J Opt
https://doi.org/10.1007/s12596-024-02060-0

DISCUSSION

Route planning and optimization tools for optical networks: a comprehensive analysis

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Received: 6 April 2024 / Accepted: 13 July 2024

Abstract This work aims to provide a review of the route planning and optimization tools for optical networks from optimization algorithms to their evaluation approaches. Optical networks are considered one of the most famous technologies in order to implement telecommunications backbones. The optimal performance of optical networks and the recognition of possible performance bottlenecks are of significance to network operators. Nevertheless, since each vendor uses a diverse set of performance indicators and performance prediction approaches, it is very difficult to create a single, vendor-neutral performance map of an optical network. In internet traffic, the steady rise demands large-scale and high-speed optical networks with effectual spectrum resource utilization. Thus, cautious allocation of optical resources is needed; mainly Gaussian Noise simulation in Python (GNPy)-based transmission parameters for route planning is employed. In this paper, various approaches based on different route planning techniques in optical networks are exploited. The research works are analyzed by classifying them based on the approaches used in preceding works. Additionally, the research gaps and challenges recognized in the conventional studies are mentioned; thus, it will assist the researchers in finding an enhanced solution and also improve their studies in the future. In this study, the related works used are verified on the basis of several scenarios, such as platform employed and performance evaluation measures. It is noted that the most commonly used tool using GNPy package is Python. Also, this study enlists the future scope by examining the research gaps present in the related works to researchers; thus, it enhances their studies.

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Keywords Routing · Optical network · Transmission · GNPy · Route planning

Abbreviations

EONs	Elastic optical networks
GA	Genetic algorithm
SAA	Simulated annealing algorithm
ASP	Adaptive service provisioning
EDFA	Erbium-doped fiber amplifier
RCWA-CP	RCWA with core perception
LCM	Low-crosstalk-margin
QAM	Quadrature amplitude modulation
ROADM	Reconfigurable optical add-drop multiplexer
QPSK	Quadrature phase shift keying
DNN	Deep neural networks
WDM	Wavelength division multiplexing
RCWA-XTP	RCWA with crosstalk perception
MPRSA	Multi-path routing and spectrum assignment
FSs	Frequency slots
RMFSSA-w–P	Routing, modulation format, space and spectrum allocation with protection-with-protection
RSA	Routing and spectrum allocation
CNN	Convolutional-neural-network
ILP	Integer linear programming
ESFLA	Enhanced shuffled frog leaping algorithm
RRA	Routing and resource assignment
WDM	Wavelength division multiplexed
DRL	Deep reinforcement learning
QLRs	QKD light path requests
RCWA-WP	RCWA without perception

Published online: 30 July 2024

RCWA	Routings, core, and wavelength allocation
LCM	Low-crosstalk-margin
LP	Light path
SS-FONs	Spectrally-spatially flexible optical networks
2-D	Two-dimensional
OSNR	Optical signal-to-noise ratio
TRXs	Transceivers
STA-RSA	Steiner tree approach for RSA
IBFW	Improved Bellman Floyd Warshall
QoT	Quality-of-transmission
STA	Steiner tree approach
GSNR	Generalized signal-to-noise ratio
BVTs/SBVTs	Bandwidth variable transponders /slice-able bandwidth variable transponders
GNPy	Gaussian noise simulation in Python
RCWA-SP	RCWA with spectrum perception
QoS	Quality of service
OFDM	Orthogonal frequency division multiplexing
SPT-RSA	Shortest path tree based routing and spectrum allocation
ODTN	Open disaggregated transport network
PCE	Path computation element
JSON	JavaScript object notation
RDA	Resource dimensioning and allocation
MIUFS	Maximum index used frequency slots
RWSA	Routing wavelength and spectrum assignment algorithm

Introduction

As traffic volumes and their capacity specifications rise significantly, a major priority is required to find efficient ways to use the network's available resources. Because of high bandwidth of optical fibres, the optical networks can sustain aforesaid rising demand for traffic. Generally, elastic optical networks are flexible in any circumstance, wherein the resources of spectrums are partitioned into frequency slots, which are severely regulated. Such slots are allocated to a user, in regard to allot a specific number of frequency slots to different optical links. The optical network's capacity has been limited because of the constant rise in diverse traffic and its associated bandwidth demands. The demands of next-generation optical networks for heterogeneous granularity and large capacity in traffic can be met with the advent of EONs [1]. For high-speed networks, EON is considered a potential solution, which convenes exponential growth of internet applications having high bandwidth requirements [2]. The coarse granularity of a single wavelength is only provided by the wavelength division multiplexing networks. Thus, it cannot be adaptively applicable to several bandwidth connection needs. Nevertheless, by employing the OFDM technology, EONs can present flexible and variable bandwidth to each connection request and obtain enhanced spectrum utilisation [3].

Currently, numerous global networks and applications employ optical transport networks with maximum speed as infrastructure appropriate to link companies, cities, organizations etc. Nonetheless, the issue of wavelength and routing is important to enhance and expand the effect of the routed wavelength optical networks. In addition, the optical path formulation is considered an important approach for communication. Also, in order to transmit the information in a routed wavelength optical network, the routing approaches and wavelength assignment were considered. Apart from that, wavelength continuity is considered the most general problem, where it should have the same wavelength on the path that will set up the connection. To resolve this challenge, the converters of optical wavelength are being employed, and while crossing via diverse fibre links, a lightpath might employ numerous wavelengths. The conventional GA, SAA, and other approaches were used in optical network communication [2], which can decrease power loss to a definite extent, also these conventional search approaches led to converging in the local sub-optimal solution earlier that tends to premature stagnation in search. That means they simply fall into the local optimal solution, as well as it is not possible to make sure that the communication path identified is a routing path with minimal power utilization [4].

The most important objective of this work is to analyze research papers based on different route-planning techniques in optical networks. In this work, related works are categorized based on the approaches used in the previous studies including the methods that employ GNPy tool. Also, the research gaps identified in the conventional works are enlisted; thus, in the future, researchers can enhance their study and offer improved solutions.

The organization of the paper is organized as follows: Sect. "Related works" describes the related works; Sect. "GNPy architecture" emphasizes the analysis and discussion. Sect. "Analysis and Discussion" explains research gaps and future works, whereas Sect. "Research gaps and future work" concludes the paper.

Related works

This work contains several techniques adopted for routing in various research papers regarding the optimal network and they are emphasized in this section. The classification of routing in optimal network techniques is shown in Fig. 1. Here, various methods based on optimization, deep

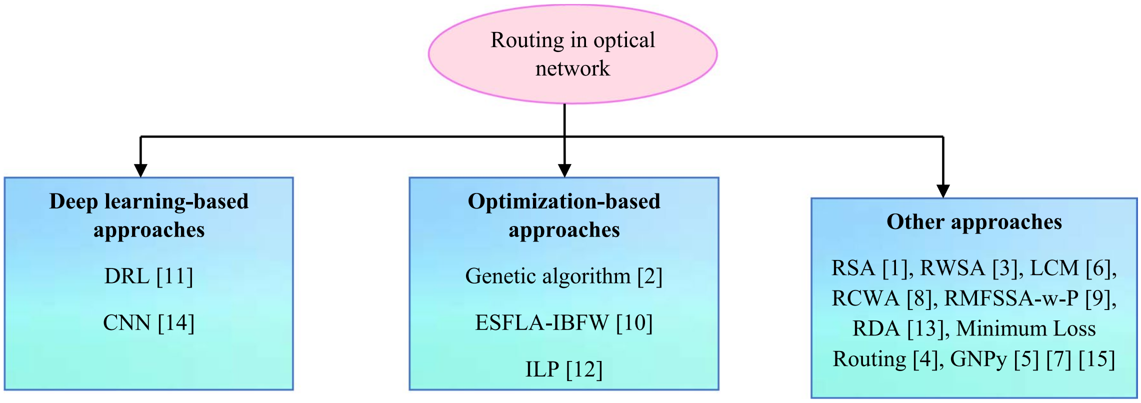

Fig. 1 Analysis based on approaches for routing in optical networks

learning and other approaches were used for routing in optical networks.

Optimization-based approaches

The section states the studies and researches related to route planning and optimization tools for optical networks based on optimization-based techniques. It improves overall performance, minimize costs, and increases efficiency.

Xuan et al. [3], presented an effectual genetic algorithm with tailor-made mutation, crossover, and local search operators to decide optimal strategies for routing. Various experimental analyses were performed on two diverse multi-domain EONs to estimate the approach. The goal of optimization model is to find the best routing, spectrum and core allocation schemes by decreasing the highest index of used frequency slots. A genetic algorithm with two populations is created to efficiently solve the optimization model. Finally, the simulation outcomes exhibit that the approach possesses maximal performance than the conventional techniques. Selvakumar and Manivannan [1] worked on an effectual routing approach besides spectrum allocation optimization for an EON. Here ESFLA and IBFW shortest path routing were utilized. This method minimizes the fragmentation complex of the spectrum and facilitates flexible spectrum fragmentation and efficient routing, which are the two key concerns in elastic optical networks. The experimentation was evaluated with the RSA techniques with suitable measures, in which it obtained enhanced spectrum utilization and minimized number of blocks. Ujjwal et al. [5], presented an approach, called ASP, to deal with a solution to the MPRSA issue. By adaptively fragmenting connection requests on separate paths according to hardware BVTs/SBVTs availability and pre-computed capacity, ASP increases the number of connections handled. Also, by accurately managing scattered spectrum slots, it reduced the spectrum fragments in the network. This approach carried out the demand of adaptive traffic splitting on disjoint paths in case it was not capable of being served using the k-shortest routing paths based on metrics, like capacity available, demand and hardware support. To solve the MPRSA issue in large optical networks, an ILP approach and a heuristic approach were also developed.

Deep learning-based models

The section states the studies and researches related to route planning and optimization tools for optical networks based on deep learning based models. The deep learning based model minimizes computation, highly accurate and has the ability to handle large datasets.

Sharma et al. [6], addressed the RRA issue in the quantum signal channel. The RRA problem was a complicated decision-making issue, where suitable solutions depended on comprehending the networking environment. The authors have used a DRL model for complicated issues. Understanding the networking environment is necessary to provide effective solutions for the complicated RRA problem of QKD-ONs. DRL is used to tackle the RRA problem and a DRL-based RRA scheme is driven by the new developments in DRL for complicated problems as well as its capacity to learn directly from experiences. By utilizing the DNN, the method learnt the optimal policy to choose a suitable route and allocated appropriate network resources for the establishment of QLRs. Usmani et al. [5], presented a CNN-based structural design to precisely compute QoT to the actual deployment of LP in a hidden network and in order to extract usable features, the CNN architecture comprises two networks, a regression network that estimates the GSNR of LP before it is actually provisioned in a network, and feature extraction with input and two conv-layers. The approach was trained on the data obtained from already set up LP of an entirely diverse network. To estimate the QoT of LP, the measure of GSNR was considered. By employing a well-evaluated GNPy simulation tool, the synthetic dataset was generated.

Other approaches

The section states the studies and researches related to route planning and optimization tools for optical networks based on other approaches. Other approaches such as RSA, RWSA, LCM, RDA, and minimum loss routing offer benefits such as enhanced fault tolerance, reduced power usage, and increased network performance.

Choudhury et al. [2], investigated RSA models in EONs for multicast traffic demands. For each multicast traffic demand, a light tree was constructed and by utilizing the first-fit spectrum allocation policy, the spectrum was allocated to this light tree. An approximation-based STA-RSA were presented and compared with spectrum allocation SPT-RSA and shortest path tree-based routing to exhibit in favour of STA-RSA over SPT-RSA. In order to minimize spectrum usage and lower the chance that the traffic demands will block bandwidth, this concentrated on finding solutions to the problems of traffic routing and spectrum allocation for multicast traffic demands. Finally, experimental outcomes have shown that the model performed better than conventional techniques regarding the bandwidth-blocking probability. D'Amico et al. [7], examined the accurateness of a QoT- estimator within a laboratory flex-grid flex-rate model. It considered 8 multi-vendor TRXs with symbol rates ranging from 33 to 69 Gbaud, and variable constellations. Also, 8-QAM, QPSK, and 16-QAM probabilistic constellation shaping, a flex-grid WDM spectrum, and data rates of 100 Gbits/s up to 300 Gbits/s, with channel spacings of 50 and 75 GHz were performed. Moreover, an improved execution of open-source GNPy project was utilized. With an average error value of not exceeding 0.5 dB, QoT-E offers a high degree of precision in the computation of the GSNR. The TRX model, which is derived by back-to-back characterization, is used to calculate these values with regard to the measured bit-error ratio translated to the GSNR. These findings show that power spectral densities, rather than power per channel, as in conventional fixed-grid systems, are the key to optimum management of flex-grid flex-rate WDM optical transport.

Ferrari et al. [8], described the confirmation of GNPy, which was an open-source application. Here, optical layer followed a disaggregated idea, as well as its core engine was a QoT estimator for coherent WDM-based optical networks. Also, the GNPy software was flexible, which was utilized to organize a request for proposal/request for quotation. Also, network configuration to take benefit of channel capacity was optimized and capacity and deployed network performance were examined. GNPy can be used in an optical line controller to calculate the optimal operating point since it can accurately anticipate the optimum transmitted power to within 0.5 dB. This validation finding demonstrated QoT estimator's capacity to forecast the frequency variation of the GSNR by probing the C-band on several spectral areas and altering the paths' lengths, modulation format, and network architecture. Borraccini et al. [9], designed an optical network framework based on physical layer digital twin of optical transport, which was employed within a multilayer hierarchical control. Here, the solution was based on GNPy as an optical physical layer digital twin as well as ONOS as an intent-based network operating system. The optical control reliability was independent of data plane operation is experimentally demonstrated through the use of software optical amplifier models constructed from component characterization using GNPy as an open LP computing engine. The experimental analysis showed that the optical control's reliability of a model, when separated from the data plane's operation, involved the utilization of GNPy as an open LP computation engine and software-based optical amplifier techniques, which was derived from characterization of module.

Yang et al. [4], presented a 5×5 all-pass optical router approach for 2-D mesh-based ONoCs. Also, an algorithm was developed to choose the routing paths with minimal power loss based on a broad optical router approach as well as computational approaches of crosstalk noise and power loss. Meanwhile, it can make sure that the routing paths have the best OSNR. At last, Cygnus optical router was employed to confirm routing approach. The outcomes exhibited that the approach can efficiently minimize power loss and enhance OSNR in scenarios of network sizes of 6×6 and 5×5. Finally, algorithm can carry out better in increasing the OSNR and minimize the power loss with augment of the optical network scale. Agrawal et al. [10], exploited the spatial dimension i.e., core of SS-FONs to compute XT-aware routes and an LCM routing model. A proactive model of XT management was presented by LCM routing, wherein 2D routes using core-switching were computed and prioritized offline based on XT margins. Experimentations indicated that LCM routing attained better LP establishment while evaluated with the conventional proactive XT management techniques. Furthermore, the LCM routing achieved near-optimal performance without requirement of complicated computations. Furthermore, the LCM routing achieved near-optimal performance without requirement of complicated computations, which were carried out in a dynamic manner. Curri [11] presented the basic principles of open-source project GNPy for optical transport virtualization in designing WDM optical transmission for disaggregated and open networking. For open network management and planning, GNPy can be employed as a vendor-agnostic digital twin, and GNPy approximates the transparent LP as additive white and Gaussian noise channels. To facilitate disaggregated network management, QoT degradation of every network element was individually modelled. For optical amplifiers, fibre propagation, and reconfigurable add/drop multiplexers, the GNPy approaches were presented. Also, by utilizing the back-to-back characterisation data, coherent transceiver modelling was performed. The SDN multi-layer hierarchical controller uses GNPy as a service to provide optical line control and facilitate the open and autonomous deployment of optical circuits.

Yu et al. [12], worked on four RCWA approaches in multi-core optical networks for classical service requests and quantum service requests. It was indicated as RCWA-WP, RCWA-XTP, RCWA-SP, and RCWA-CP. By pre-calculating the distribution of secure keys and data in the multi-core optical network, a spectrum-perception RCWA algorithm is created to fully utilize the network's resources. Experimentations were performed to assess the performance of the network regarding key utilization, blocking probability, and average crosstalk intensity. The comparative outcomes show that the RCWA-SP approach can enhance the performance of the network and minimize blocking probability, whereas the RCWA-XTP model can decrease inter-core crosstalk throughout transmission. Iyer [13] introduced the RMFSSA-w–P approach that was independent of the failures in securing the routes. Additionally, the modulation format adaptation was considered. A wide experimentation was performed by considering the realistic networks, and achieved outcomes exhibited better performance of the model than the conventional models. Khan et al. [14], worked on an optimization issue that uses information, such as traffic between end nodes, network topology, and the target level of congestion at each link/node in WDM networks. It has been demonstrated that add/drop traffic on all nodes only requires a small number of access ports. The amount of traffic that originates and terminates at a switch node mostly determines the access ports. The total network cost was minimized to maintain a minimal congestion level on all links which presented a well-organized trade-off solution for the network design issue. In WDM networks, the optimal information was used for dynamic traffic that was exhibited to attain the required performance with definite QoS in diverse networks.

GNPy architecture

This section elaborates GNPy, which was used as an optical network simulation tool in most of the existing works reviewed above. Figure 2 demonstrates the general framework of GNPy. GNPy presents a range of features centred on a core engine, which is responsible for managing QoT estimation and signal propagation effects. Generally, this core engine is set up to experiment with the transmission of a fully loaded spectrum between two specified points, A and B, within a complicated network topology. Moreover, this network is constructed by utilizing atomic network modules, namely EDFA and optical fibers, and needs a set of parameters expressing each network element of the network to have meaningful outcomes. In stable releases of the code, these measures can be presented to GNPy in JSON format or by utilizing internally transformed XLS files into a JSON framework. Amplifiers can be abstracted in accordance with three diverse data models, like black box, white box and operator model, which depend on actual knowledge of the amplifier [15].

An accurate description is not possible in a few cases. Therefore, in accordance with the heuristic and design rules, GNPy has an auto-design feature, which has the ability to configure the amplifier. The input topology is unfinished, while auto design is employed. The amplifier model and operating point are not unrecognized, the spans have not all amplifiers. In this scenario, appropriate amplifiers are selected by the auto-design from an equipment library and it divides fibre spas that are too long. A set of features is used to ease the user experience for what if cases and planning as it permits the evaluations of numerous requests on a similar network, and a similar configuration. Also, the GNPy assists the common planning constraints, such as path disjunction, assignment of spectrum, selection of obligatory nodes, transponder mode selection and so on. The shortest path model was implemented by the path computation phase and it set up the advancement of an API to combine the optical line system controllers. In an ODTN exhibition, such API was featured. GNPy is used to estimate the path feasibility in a release of the Transport PCE controller project GNPy requires a network description presented via JSON file. Such network is abstracted as optical impairment aware topology done of network elements and it returns the GSNR of each channel besides a path. The formulation of GSNR is stated below [15]:

$$GSNR_a = \frac{A_{S,a}}{A_{ASE}\left(e_i\right) + A_{NLI}\left(e_i\right)} = \left(OSNR_a^{-1} + SNR_{NL,a}^{-1}\right) \tag{1}$$

where OSNR and SNR are calculated below,

$$OSNR_a = \frac{A_{S,a}}{A_{ASE}\left(e_i\right)} \tag{2}$$

$$SNR_{NL,a} = \frac{A_{S,a}}{A_{NLI}\left(e_i\right)} \tag{3}$$

where $A_{S,a}$ represents the signal power of the a^{th} channel and e_i represents its central frequency.

$$A_{ASE}(e) = heNF(e)G(e)C_{ref} \tag{4}$$

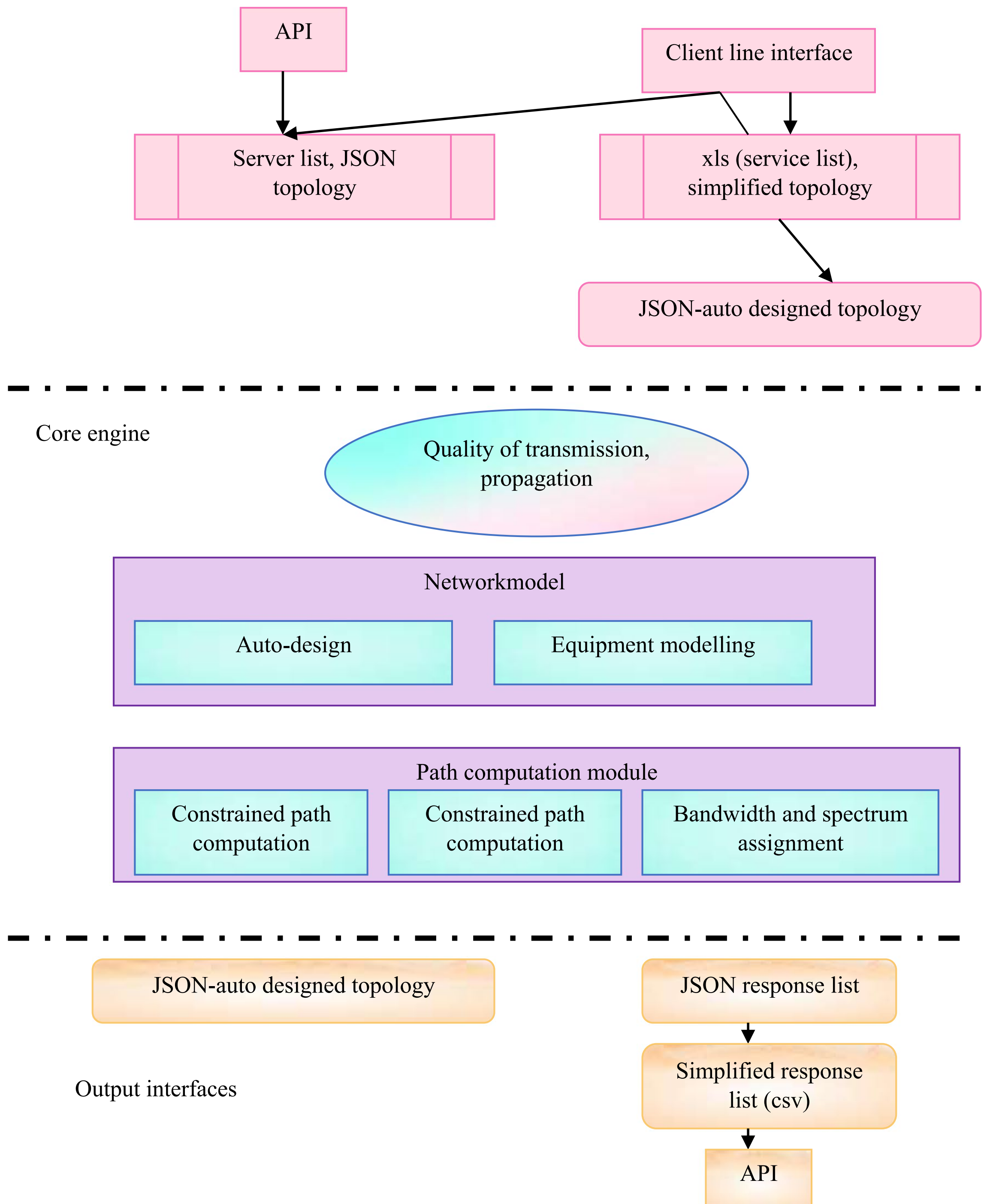

Fig. 2 General framework of GNPy

where $G(e)$ represents gain, h represents Plank constant, C_{ref} represents reference bandwidth equivalent to the channel symbol rate.

$$A_{NLI}\left(e_i\right) = G_{NLI}(e)C_{ref} \tag{5}$$

where $G_{NLI}(e)$ represents the NLI power spectral density which depends on the fiber parameters and the WDM spectral occupancy.

Analysis and discussion

To demonstrate the effectiveness and efficiency, several experiments are conducted, and the results are presented in this section. In Sect. "Analysis based on metrics", the analysis based on metrics is given. Analysis based on platforms is presented in Sect. "Analysis based on platforms". Sect. "Analysis regarding complexity" shows the analysis regarding complexity. Analysis regarding block probability is given in Sect. "Analysis regarding block probability". Finally, the techniques employed are given in Sect. "Techniques employed".

Analysis based on metrics

This section describes analysis based on the performance measures utilized in different research works. Table 1 elucidates several performance metrics used for routing in optical networks. The most commonly used performance metrics are Block probability, BER, spectrum utilization, and SNR. The sensitivity and blocking probability metrics are used in [2]. In [1], the metrics, like blocking probability, spectrum utilization and MIUFS are employed. The metrics, like SNR and GSNR are employed in [9] while GSNR and MAE metrics are utilized in [5].

Analysis based on platforms

Figure 3 elucidates analysis based on the platforms. Strong capabilities for data analysis, manipulation, and visualization are available in Matlab. Key advantages of Python are its ease of use, short and simple syntax, and extensive library. Additional benefits of Python include its enormous user base, adaptability, portability, and free and open source licensing. Here, the most utilized platform for the simulation of routing in optical networks is the python, which was used by 75% of researchers, whereas 25% of researchers have used Matlab. From the analysis, it is clear that Python is the most commonly used tool using the GNPy package.

Table 1 Analysis based on metrics

Metrics	Cited articles
Sensitivity	[2]
BER	[9]
Blocking probability	[1, 2, 5, 6, 10, 12]
RFSU	[3]
Spectrum utilization	[1, 5, 10]
Key utilization	[12]
MIUFS	[3] 1
GSNR	[5] 8
Power loss	[4]
SNR	[7] 9
MAE	[5]
Traffic load	[13]

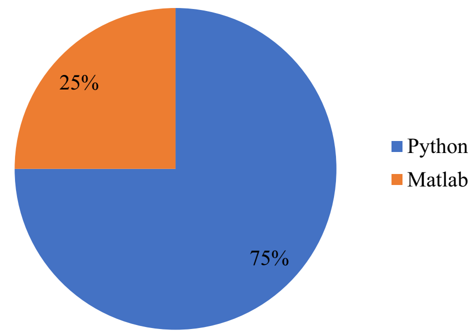

Fig. 3 Analysis based on simulation tool

Analysis regarding complexity

Computational complexity or complexity analysis or theory is a theoretical evaluation that measures the computational resources needed by a technique to resolve a computational issue. Also, complexity of an approach is nothing but a function that emphasizes the effectuality of an approach depending upon the amount of data that the technique requires to process. The computational complexity is helpful in selecting the most effective algorithms with favorable complexity and can manage more difficult tasks and bigger datasets. Table 2 demonstrates the analysis regarding complexity.

Analysis regarding block probability

Figure 4 demonstrates an analysis based on the blocking probability. From the above analysis, it is clear that the blocking probability is the most common utilized metric. Thus, the blocking probability metric is analyzed in this work. Here, the least blocking probability is achieved by[8], whereas the [6] achieved a high blocking probability. The network load of [2] achieved 0.003 blocking probability while the method in [5] attained a blocking probability of 0.017.

Table 2 Analysis regarding complexity

Cited articles	Complexity
[2]	$O\left(\vert D'\vert^2\vert E\vert\log\vert V\vert+\vert D'\vert\vert V\vert+\vert F\vert\vert E\vert\vert M\vert\right)$
[3]	$O\left(KN^2N^R+2G_{\max}P_SN^3FN_c\right)$
[10]	$O\left(\vert Q\vert\vert V^2\vert k\vert G\vert^P\right)$
[12]	$O(WKV(E+V\log V)\log C)$
[13]	$O(\Vert E\Vert+\Vert V\Vert\log\Vert V\Vert)$
[5]	$O\left(K*N^3(E+N*\lg(N))\right)+O(K*N*S)$
[14]	$O(\vert N\vert)^3$

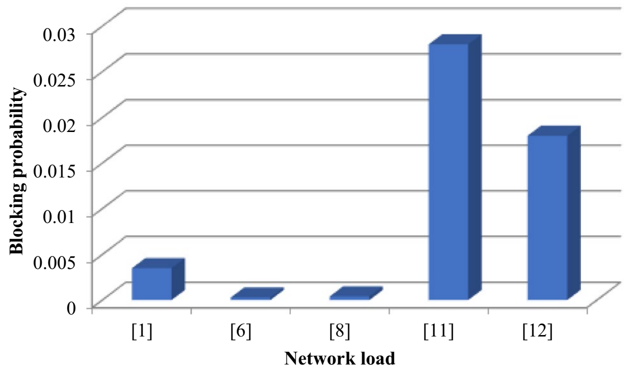

Fig. 4 Analysis based on blocking probability metric

Table 3 Techniques employed

Cited articles	Publication year	Techniques
[2]	2020	RSA and STA
[3]	2020	GA
[7]	2022	RWSA
[4]	2020	Minimum-loss routing algorithm
[8]	2020	GNPy
[10]	2019	LCM Routing
[11]	2022	GNPy
[12]	2021	RCWA algorithms
[13]	2020	RMFSSA-w–P algorithm
[1]	2021	ESFLA
[6]	2023	DRL
[5]	2021	ILP mode
[14]	2021	RDA optimization
[5]	2021	CNN
[9]	2020	GNPy

Techniques employed

Table 3 describes the techniques employed in this work. The techniques, RSA and Steiner tree approach, Genetic Algorithm, RWSA, Minimum-Loss Routing Algorithm, LCM Routing, RCWA algorithms, RMFSSA-w–P algorithm, ESFLA, DRL, ILP mode, RDA optimization, Convolutional neural network and GNPy are employed in route planning and optimization tools in optical networks for demonstrating better effectiveness and efficiency of the model.

Research gaps and future work

The main limitation of the genetic algorithm presented in [3] is its extended computational time compared to the other conventional algorithms. Furthermore, this algorithm requires the connection requests to be sorted in advance; thus, it is appropriate only to address core allocation, static routing, and spectrum assignment issues. A promising approach was developed in [8] by employing a multi-objective function. This technique aims to enhance various aspects, including optimizing spectrum demand, reducing fragmentation, and refining slot scheduling. However, it failed to consider brown-field validation in order to examine accuracy in the presence of environmental and ageing problems. Also, the DRL technique in [6] has proven inadequate in effectively tackling the diverse networking challenges encountered in QKD-ONs. Another complexity arises in [14], where EON necessitates not only spectrum continuity but also spectrum contiguity constraints. The last constraint implies that FSs should be nearby beside optical path, by adding a layer of intricacy to the network's resource allocation and optimization processes.

In future research by addressing aforesaid challenges, it will be critical to enhance the performance and adaptability of optical networks, specifically in terms of emerging technologies and advanced communication requirements, with particular emphasis on optimizing GNPy-based transmission parameters for route planning in optical networks. In addition, by taking traffic grooming and spectrum overlaps into account, reducing longer calculation times, and sorting connection requests, can investigate ways to reduce fragmentation, spectrum demand, and slot scheduling.

Conclusion

A comprehensive analysis of various route planning techniques in optical networks was presented in this work. Here, the research papers were categorized based on the techniques, which was used in preceding works. Additionally, the research gaps and challenges present in the conventional literature were identified, which provides valuable insights for researchers to address and enhance their future studies. The works analyzed in the literature provided a detailed analysis of the works, which considers several aspects, such as performance evaluation metrics and software tools. Additionally, future research outlined prospects by analysing the research challenges that exist in the literature, which presents guidance to researchers to enhance their work. Moreover, to manage the high traffic at a high bandwidth application and multi-objective functions to improve the fragmentation, spectrum demand and slot scheduling can be also be included in near future.

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