(s) compared to the *MOSF* approach. LSOHOF metricLSOHOF metricLSOHOF metrichops metric metric MOSF LSOHOF □ MOSF remetric□ MOSF remetric□ MOSF metricM M metricMOSF re□ MOSF remetric□

To better understand the difference between the *MOSF* and the *re-MOSF* approaches, we use the following example: let the following five candidate routes exist viz., , which have the following demanded parameters, respectively: (i) Path lengths , (ii) MF used by is the same, and is also higher than the MF used by which also use the same MF, (iii) the evaluated metrics are represented as follows: > > > >. Further, the *SHPF* approach checks the candidate routes as per the following order: (i) , (ii) the *MOSF* approach: , and (iii) the *re-MOSF* approach: . 5 4321, , , , rrrrr5 4 3 2 1 LLLLL□ □ □ □ 32 1, rand rr5 4 rand rMOSF metric5 MOSFmetric4 MOSFmetric3 MOSFmetric2 MOSFmetric1MOSFmetric5 4321rrrrr1 2 3 4 5 rrrrr4 5 1 2 3 rrrrr

Lastly, it must be noted that the *MOSF*, *LSOHOF* and *re-MOSF* approaches consider the metrics which are evaluated dynamically (i.e., online), and which are varied during the operation of network. As an example of the aforementioned, the usage of the link (i.e., link utilization) is varied during our simulations. Further, the *MOSF* and *LSOHOF* approaches aid in traffic spread over any network.

B. Spectrum Allocation

Following the routing step, the spectrum allocation approach chooses a contiguous FSs set along the evaluated route as more than one such set may exist. Thus, the spectrum allocation rule chooses the FSs set across specific links. In this study, we investigate the first-fit (FF), exact-fit (EF) and best-fit (BF) spectrum allocation rules. Before explanation of the aforementioned rules, we introduce the N r concept of 'spectral void (SV)', which refers to free spectrum range between the existing optical connections, and further, size of such a void in terms of FSs numbers is specifically considered by the EF and BF rules.

The most common spectrum allocation rule is the FF rule [9, 13, 15] in which a demand is allocated in the initially found available FSs set along a route. The EF rule initially searches for the sized voids which are between the existing connections [14, 15]; if the sized void is found, the EF rule assigns the first free sized void; else, the FF rule is adopted. The BF rule [13] considers those voids in which the size is equal to or larger than the required , and the first smallest one is assigned; hence, the bigger voids are left for the future demands. The authors in [14] have proposed the BF rule as the smallest fit (SF) rule. N N N N N The above presented dual step RSA approaches are investigated in terms of the performance. Firstly, performance of the routing methods is evaluated followed by performance of the spectrum allocation rules.

III. SIMULATION SETUP

In this section, we detail the metrics used in our study and also introduce the simulation model with the considered assumptions. To provision flexible (elastic) transmission in EONs, in regard to the access to spectral resources and bandwidth allocation, parameters such as frequency grid and slot capacity are of importance. To investigate the RSA, as the metrics, we consider the following: (i) BWBP: the ratio of rejected demand's bandwidth and the total demanded bandwidth, and (ii) spectrum utilization ratio (SuR): the ratio of mean occupied FSs numbers and all the network resources. For simulations, following the study in [16], we consider the Deutsche Telekom (DT), and the GEANT network topologies which are shown in Fig. 2, with their various dimensions values shown in Table 1. The following is also assumed in our study: (i) an elastic grid in which, spectrum of each link is divided into 300 FSs each with a width of 12.5 GHz [6], (ii) neighboring connections with a separation by a GB of one frequency slice which amount to 12.5 GHz, and (iii) the assumed TR values of the considered MFs (each MF is characterized by M bits per symbol, and the maximum supported transmission distance), as per the study in [16], and presented in Table 2. It must also be noted that for a given route length, the highest usable MF is selected.

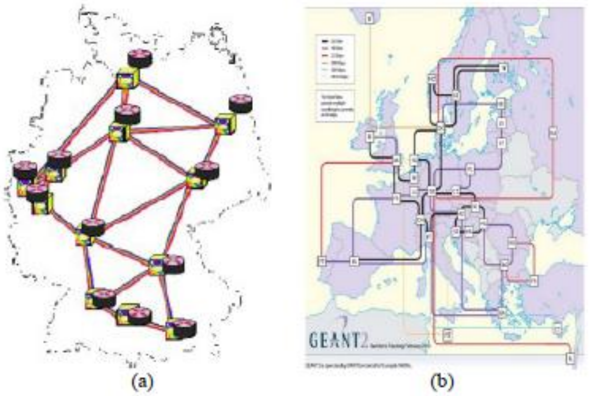

Fig. 2. Network topologies used in the simulations (a) DT, and (b) GEANT.

Table 1 Various network topology(s) characteristics used in the simulations

Network Topology	Location	Nodes numbers	Bidirectional Links numbers	Mean Link Length (km)	Maximum Link Length(km)
DT	Germany	12	40	243	459
GEANT	Europe	34	54	752	2361

Table 2 Transmission reach and bit-rate for various modulation formats.

Modulation Format	Transmission Reach (km)	M
BPSK	4000	1
QPSK	2000	2
8-QAM	1000	3
16-QAM	500	4

The demands are uniformly distributed among all directed node pairs. The demanded connection bandwidth BWreq is randomly generated under uniform distribution. In the simulations, we test two cases of BWreq ; case\
1: BWreq is chosen randomly between 10 Gbps and 200 Gbps, and case 2: BWreq is either 40 Gbps, 100 Gbps, or 400 Gbps. The FSs number N , which is required for BWreq along the route r , is evaluated as per the following equation:

$$N = \left\lceil \frac{BW_{req}}{MF_P \cdot C_{FS}} \right\rceil + GB \qquad (1)$$

where is the demanded connection bandwidth (Gbps);the MF (bit per symbol) accommodated by the route;the FS capacity employing BPSK, which is equal to 12.5 Gbps, andthe FSs number for the GB. req BWP MFFS CGB

The demands are assumed to arrive one by one as per the Poisson process with an arrival rate of and a negative exponentially distributed holding time with , and hence, traffic load is specified as Erlangs. In the simulations, owing to the non-steady nature of the network, for every traffic load, first 10,000 demands are not considered, after which, the next demands are evaluated, and further, for every point, the simulation is repeated 50 times with 95% confidence intervals evaluated using the normal distribution. □ □ 1 □ □ 8 10

In view of calculation(s) simplification, pre-computed k-shorted routes are assumed in the initial phase. In view of investigating the routing step, a candidate route(s) set with k=5 is used for the *MOSF*, *LSOHOF*, and *re-MOSF* approaches. In addition, k=10 and k=20 candidate routes are used for the *SHPF* approach. Also, in the simulations we do not consider computational complexity of various approaches, and hence, compared to the other approaches, many candidate routes paths could be found for the *SHPF* approach. Lastly, the following two points must be noted in regard to our conducted simulations (i) FF rule is used to allocate the optical resources, and (ii) for the investigation of spectrum allocation, the SHPF approach with k=3 and k=5 candidate routes is used to realize the routing step.

IV. SIMULATION RESULTS AND DISCUSSION

For simulations, we use the network topologies shown in Fig. 2, and for each topology, results are presented for various routing approaches under the case 1 and case 2, respectively. Further, obtained results are compared to provision an insight and evaluate spectrum allocation rule(s)'s performance.

A. Results for the routing step

Because Firstly, we present the results of the BWBP and the SuR with a variation of traffic load for the DT network topology under the (i) case 1 in Fig. 3 and Fig. 4, and (ii) case 2 in Fig. 5 and Fig. 6. From Fig. 3 it can be observed that, compared to the other approaches, the LSOHOF approach is able to obtain the minimum BWBP. For low traffic load values, the re-MOSF approach shows higher BWBP compared to the MOSF approach; however, when traffic load increases (specifically above 2.4) Erlangs, BWBP for the two approaches tends to be similar. It can also be observed that with an increase in the candidate route(s) number(s) (i.e., from k = 5 to 20), there occurs no improvement in the SHPF approach's performance.

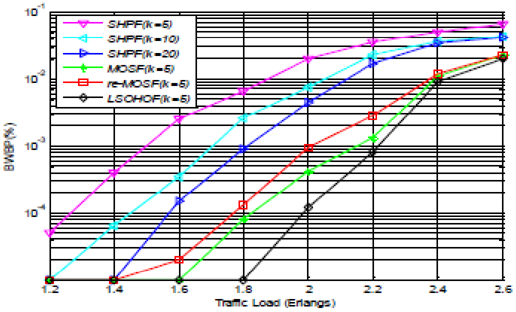

Fig. 3. BWBP with variation of traffic load for routing approaches using FF in DT topology under case 1.

From Fig. 4, in regard to the SuR results, it can be observed that compared to all routing approaches, the MOSF approach demonstrates the maximum value, whereas, the LSOHOF approach shows the minimum value. Amongst the SHPF approaches, it is observed that for low traffic load values, SuR of every approach is approximately same; however, as the traffic load increases (specifically above 1.7 Erlangs), it is seen that the SuR of SHPF(k=5) approach starts to lessen compared to that of the SHPF(k=10) and SHPF(k=20) approaches, owing to the higher BWBP of SHPF(k=5), as observed in Fig. 3.

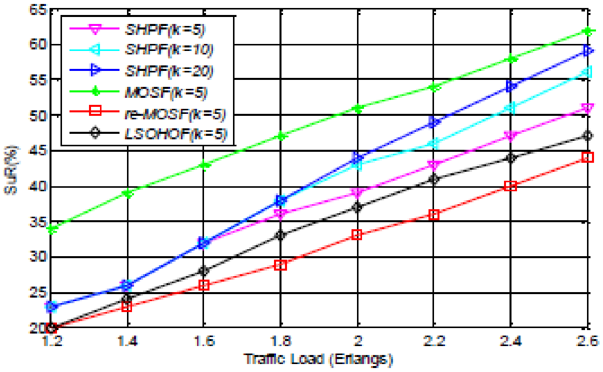

Fig. 4. SuR with variation of traffic load for routing approaches using FF inDT topology under case 1.

Considering case 2, from Fig. 5 it can be observed that compared to other routing approaches, the LSOHOF approach is able to achieve the minimum BWBP. Comparing the MOSF and re-MOSF approaches shows that BWBP for the MOSF approach is higher. Also, even with an increasing in candidate route(s) number(s), there is no improvement in performance of SHPF approach.

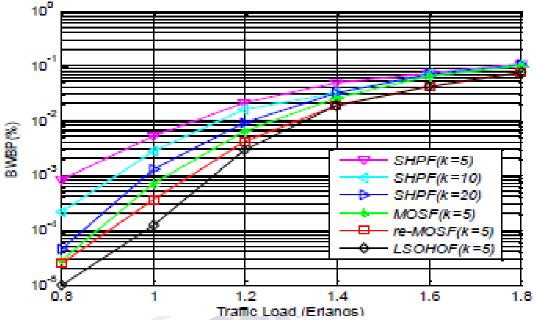

Fig. 5. BWBP with variation of traffic load for routing approaches using FF in DT topology under case 2.

From Fig. 6 it can be observed that MOSF approach has the maximum SuR value amongst all the other routing approaches. Also, MOSF rejects more requests, and provides higher BWBP compared to the re-MSF approach (see Fig. 4). It can also be observed from Fig. 5 that the SUR for MOSF is higher than the re-MOSF approach. Finally, in regard to SuR, it is seen that for SHPF approaches, the results follow the same trend as for case 1.

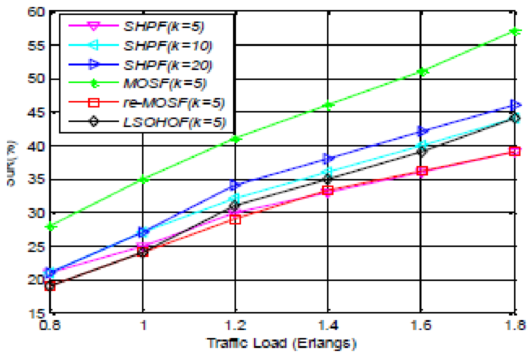

Fig. 6. SuR with variation of traffic load for routing approaches using FF in DT topology under case 2.

Next, we present the results of the BWBP and the SuR with a variation of traffic load for the GEANT network topology under the (i) case 1 in Fig. 7 and Fig. 8, and (ii) case 2 in Fig. 9 and Fig. 10.

When the GEANT topology is considered, under case 1, it can be observed that compared to other approaches, the BWBP is lowest for the re-MOSF approach (see Fig. 7). For the re-MOSF approach, the largest BWBP minimization is noticeable between 0.4 and 0.5 Erlangs. Also, for the aforementioned traffic load value range, BWBP values are approximately the same for the SHPF(k=20) and the MOSF approaches. In addition, for a traffic load value greater than 0.5 Erlangs, the BWBP values for the SHPF(k=15), re-MOSF and LSOHOF is observed to be approximately the same.

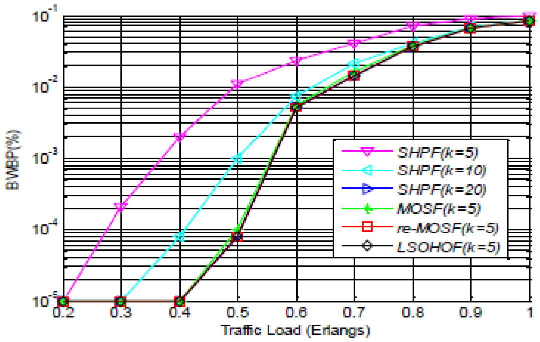

Fig. 7. BWBP with variation of traffic load for routing approaches using FF in GEANT topology under case 1.

In regard to the SuR values, from Fig. 8 it can be observed that the MOSF approach has the largest SuR even though its BWBP is higher than re-MOSF, SHPF(k=20), and LSOHOF approaches. Also, for the SHPF approaches, it can be seen that the trend is similar to the ones obtained for the DT topology scenario.

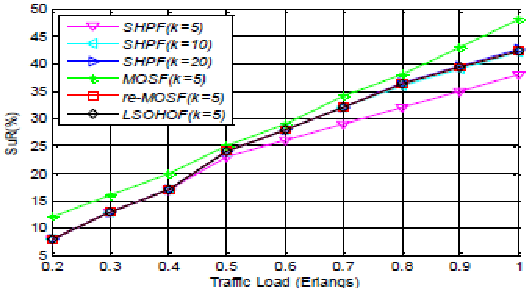

Fig. 8. SuR with variation of traffic load for routing approaches using FF in GEANT topology under case 1.

For the GEANT topology under case 2, it can be observed from Fig. 9 that SHPF(k=20) approach achieves minimum BWBP compared to all the other routing approaches, and lastly, Fig. 10 shows that in regard to SuR, the SHPF methods again follow same trend as in the scenario of case 1.

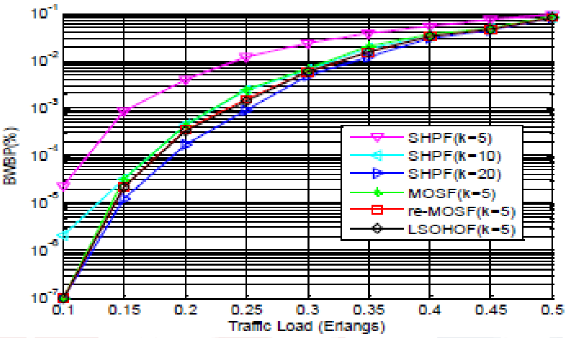

Fig. 9. BWBP with variation of traffic load for routing approaches using FF in GEANT topology under case 2.

in GEANT topology under case 2.

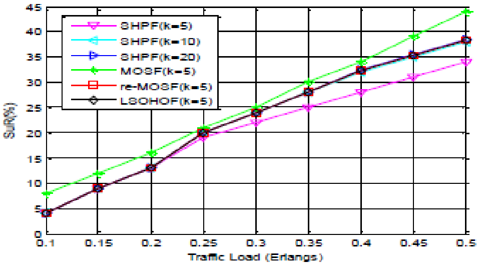

Fig. 10. SuR with variation of traffic load for routing approaches using FF in GEANT topology under case 2.

Overall, from the aforementioned obtained results, it can be inferred that, amongst all the approaches and considering both topologies, SHPF(k=5) approach shows worst performance. The results under case 1 and case 2 show that the LSOHOF and re-MOSF approaches, respectively may be the 'best' transmission choice when the considered topology is DT. Further, for the GEANT topology, the results under case 1 and case 2 show that the re-MOSF and the SHPF(k=20) approach, respectively may be the 'best' transmission choice.

B. Results of the spectrum allocation step

Number Next, we conduct the simulations in view of comparing the performance of various spectrum allocation approaches. In these simulations, for route determination, SHPF approach with k = 3 and k = 5 candidate routes is adopted. The variation of BWBP with traffic load for various spectrum allocation approaches considering the DT topology under case 1 and case 2 is shown in Fig. 11 and Fig. 12, respectively. Further, variation of BWBP with traffic load for various spectrum allocation approaches considering GEANT topology under case 1 and case 2 is shown in Fig. 13 and Fig. 14, respectively. Also, as additional results, we present the average BWBP values for the spectrum allocation rules Table 3 and Table 4 for the DT and GEANT topology, respectively. From Fig. 11 it can be observed that for the DT topology under case 1, FF rule shows the worst performance compared to all the other rules. Also, compared to the EF and FF rules, the BF rule is seen to obtain the best performance in terms of BWBP reduction. As can be noted from Table 3, BWBP values are same for BF and EF rules. Also, an interesting point is noted that candidate route(s) number(s) has no effect on the ranking (i.e., best to worst) performance order amongst various spectrum allocation approaches. For instance, for k=3, lowest BWBP is incurred by BF rule, followed by EF, and finally, the FF rule which achieves the highest BWBP.

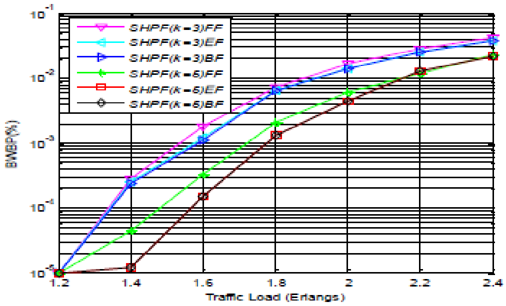

Fig. 11. BWBP with variation of traffic load for spectrum allocation approaches using FF in DT topology under case 1.

For the DT topology under case 2 (see Fig.12) the results show that BF rule shows worst performance in comparison to all the other rules. Also, in regard to the ranking (i.e., best to worst) performance order amongst the various spectrum allocation approaches, lowest BWBP is achieved by the EF rule, followed by the FF rule, and finally, the BF rule, which shows the highest and same BWBP for k=3 and k=5.

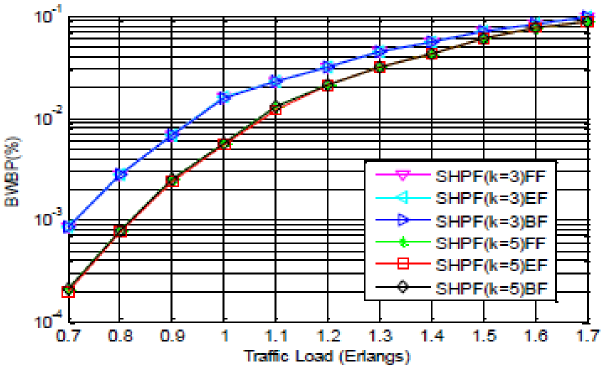

Fig. 12. BWBP with variation of traffic load for spectrum allocation approaches using FF in DT topology under case 2.

Table 3 Average BWBP value for the slot assignment approaches considering the DT network topology.

Method	Case 1	Case 2
SHPF($k = 3$)FF	0.0198 ± 0.0004	0.0712 ± 0.0006
SHPF($k = 3$)EF	0.0178 ± 0.0002	0.0680 ± 0.0005
SHPF($k = 3$)BF	0.0176 ± 0.0003	0.0673 ± 0.0004
SHPF($k = 5$)FF	0.0110 ± 0.0002	0.0572 ± 0.0005
SHPF($k = 5$)EF	0.0096 ± 0.0002	0.0568 ± 0.0006
SHPF($k = 5$)BF	0.0092 ± 0.0001	0.0542 ± 0.0005

In comparison to the DT topology, the results for GEANT topology show that the FF rule achieves the best performance (see Fig. 13 and Fig. 14). Also, it can be noted from Table 4 that the BWBP values of the EF rule are very similar to the FF rule owing to the fact that a void(s) lack with a size that is equal to the FSs number required results in the EF rule to assign the resources in a FF manner. Analogous to the DT topology scenario, in the GEANT topology also the available candidate route(s) number(s) has no influence on approach's order in terms of the performance for case 1 and case 2.

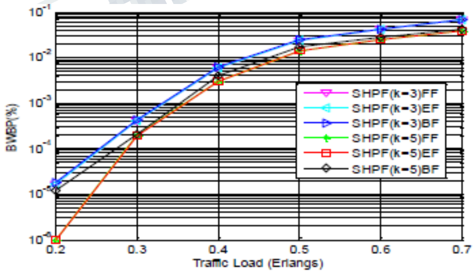

Fig. 13. BWBP with variation of traffic load for spectrum allocation approaches using FF in GEANT topology under case 1.

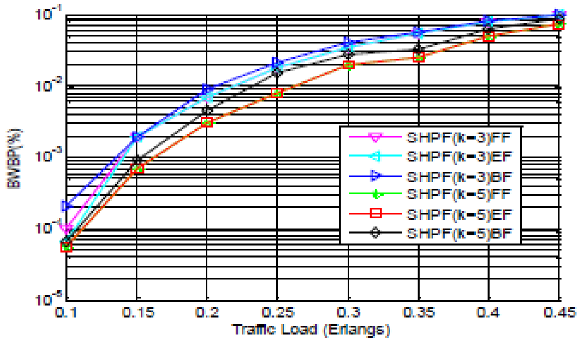

Fig. 14. BWBP with variation of traffic load for spectrum allocation approaches using FF in GEANT topology under case 2.

Table 4 Average BWBP value for the slot assignment approaches considering the GEANT network topology.

Method	Case 1	Case 2
SHPF($k = 3$)FF	0.0454 ± 0.0005	0.0448 ± 0.0007
SHPF($k = 3$)EF	0.0455 ± 0.0006	0.0451 ± 0.0008
SHPF($k = 3$)BF	0.0474 ± 0.0005	0.0489 ± 0.0007
SHPF($k = 5$)FF	0.0342 ± 0.0006	0.0335 ± 0.0005
SHPF($k = 5$)EF	0.0348 ± 0.0005	0.0342 ± 0.0007
SHPF($k = 5$)BF	0.0364 ± 0.0008	0.0382 ± 0.0009

Overall, from the aforementioned results it can be observed that the FF rule's best performance in one network topology does not guarantee similar results in terms of BWBP reduction in another network topology.

V. CONCLUSION

In this study, we have we compared the various dynamic dual step RSA approaches which are applicable for the EONs. In view of the aforementioned, initially the k-shortest path based approaches are implemented, which are followed by the application of a three slot assignment rule. The detailed approaches are evaluated through the simulations considering a Poisson traffic model, and two realistic network topologies which exploit two demanded bandwidth cases. The obtained simulation results demonstrate performance

effectiveness of the RSA approaches in terms of bandwidth blocking probability's reduction. Further, with neglect on the computation complexity, it is observed that with an increase in the candidate route(s) numbers, performance of the shortest path approach improves for a network topology with higher numbers of nodes and links (i.e., the GEANT network). Also, alteration of ordering routes in the Most Slots First approach improves the performance in three of the four analyzed cases.

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