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The Recent Contributions of Routing and Spectrum Assignment Algorithms in Elastic Optical Network (EON)

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Abstract*: *The speed is an important aspect of the current generation of Internet users. Currently WDM based optical fiber technology provides a good solution, still it is insufficient for future growth of cloud data centers, social media applications, online gaming, high definition video streaming and broadcasting, etc. The Elastic Optical Networks (EONs) recently added an energetic research field in the fiber-optic network. The EON is next generation of network that can provide flexibly in spectrum, improved service provisioning and accommodate high bandwidth applications in the single channel. In WDM, the Routing and Wavelength Assignment (RWA) is problem, likewise the EON has Routing and Spectrum Assignment (RSA) problem. In RSA problem the frequency slots (FSs) should allocate in continuity and contiguous manner for every demand request. Many research articles are published over the years to find the new feasible solutions for the RSA problem. This paper presents the recent approaches based on routing and spectrum assignment problem and fragmentation schemes which examines and compare the performance, features, and complexity of the approaches. This paper provides merits and demerits of existing approaches in RSA problem and provides more information about the approaches it will help for feature research.

Keywords* : *Routing and Spectrum Assignment (RSA), Elastic Optical Networks (EONs), Spectrum Assignment (SA), Routing, Modulation and Spectrum Assignment (RMSA).

I. INTRODUCTION

The growth of mobile users, social media applications, high volume cloud datacenters, and online high definition video broadcast has demanding high range transmission capacity networks. As result a high throughput bandwidth, flexible and low cost scalable networks are needed. Many network companies are recently facing these issues due to high bandwidth applications, and they are not adequately utilizing the spectrum capacity. Currently, wavelength-division multiplexing (WDM) based fixed grid fiber optics provides an excellent solution for high bandwidth applications, but it's still insufficient for the upcoming 5th generation telecommunication (5G) systems. Recently the elastic optical network (EON) provides promising solutions for the upcoming generations of networks. The main goal of EON is that a flexible spectrum slot (FSs) which provides a better way to network transmission in the light path, and it utilizes the spectrum more efficiently [1]. EONs are OFDM-based spectrum efficient, flexible and adaptive networks. Well - equipped flexible transceiver with adaptable network elements are proposed recently as an improvement over traditional networks. EON provides an alternate to the single carrier modulation technique by dividing data stream and multiplexed onto multiple consecutive low rate subcarriers and it increases transmission data rate [2].

The traditional WDM-based fixed grid optical network divides the channel space either 50GHz or 100 GHz called the spectrum slots. For example in 50GHz channel space capable to carry 100Gbps in single transmission light path. The 37.5GHz spectrum slot utilized from 50GHz carrying transmission bit rate and 13.5GHz (2 x 6.25GHz) used as spectrum guard band for avoiding light interference. It wastes the spectrum space when the demand request is short bit rate and also it needs unnecessary spectrum guard for large single demand. When the short bit rate demands utilized minimum amount of spectrum slots. The EON provides channel space either 6.25 GHz or 12.5 GHz as frequency slots. So it can accommodate more bandwidth requirements and utilized spectrum efficiently. The Fig.1. Show spectrum provision model between current fixed ITU-T optical grid and EON. The EON provides better spectrum utilization. The term elastic, it means flexibility at transceivers and adaptable spectrum slots. The Key components of EONs are, 1) Bandwidth Variable – Wavelength Cross Connects (BV-WXC), 2) Flexible Optical Spectrum and 3) Sliceable - Bandwidth Variable Transponder (S-BVTs). The EON also provides promising solutions for variable demand bandwidth. It allocates FSs and flexible modulation format based on the distance between intermediate the nodes. The EON also supports sliceable variable transponders (S-BVTs) that are capable of dynamically tuned bit rate and bandwidth between reach and capacity [3]. Bandwidth variable wavelength selective switches (BV-WSS) which are used to allocate the spectrum efficiently based on the bandwidth requirements on the optical path according to the traffic in the network [4]. The EON provides super-channel to avoid wasting of unnecessary spectrum guard bands that hold a single transmission light path channel for required demands, unlike a fixed grid used multiple channels for unique demand and waste the spectrum [5].

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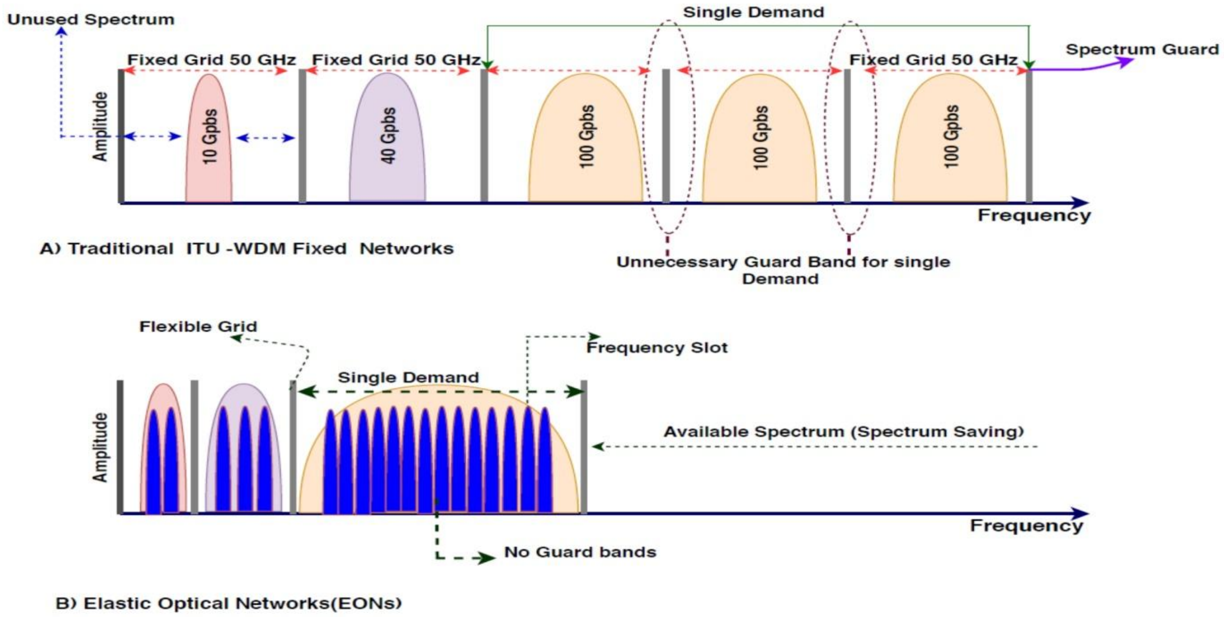

Fig.1. Traditional WDM fixed grid Vs EON

An efficient network route path scheduling and dynamic spectrum allocation provide benefits from the adjustable data rate. Such adjustable scheduling deserves high transmission capability over the high traffic networks. One of the vital complications in EON is routing and spectrum assignment (RSA), currently many research contributions involves based on the RSA and fragmentation issues in EON. The RSA problem which is very similar to routing and wavelength assignment (RWA) problem in an optical network, but the significant difference is RSA has additional contiguity constraints and contiguous allocation of Frequency slots for demand bandwidth [6].

II. CHALLENGES IN EON

The Elastic Optical Network (EON) is a future generation of network model. It is a great solution for future network traffic and high bandwidth data rates. The main challenging task in EON is Routing and Spectrum Assignment (RSA), the number research concept and formulation provides from various researcher to find the better solution for RSA. Another key challenge in EON is the fragmentation, when the connection accommodation and release the spectrum slots [7].

In RSA, each variable demand bandwidth requests and traffic as input to allocate light route path of optical network and space slots of the spectrum with efficient utilization. The FSs should allocate contiguously (contiguous manner). It has provided spectrum same for overall routing links, ie., continuity constraint and each request should include a non-overlapping optical link (allocate disjoint spectrum slots). Additionally, inconstant traffic conditions to allocate and release the spectrum resources may lead to the spectrum fragmentation issue.

In the last decade, many research articles and novel algorithms are proposed based on the RSA problem in EON. The current speed of the network and compactibility with all high bandwidth applications is essential aid. The survey of RSA problem consists of two categories, one is spectrum continuity allocation and next categories assign flexible modulation format between the light path nodes. There are some review articles published about RSA in EON [2, 4, 7, 8 and 9]. In [4] presents detailed comparative analysis of Routing and Spectrum Assignment and Routing, Adaptive modulation and Spectrum Assignment algorithms performance and complexity in EON. The detailed study report of OFDM based EON architecture and features are presented in [2]. The spectrum assignment techniques are compared with performance standard metrics in [8 and 9]. This review article presents contribution of recent research articles that are classified into three categories first RSA based approaches, second RMSA based approaches, and third fragmentation and physical layer impairments aware schemes. Each categorized algorithms are compared with standard metrics like spectrum utilization ratio, support traffic type, and computational complexity. Current speed of the network and compactibility with all high bandwidth applications is essential aid. The study of RSA problem consists of two categories, one is spectrum continuity allocation and next categories assign flexible modulation format between the light path nodes. There are some review articles published about RSA in EON [2, 4, 8 and 9]. In [4] presents detailed comparative analysis of RSA and RMSA algorithms performance and complexity in EON. The detailed study report of OFDM based EON architecture and features are presented in [2]. The spectrum assignment techniques are compared with performance standard metrics in [8 and 9]. This review article presents contribution of recent research articles that are classified into three categories first RSA based approaches, second RMSA based approaches, and third fragmentation and physical layer impairments aware schemes. Each categorized algorithms are compared with standard metrics like spectrum utilization ratio, support traffic type, and computational complexity.

III. ROUTING AND SPECTRUM ASSIGNMENT ALGORITHM BASED APPROACHES

Mohammad Hadi et al [10] proposed a new dynamic resource assignment method for the metro elastic optical network. This approach addressed the issues in service level provisions and firmness of network constraints. This method has formulated new ILP by using Lyapunov drift optimization. Normally ILP is Non-deterministic polynomial-time it is not suitable for dynamic traffic but it considers the dynamic network traffic and vary in demands. Each new connection request initially calculates the required bandwidth and cost distance according to the service level agreement. Lightpath routing is assigned by using K- Shortest path algorithm. When the new request Ri on selected path Pi should provide contiguous frequency slots (FSs). The Lyapunov penalty method is used to block the request when the new request demand and selected path does not satisfy the constraint.

Yuxin Xu et al [11] addressed the physical layer estimation to provide an efficient RSA approach for EON. The good physical layer impairments (PLIs) estimation provides better efficient transmission and average spectrum utilization. These approaches estimate the PLIs in the proper way to provide efficient RSA problem. This method introduce a link-based MILP and heuristic approach called sequential iterative optimization (SIO) that reduces the computational complexity and produce better blocking performance over other ILP based approaches. The SIO algorithm adjusts regenerator's places and spectrum slot provisioning based on the incoming demands concurrently. This research work has produced a new solution for transmission reach based on the existing Gaussian Noise (GN) model.

Panayiotou et al [12] presents a framework that is adaptable to network traffic and time-varying demands. This framework treats network connection separately based on network load and route traffic. The authors formulated a new method for Bandwidth Assignment (BA) called Partially Observable Markov Decision Process (POMDP). It is based on partial reinforcement learning model which is accomplished unceasingly and autonomously for each connection demand according to the traffic demand behaviour. This framework has two controllers 1) local controller 2) Central network controller. The central controller determines whether each demand met the Quality of service (QoS). If the incoming demands not met the QoS the central controller modifies the training process according to applied RL method. The local controller has monitor traffic data and model training with reward function R. The next phase of the framework is spectrum assignment that formulates new ILP and also heuristic approach for complex network. If ILP formulation not produces optimal solution, then the heuristic approach assigns the spectrum slot according to the bandwidth.

J. Wu et al [13] formulates a new MILP for calculating route path selection and spectrum assignment algorithm called next – state- aware (NSA) spectrum assignment. This MILP allows selecting a routing light path based on some pre-inspected procedures instead of finding a better path each time for all incoming demands. Whenever a new request arrives at the network light path that accommodates and next path selection is made by predetermined probabilities. The next NSA spectrum allocation algorithm tries to assign the spectrum slot for each new request after selecting the path according to the current occupied slots. If the request is not satisfied then the connection must block selected the route path.

Boyuan Yan et al [14] provide a new solution for network traffic distribution and RSA problem. The traffic distribution is an important role when variety of Internet users uses different network services over different times and dissimilar places. The authors mathematically express a new model called Onion Tidal Traffic Model (OTTM). The OTTM is accounts the network traffic into three groups 1) Random connection arrivals, 2) business peak hour's arrivals, 3) The local inhabited peak hour's arrivals. The trigonometric sins are used to formulate the traffic flow and the connection producer builds to for each arrival P0….Pn according to tidal traffic. The authors introduced two new tidal-traffic aware algorithms called pre-detour RSA (PD- RSA) and pre-detour k-shortest paths RSA (PDK-RSA). All greedy algorithm based approaches allocates spectrum slots in high load network before the traffic tidal is rising. So it may lead to high blocking probability and less utilization of spectrum resources. The PD-RSA provides a better solution for above problem by increasing the spectrum utilization and reduces blocking probability. The PDK-RSA algorithm calculates the number feasible path possibility in a simple manner.

A. N. Khan [15] provides a new optimization model to reduce the cost between network light path node pairs. This model consists of two stages, early stage to find the routing data which is exploited on operational traffic. Next stage introduces a new RSA approach to minimize the cost routing path between source to target node. When a certain bandwidth request arrives at the network path, the request will stay for some finite time period until spectrum resources is available then it departs. The frequency slots are assigned based on the first fit heuristic method where each incoming demands with continuity constraints and contiguous slots. When the contiguous slots are not available then requested bandwidth are blocked.

J.-C. Bermond and F. Z. Moataz [16] presents a new spectrum allocation (SA) scheme for assigning the minimum number of spectrum slots and maximum utilization of the spectrum for each new request. This scheme focus on some special cases like tree or star (or binary star tree) based networks. Literally SA is NP-hard even the wavelength assignment (WA) tractable in the network path. First the greedy algorithm is used to assign the spectrum slots then the next continuation of the workflows finding the solution for the Interval coloring (IC) problem or contiguous coloring problem. The boxing vertices techniques are used for approximation in IC interval graphs. It provides solutions for the dynamic storage allocation problem (DSA). The motivation of DSA is to minimize the storage usage of network paths.

P. Afsharlar et al [17] introduced a new spectrum allocation method namely Delayed Spectrum Allocation (DSA). It majorly focused on limited assignment of spectrum resources when the overlapping incoming demands on to a light path of the network. The DSA algorithm works on basic principle of Delayed allocation (DA) in WDM networks. This algorithm divided into different two phases.

The first phase is Request Provision Phase (RPP), in this phase the shortest path is calculated by using Dijkstra's algorithm and then each demand arrival is calculated (R1…Rn) and provide resource at the time of arrival to the network by RPP. The second phase is Request Allocation Phase (RAP), it receive the request demand then it ensure if possible to provide necessary spectrum slots with continuity and contiguous constraint then it allow to allocate. Otherwise, rearrange the request and tries to re-provision the resource, this approach reduces the blocking probability ratio and increase the spectrum efficiency.

Talebi and G. N. Rouskas [18] acquaint to find the solution for spectrum allocation by using the Distance Adaptive RSA. Usually the problem arise when trade-off between spectrum resources and reach. It may lead to the choice of modulation format and inefficient spectrum utilization. This work allocates the spectrum demand matrix into two stages,1) traffic demand generation - this phase calculates the traffic rate and distance between the node pair 2) DA spectrum allocation – this phase calculates the number of spectrum slot needed for each request depends upon data rate and distance (ie., Lightpath length). The DA-RSA reduces the computational complexity of spectrum assignment.

IV. ROUTING, MODULATION, AND SPECTRUM ASSIGNMENT ALGORITHM BASED APPROACHES (RMSA)

Pedro M. Moura and Nelson L. S. da Fonseca [19] proposed four different algorithms Routing, Core, Modulation and Spectrum Assignment (RCMLSA) based on two image processing techniques namely Connected Component Labeling (CCL) and Inscribed Rectangles Algorithm (IRA). This method aims to reduce the subcarrier blocking ratio and efficiently increase the spectrum utilization in the multicore fiber with the low computational cost. The CCL algorithm is mainly used in image and pattern recognition to identify fingerprint, character identification, and some other uses. This method applies the CCL algorithm to identify the allocated slots in the spectrum and satisfy contiguity constriction for remaining spectrum slots. The CCL algorithm determines in the spectrum slots image by examining the connectivity of the pixel of that image. The 4 – connectivity and 8 – connectivity these two different connectivity models identify the spectrum slots. Whether objects are in the connected pixels that labeled by 1 otherwise it's labeled by 0. After towards applied largest rectangle based Inscribed Rectangles Algorithm (IRA) to divide the lightpaths into lesser cores, accordingly demanding at least fewer band guards and producing lesser cross talk concerning the coupled cores. In this method authors set three conditions must verify the available spectrum slots 1,) Spectrum slot should not allocate other light paths 2,) The Signal to Noise Ratio should not lesser than the threshold value for corresponding spectrum slot 3,) The light path containing spectrum slot must have an acceptable cross talk. The algorithm extends with four fitting policies 1,) Connected Component Labeling – Best – Fit policies minimize the spectrum wastage which inhibits spectrum fragmentation and non –contiguous spectrum slot cannot assign upcoming new requests 2,) Connected Component Labeling – Random-Fit policies which is allocated random region for random traffic demands in the light path this will avoid inter-core cross talk 3,) Inscribed Rectangles Algorithm- Minimal –Blocking this algorithm is to allocate a single core for the lightpaths on every occasion possible, possibly decreasing the cross talk, subsequently the spectrum in contiguous cores is not used 4,) Inscribed Rectangles Algorithm- Minimal –crosstalk this policy to allocating the request based on random weighted function and focus to reduce the crosstalk.

Mohsen Yaghubi-Namaad et al [20] proposed a new Routing, Modulation level, Space and Spectrum assignment Algorithm (RMLSSA) by using Integer Linear Programming (ILP) and stepwise greedy approach. RMLSSA is formulated path based ILP on steady-state network traffic and achieve the optimal solution for small networks, but ILP is not suitable for complex networks. Then the authors introduce a heuristic-based algorithm stepwise greedy to achieve a near-optimal solution for large and complex networks. The ILP formulation attempts to resolve the network forecasting stage with static traffic, thus there is no congested connection request. This method aims to achieve optical transmission without effect on other channels. The ILP formulation reacts in contradiction to the existing crosstalk. Three parameters to produce the quality of optical transmission 1,) Cross talk control and reduce by guard bands 2,) each light path can be allocated with space contiguity constraints 3,) Third parameter Lpmod can be fixed maximum possible modulation level achieve tolerable cross talk. The four decision variables used in ILP formulation these variable sets and allocated spectrum slot and modulation level based on demand and distance of the optical path. The second phase is a heuristic-based approach for the large and complex optical network topology. In this phase, the authors used two phases of the stepwise greedy algorithm with four sorting policies for RMLSSA. That sorting policies allocated space and spectrum for required frequency slots and increase more utilization of the spectrum.

Elham Ehsani Moghaddam et al [21] proposed a novel Routing, Modulation and Spectrum Assignment (RMSA) method for Survivability in EON with support multiclass traffic demand. In this method, authors formulated new Integer linear programming (ILP) to giving the solution to Routing, Modulation level spectrum scheduling problems in EON. Then they are used some heuristic-based algorithms to reduce the complexity of large scale networks while using ILP. This approach tries to achieve optimal solution both static and dynamic traffic stresses in EON. This technique attempts to choose the routing paths that stability the link bandwidth convention while exploiting the lesser number of frequencies slices. The three approaches used for Spectrum Allocation and scheduling are following 1) Least Time to Wait (LTW) , 2) Least Starting Frequency slice index (LSF) and 3) Least TF parameter (LTF). In Addition, they are introducing one more scheme called Spectrum window plane (SWP) used for a feasible path of each spectrum window. This method is evaluated with BBP, Average initial delay and spectrum utilization efficiency and it performed well with less computation run time. Hong Guo et al [22] proposes three mechanisms and placement approaches for the regenerator and share that regenerator among the nodes to reduce the bandwidth blocking probability (BBP) and heuristic-based algorithm provides adaptive modulation and spectrum adaptation of each light path .

This approach covers Regenerator distribution, Flexible modulation, Routing and Spectrum Assignment (RMRS) problem in a shared backup path protection based EON. This approach aims to reduce the network resources when the Shared Backup Path Protection (SBPP) is implemented by maximizing the regenerators and spectrum sharing. The heuristic-based algorithm having three steps 1) finds all possible routes between source and destination and corresponding protection routes for each request. 2). Next, try to establish the working light paths and placed a regenerator between all intermediate nodes. Calculate the total number of frequency slots (FSs) for every fiber link. 3). finally, improve network BBP performance by increasing the number of regenerators between the intermediate nodes. These regenerator placement approaches give better network utilization compare to modulation format change algorithms but this method more cost-effective.

Zheyu Fan et al [23] propose a new scheme for All-optical Multicast Routing, Modulation and Spectrum Assignment problems under in cooperation static and dynamic traffic loads. For static traffic authors formulated new ILP to obtain the optimal solution for unicast request. That path link ILP model uses several subtree methods to serve every request and gives solution individual spectrum allocation requested subtrees. In that ILP formulation guard band as fixed size and also this varies based on the modulation it helps spectrum utilization efficiency. For multicast requests in ILP models is not time effective and it is not fit for large complex networks. So Authors propose three heuristic-based algorithms for multicast requests, one for a group of the destinations which some portions of paths can share to every fiber links to single subtree. First algorithm namely K- Shortest path based tree (KSPT) used to reduce the Bandwidth Variable Transponder (BVT) usage. It tries to serve separately multicast demand in a single path tree.

Oliveira and Fonseca [24] proposed protection against failure in a light path algorithm called ProtEcting, Routing, modulation Format, corE and speCTrum Allocation (PERFECTA). This algorithm introduces to find the shortest path as a primary path and that engage p-cycle as the backup path. This approach not only provides protection also provides adaptive modulation formats based on the distance between the communication nodes. The algorithm finds all shortest paths between source and terminus nodes. Then it chooses a very less expense cost path with the constraint of continuity and contiguous provision of frequency slots. If the path is not available or satisfactory the constraint then it will block the request demand. If it satisfies the constraints p cycle path provide protect that light path for existing request and also the new demand requests. This approach has much restoration time.

Vale and Almeida Jr [25] presented a new RMSA algorithm called Power, Routing, Modulation Level and Spectrum Assignment (PRMLSA) which is considered the physical layer effects on the EON. This work mainly focused on assigning power of each light signal self-sufficiently, Because of Amplified Spontaneous Emission (ASE) noise impairments in the light signals and Non-linearity optical path in a dynamic scenario. This algorithm divides the work into three stages for the first stages to calculate the incoming demands bitrate and find the distance between the communication nodes. After calculating the distance computes the network traffic load. The second stage of algorithm decides the incoming demands can allow or block by using three constrains 1) if the spectrum is not available 2) ASE Threshold has existed over Optical signal to noise ratio (OSNR) 3) ASE + Non-linearity impairments (NLIs) does not reach OSNR threshold. Those three constraints should satisfy all incoming demands to admit and provide resources for the transmission. Otherwise, the incoming demand should block at least once.

V. THE COMPARISON OF RSA AND RMSA ALGORITHMS

In this section, the different RSA and RMSA algorithms are compared based on the features, routing mechanism and supporting traffic in the network. The table I show a comparison between recent RSA algorithms distinct features, routing mechanisms of each algorithm and supporting traffic type. Some algorithms that support the static traffic type that means preliminary stages or circumstances are stated according to the assumed traffic matrix. In dynamic traffic the situations can adopt any traffic demand matrix that means it can support when the conditions rapidly change from the time. The competence of the RSA algorithms is contingent on granularity of its origin. The slot-based algorithms are high complexity compare with sub-carrier-based algorithms. Because the number of subcarriers is less compare with frequency slots. The LDO and PD-RSA is providing feasible solutions to dynamic traffic situation. In PD-RSA frequency slot-based algorithms are less complexity compare with LDO but LDO spectrum utilization and bandwidth blocking probability improved when the high traffic load. The DA-RSA algorithms provide effective routing and spectrum allocation in dynamic load and traffic. In addition the spectrum utilization and number blocking need to improve when the high traffic intensity. The MPS and NSA algorithm is capable to provide multipath routing selection of the single request; this algorithm calculated next state of availability that helps to utilize the spectrum slots contiguous manner.

The spectrum assignment techniques, network topology used and computational complexity compared with RSA algorithms and is presented in table II. The First Fit (FF) techniques are used for majority of the spectrum assignment algorithms. The FF is simple and convenient and less complexity to assign the frequency slot, but it is suitable only static situation in the dynamic situation first last exact fit provide better achievement in spectrum allocation. The Exact Fit (EF) reduces fragmentation complexity of the dynamic network. But it will achieve after some complication process and also this policy using FF to assign the spectrum. The First Last Fit policy is separated the spectrum slots then it will allow finding lower spectrum and higher spectrum connection with two different partitions. In MPS-NSA [13] used next state aware allocation policy is good for fragmentation spectrum because each request light path connection assigned then it will find to the free space spectrum slot for needed so it reduces the number of blocks.

Table I. RSA Algorithms Features, Routing mechanism used and Support traffic type.

Algorithm	Features	Routing Mechanism	Traffic Support
Lyapunov Drift Optimization [10]	1. This work more flexible between network resources. 2. Spectrum allocation and reallocation are in a very short time.	k shortest path routing	Dynamic/ Metro EON
CLGN and sequential iterative optimization (SIO) [11]	1. This approach provides exact PLIs estimation. 2. The SIO saved a more spectrum scalable manner.	k shortest path routing	Static Traffic
PODMP [12]	1. Allocating the bandwidth requirements is efficient.	Dijkstra's algorithm	Static Traffic
MPS and NSA [13]	1. Path selection made dynamically and choose multipath for a single request. 2. Improve Spectrum efficiency.	Multipath selection method	Dynamic Traffic
OTTM (PD-RSA and PDK-RSA) [14]	1. The Frequency slots are assigned by the end to end connection. 2. Reduce blocking probability	Dijkstra's algorithm and Yen's algorithm[17]	Dynamic Traffic
HRSA [15]	1. Reduce incoming blocking demands in the dynamic scenario.	Least Cost Routing algorithm	Dynamic Traffic
DSA [16]	1. This approach advances in resource utilization. 2. The delayed allocations provide a much better slot promising for incoming demands.	Static fixed-path routing	Static /Dynamic Traffic
DA-RSA [17]	1. Try to reduce the computational complexity and utilize spectrum slots in a fair manner.	Yen's algorithm[17]	Dynamic Traffic

The LDO [10] uses the Lyapunov penalty coefficient that helps to allocate and reallocate the spectrum resources periodically based on intention of traffic flows. Also, LDO provides much better solutions defragmentation and produce the higher spectrum resource utilization under large number of the connection request.

In table III presented different routing mechanisms, support traffic type and features of RMSA based approaches. The RMSA algorithms are also compared very similar to RSA algorithms comparison presented earlier in this section. The RMSA algorithms are used different routing mechanism and spectrum assignment techniques for reducing the complexity and increase the spectrum utilization. The heuristic algorithms provide better solutions and join heuristic algorithms for large networks. The Channel-based techniques such as RCMLSA and RMSA have less computational complexity compare with FSs based algorithms (AOM-RMSA).

The spectrum assignment techniques, network topology used and computational complexity compared with RMSA algorithms and presented in table IV. The static RSA and RMSA algorithms try to reduce the bandwidth blocking to increase the transmission rate. The dynamic RSA and RMSA algorithms target improve spectrum utilization. To compare all RSA and RMSA algorithms based on NSFNET 14 node 21 bidirectional links topology. The testing conditions for simulation with three traffic intensities (50,100,150 Erlangs Distribution) and different traffic loads.

The spectrum utilization (SU) can be calculated by following equations 1,

$$SU=\frac{\sum \mathbf{UFSs}}{\mathbf{MFSI\ X\ Cp\ X\ number\ of\ links}} \qquad \mathbf{(1)}$$

Where UFSs are the total utilized frequency slot, MFSI is the maximum utilized frequency slot index and Cp is spatial paths. In figure 2 shows spectrum utilization of RSA algorithms with two different spatial paths and with respective network loads (60, 80). The LDA and PODMP algorithms provide much better spectrum utilization compare with other algorithms under dynamic traffic.

Table II. RSA algorithms Spectrum Assignment Techniques, Network Topology used and Computational Complexity of Algorithms.

Algorithm	Spectrum Assignment Techniques	Network Topology Used	Computational Complexity
Lyapunov Drift Optimization [10]	Lyapunov drift optimization	66 Node 70 optical links Metro EON Topology	$O(k \times B \times W \times N \times \|L\|)$ k – is no of candidate shortest paths, B- is Bandwidth, W- Frequency slot bandwidth, N – is number of requests and L – is Lyapunov penalty coefficient
CLGN and (SIO) [11]	Random Fit	NSFNET 24 Nodes 86 unidirectional links and 14 Node and 46 links generic Deutche Telecom	$O(D \times N \times k \times \log\|\|D^*\|\|)$ D – is set of Demands, N the number of iteration per stage, k no of routes and D* - Current processing Demands .
PODMP [12]	Fixed Spectrum Allocation policy or semi elastic spectrum allocation policy according to bandwidth	Deutsche Telecom Network	$O(\|\|E\|\| + \|\|V\|\|\log\|\|V\|\|)$ V-Set of Nodes, and E – Set of Edges.
MPS and NSA [13]	Next-state-aware SA	Pan - European Topology 21 bidirectional links and 14 node NSNET Topology	$O(S\times.N^3)$ The maximum number of hops in a path is O(N) and Total number of Slots in each link
OTTM (PD-RSA and PDK-RSA) [14]	Random Fit	Metro Optical Topology (28 Node and 52 Links)	*For PD- RSA* $O(S\|V\|+\|E\|+\|V\|\log\|V\|)$ *For PDK – RSA* $O(k\|V\|(\|S\|+\|E\|+\|V\|\log\|V\|))$ S – Available Slots, V- Traffic Distribution and k- path selection based on the traffic
HRSA [15]	First Fit	14 switch nodes and 64 links topology, 30 nodes and 140 links Topology and 16 nodes and 48 links Mesh topology	$O(\|N^2\|)$ $\|N\|$ number of switch nodes
DSA [17]	Random Slot Allocation Scheme	21 bidirectional links and 14 node NSNET Topology and Pan - European Topology	$O (S \times N^3)$ N – is maximum no of Hop in the network and S – total number of slots
DA-RSA [19]	List Scheduling Algorithm	CORONET CONUS (60 Node), 21 bidirectional links and 14 node NSNET Topology and GEANT2(32 Nodes)	$\mathbf{O(kM^4)}$ k- is number of alternative paths and M– is number of nodes in the network

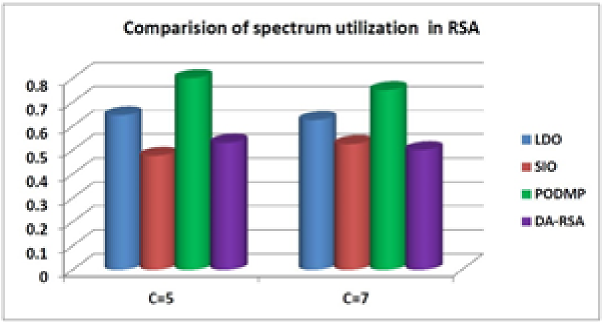

Figure 2. The comparison of Spectrum utilization between RSA algorithms.

Fig.3. shows comparison of spectrum utilization between various RMSA algorithms. Here also the conditions of the same simulation are applied with same topology (NSFNET) are used to comparison. The RMSA and AOM-RMSA algorithms provide much high utilization compare with other algorithms.

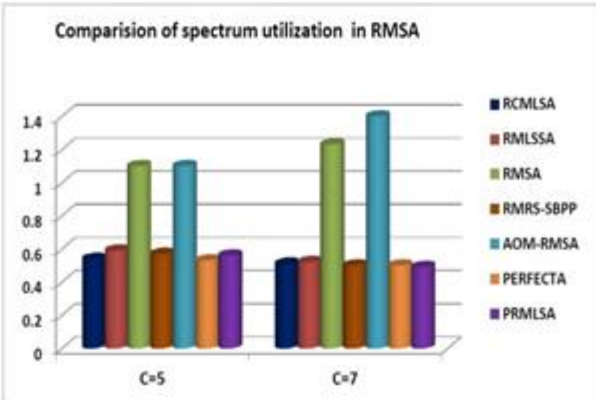

Figure 3. The comparison of Spectrum utilization between RMSA algorithms.

Table III. RMSA Algorithms Features, Routing mechanism used and Support traffic type.

Algorithm	Features	Routing Mechanism	Traffic Support
RCMLSA [19]	1. To reduce the subcarrier blocking probability. 2. Considering crosstalk and increase the spectrum utilization in multicore fibers.	k- Shortest Path Algorithm	Static/Dynamic
RMLSSA [20]	1. The sorting policies are reducing complexity in serving each incoming demand sequentially.	k-Shortest path Algorithm	ILP for Static traffic. Stepwise Greedy approach For Dynamic traffic.
RMSA [21]	1. To minimizing bandwidth utilization and reduce connection blocking. 2. It provides connection protection and restores backup light paths.	k- Shortest Pairs of disjoint paths (SP) k-Least Loaded Pairs of the disjoint path (LLP)	Dynamic traffic
RMRS-SBPP [22]	1. To shared backup lightpath protection with minimizing network resources. 2. The regenerators are significantly reduced bandwidth blocking probability.	k-disjoint shortest path searching algorithm	Dynamic traffic
AOM-RMSA [23]	1. This approach reduced the required bandwidth in the network. 2. When using more BVTs the subtree algorithms are effective and reduce incoming demand blocking.	pre-computed shortest paths	Static traffic
PERFECTA [24]	1. This approach avoids unnecessary slot allocation and fragmentation. 2. It can support a large number of contiguous slots when it is needed	Dijkstra's algorithm	Static Traffic
PRMLSA [25]	1. This approach considers physical impairments such as non-linearity effects and Amplified Spontaneous Emission 2. There is no prior analysis of power requirements it allocates real-time power requirements.	k-Shortest path Algorithm	Static Traffic

Table IV. RMSA algorithms Spectrum Assignment Techniques, Network Topology used and Computational Complexity of Algorithms

Algorithm	Spectrum Assignment Techniques	Network Topology Used	Computational Complexity
RCMLSA [19]	CCL-Best-Fit and CCL-Random-Fit	• 16 node 25 links NSFNET Topology • 24 nodes and 43 Links USA Topology	$O(k \times m \times c \times s)$ k- Candidate path, m-Modulation, c- is no of cores and s is no of slots.
RMLSSA [20]	Stepwise Greedy Algorithm	• 6 node bidirectional Links • 21 bidirectional links and 14 node NSNET Topology	$O(\|D\| \times k \times q_{max} \times f_{max} \times c_{max} \times \|E\|)$ |D|- Demands and k routes
RMSA [21]	Least Time to Wait policy	• 5 Node 6 link Topology • 21 bidirectional links and 14 node NSNET Topology	$O(D \times P \times T \times F)$ and $O(\|E^2\| \times T \times F)$ |E| - No of Links, T x F – Resource Element and P routes
RMRS-SBPP [22]	First Fit Policy	• 21 bidirectional links and 14 node NSNET Topology • COST 239 Network with 11 Node and 26 Links	$O(\|R_p\| \times (\|N^2\| + W \times L \times \|C\|))$ N - Total no of Nodes, $\|R_p\|$ Protection route node pairs, L is no of optical links,
AOM-RMSA [23]	First Fit Policy	• 6-node, 9-link N6S9 • 21 bidirectional links and 14 node NSNET Topology • 24 nodes and 43 Links USA Topology	Link-Sharing Ratio Grouping (LRG) $O(\|E\|2 + \|E\| \times \|M\| \times \|F\| \times P \times B \times \|V\|)$
PERFECTA [24]	Dynamic Alternate Direction (DAD) policy	• Pan - European Topology • 21 bidirectional links and 14 node NSNET Topology	$O(\|\|E\|\| + \|\|N\|\|\log\|\|N\|\|)$ N-Set of Nodes, and E – Set of Edges.

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VI. PHYSICAL LAYER AND DEFRAGMENTATION BASED APPROACHES

The fragmentation problem is one of the key issues in EON, this may occurred by inaccessible, non-contiguous spectrum available slots that cannot assigned to incoming new request to the network and non-aligned spectrum slots. The fragmentation problem may lead to poor spectrum utilization and high blocking ratio of new incoming request in the network. The several defragmentation approaches proposed earlier to resolve the fragmentation problem in different way. In this section provides the recent contribution of different defragmentation algorithm in detail.

Pederzolli et al [26] proposed a two different heuristic algorithm that minimizes the fragmentation error metric. The two algorithms focus on fragmentation issues in Flexi-grid optical network. Algorithm 1; Minimize-Fragmentation-1 (MF1), which examines entire possible slot assignments to arriving link between shortest path of the K-shortest paths covering at smallest one appropriately large AFRp. Algorithm2; Minimize-Fragmentation-K (MFK), analyze and identifies all possible slot assignments to the received connection with all pre-measured K-shortest paths.

Fernandez et al [27] highlighted the performance of proactive and reactive approaches from the comparison. Propose a new defragmentation algorithm based on proactive and reactive approaches and evaluated with different scenarios. The results obtained for the proactive algorithm in low traffic load is outperformed compared to the entire reactive algorithm. However, reactive algorithm overcomes the proactive algorithm in high traffic loads with short holding time. The PRDEF outperformed in each scenario, the combination of proactive-reactive strategy.

Yang et al [28] presented a new metric for computing the degree of fragmentation in a path. A holding-time-aware algorithm is proposed based on the new metric which accurately evaluated the overall fragmentation states using an optimal allocating approach. To achieve better blocking probability the holding time aware algorithm uses more network resources. Batham et al [29] addressed two issues that are inherited from spectrum allocation; one is about non-uniform spectrum assignment and the spectrum fragmentation in EONs. The proposed Least Loaded RSA homogeneously allocates the spectrum beside different links between the network and Route Fragmentation Aware RSA selects the routes which have the least fragmented. The introduced two metrics route fragmentation index (RFI) and standard deviation (SD) highlighted the noticeable advantages of the two strategies. The proposed strategies performed better compared to all quality metrics.

The table V. is presented the comparison between different approaches with respective parameters (Fragmentation Aware (FA) Technique, Spectrum Assignment Techniques, Routing Mechanism and Computational Complexity of each algorithm). Holding time aware spectrum allocation algorithm [28] calculates minimum holding time difference that helps to improve the spectrum allocation performance compared with other algorithm. The Path based fragmentation metric (Wasted-Unusable Free Ratio (WUFR) [26] is reducing number connection blocking and performed well in dynamic situations. Comparing with proactive and reactive approaches this algorithms have a high computational complexity except [28 and 30].

Table V. Comparison between defragmentation Algorithms

Algorithm	Fragmentation Aware (FA) Technique	Spectrum Assignment Techniques	Routing Mechanism	Computational Complexity
Minimize-Fragmentation 1 (MF1) and Minimize-Fragmentation K(MFK) [26]	Path based fragmentation metric (Wasted-Unusable Free Ratio(WUFR)	First Fit Policy	K shortest paths	$O(K \times N_S - N_C + 1 \times C_F)$ Where, F is the complexity of the F function, NC is the number of slots required and N_S is the Number of path
Holding time aware spectrum allocation algorithm [28]	Weighted Holding Time Difference (WHTD) metric	Random Assignment Policy	K shortest paths	$O(\lvert E\rvert \times F + \lvert V\rvert^4)$ Where, E – is set of Links, V - all pair shortest path and F is Frequency slots in each link.
Route Fragmentation Aware RSA (RFARSA) [29]	Spectrum compactness based defragmentation	First Fit Policy	Pre-computed K-alternate routes	$O(N_R \times FS_d\text{-}FS_a \times L)$ Where, L – is number of links, N_R – Available routes and FS_d-FSa Frequency slot difference
Spectrum Shared pre-configured cycles (SS-p-cycles) [30]	SS-p-Cycle Spectrum Allocation	Least Fit Policy	Dijkstra's shortest-path routing	$O(\lvert E\rvert \times \lvert I\rvert^2 + \lvert C\rvert^3 \times \Delta)$. Where, Δ - is the maximum degree in conflict graph, C – is selected cycle path, E – is set of Links, I - all pair shortest path

VII. CONCLUSION AND FUTURE SCOPE OF RESEARCH

This paper presents a detailed study on the challenges faced by the EON and the approaches employed previously in the literature for solving those issues. This paper includes algorithms and approaches proposed for Routing, Modulation, and Spectrum Assignment problems, Routing and Spectrum Allocation problems, and approaches based on Security and Defragmentation. The advantages, disadvantages of the different techniques handle, and comparative analysis of their performances was presented. The issues that were not addressed and the areas of EON that need to be enhanced were discussed such that they can be resolved in future studies. In future work will focused about good traffic prediction model, cloud data center optimization, power consumption and path security in the network that will help to reduce the spectrum allocation and fragmentation problem. The physical impairments are next consideration of this research also focused in future about it.

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