

Artificial intelligence in computer networks

Tanya Abdulsattar Jaber

Institute of Applied Arts, Middle Technical University, Baghdad, Iraq

ABSTRACT

Artificial Intelligence (AI) has been defined as a modern and intense scientific topic that enables computer-based systems or embedded systems to divide and solve problems by simulating complex biological procedures that are represented by specific algorithms along with (learning, reasoning, as well as self-correction). The present study provides a detailed assessment and review of applications of various artificial intelligence approaches for the purpose of improving the general efficiency of optical communication structures and networks and network systems in general. Using the AI-based approaches has been researched at first in the applications that are associated with the optic transmissions, beginning by characterizing and operating the additives of the network for the monitoring of the performance, estimation of transmission quality and nonlinearities mitigation. Ultimately, this study has provided as well a summary of advantages and issues in the optical networks in which artificial intelligence is expected to have an important impact on near future and which represent areas of research expected to be popular in this discipline.

Keywords: Artificial Intelligence (AI) in computer network, optical communication, computer networks

Corresponding Author:

Tanya Abdulsattar Jaber
Institute of Applied Arts, Middle Technical University
Baghdad, Iraq
Tanya.galxy@mtu.edu.iq

1. Introduction

The entities and structures of the AI are capable of performing the similar processes of decision-making and learning through simulating organic procedure, with a particular focus upon the human cognitive processes. Artificial intelligence packages like the special digital assistants, purchase forecasting, smart vehicles, smart vehicles, smart home gadgets and speech recognition, are nearly universal, and comparable AI-based strategies are now transforming the daily lives of the people in the ways which enhance the productivity of humans, their health, or safety which affects people's entertainment or communication. Mainly, AI no longer provides completely self-sustaining systems, but as an alternative it adds understanding and logical thinking to the existing data-bases, environments, and applications for making them smarter, friendlier and more sensitive to the variations in the environments. Every small step forward in studies of the artificial intelligence allows us expanding our competencies for solving new exercises and problem measures, and thus lead studies and innovations in nearly each one of the scientific disciplines. For instance, the development of communication network efficiency through software based entirely on artificial intelligence strategies has emerged as an area subject to significant amount of researches throughout the last years, which affect the switching, network management and transmission areas. The optical verbal exchange networks and structures do not remain on side-lines now; however, they began to embrace this discipline toward the optical networks that have been based upon AI altogether, from optical tools to management and control.

The present study aims at reviewing a number of measures that are currently being taken under consideration for increasing the efficiency of the optical networks using artificial intelligence mechanisms, and to provide a survey of current studies within this field, in addition to presenting a top level view of challenges and advantages that appear in such context.

2. Overview of artificial intelligence and related technologies

AI is focused upon the perception of rational agents, that is, forty-five entities that understand and act in the environments aiming to fulfill their goals or increasing the parameter of the performance. In addition to that, they are capable of improving their efficiency through the learning [1]. This paragraph, briefly outlines the 50 sub-fields of AI which were properly utilized in the optical networks, specifying the motivations behind introducing them, and presenting a few examples on their utilization in the literature if the optical networks. The only network event type which can be considered is observable, deterministic, completely known and static. In those cases, the search methods and the theory of optimization are the main AI factors [1] which is why, they were extensively utilized in the design of the optical network and managements for long periods. For instance, using the breadth search algorithms for the routing, and the formulas of the integer linear and mixed linear programming for the layout and plan of the network (for example, [2&3]). None-the-less, while a numbers of previously stated conditions have been relaxed, or while the size of the network does not allow using earlier technologies, individual technologies had been supplemented or replaced by proximity search methods and meta-heuristics like the simulated warming, swarm optimization, genetic algorithms, and learning-based optimization. And education [4, 5]. For example, the net [6, 7] and light path construction [8, 9] visual work planning made use of the techniques. In many cases, the visual community has an unmarried intelligence factor (such as a central processing node), that is, a single agent. None-the-less, in different situations, unique smart retailers are developed so that actions of the agent will affect others. For individual cases, the principle of the game may be activated, and proposals within the optical networks area, e.g., can be found in [10] (in RF / free space optical network context), [11] (within the flexible optical networks, EONs context), [12]. It comes a step forward toward turning the marketers more intelligent through using the incorporation of knowledge use, planning and thinking. In such situation, reasonable sellers maintain a database (KB) where applicable, they are roughly peripheral and the effect of their activities are stored approx. The KB has been utilized by the vendors while developing business plans on the ways to access the decision making process and may be updated for adapting to the varying circumstances. Thereby, the overarching models, such as cognitive visual networks, perceiving, acting, learning, adapting and improving their performances, were suggested by a unique researcher [13, 14, 15, 16, 17, and 18]. There are three topics worth noting that concerning integrating the intelligence in the optical networks or systems, namely, the ways to deal with uncertainty, the ways to address decision-making, and the ways to learn. Certainly, in the optical networks there are nondeterministic activities, and the absence of complete data concerning an environment isn't an unusual problem. Which is why, the intelligent agents have to have the capability for operating in a robust manner under uncertainty. Legal Guidelines for Opportunities and particularly, Bayes networks have been considered as beneficial tools to build these robust frameworks (eg, [19]). In addition to that, the optical networks systems are problems with the consistent variations. Which is why, smart marketers should incorporate temporal fashion inference algorithms to perform tasks such as prediction, smoothing, or filtering depending upon strategies such as Kalman filters and hidden Markov models (HMM) [20,21]. The second major component is using algorithms of decision-making. The basic concept of those approaches is to maximize the expected application, wherein the application characteristic is described in an attempt to assign a unique number quantity for expressing the condition desirability and the agent decides with the goal to maximize that function (such as [23]). However, real-world networking environments have to deal with uncertainty, and the proxy implementation usually relies on a series of options rather than choosing a remotely unmarried agent. The decision-making process in optical network retailers may thus be modeled as problems of the sequential decision in the environments that have uncertainty. Those issues may be solved by the use of the Markov decision processes (MDPs) in the case where the movements of the agent are more dependent effectively upon the current country of the agent, instead of its history. The MDPs have been defined using the transitional model, specifying the actions' probabilistic effects, and through reward characteristics, defining rewards in every one of the countries. The MDPs answer can be defined as the policy that link selection with each country an agent can reach. The grand policy results in maximizing the case sequence usefulness, which is encountered in the case of being executed away. Using the MDP in the optical networks is demonstrated in [24, 25, and 26]. The 3rd problem of the primary significance is the learning, which can enable the improvement of the efficiency of the agent on the future tasks, because of the acquired experiences. Including the learning is of a high importance for many reasons. The learning agent is capable of adapting to the variations in their environment and even has the capability for adapting to the unforeseen cases, which wouldn't be expected throughout the design of an agent. In addition to that, in several of the cases, the learning from the existing data can be the only means for the creation of a business model, for example [1], in some other cases,

the human engineers (or programmers) do not have any idea of ways for programming a solution at all. The machine learning and statistical learning present the theoretical aspects as well as the tools for learning from the available data that may be obtained in the systems and networks of the optical communication with help of regulating the technologies. Even though the agents are capable of dealing with uncertainty with the use of the approaches of the probability and decision theory, they have to be capable of learning their probabilistic theories from the experience. Which is why, the Bayes approaches of learning [27] result in the formulation of the learning as one of the probabilistic inference forms, with the use of the observations for updating the pre-distribution on the theories. The MAP (i.e. Maximum Post Learning) [28] chooses one of the hypotheses, which has the maximum likelihood, based on data, as well as the MAP [29] simply chooses the hypothesis increasing data likelihood. Those approaches were utilized in the optical receptors, for example, in [30, 31, 32]. Besides those abovementioned approaches, machine learning was commonly utilized as well. There have been 3 fundamental classes of machine learning. In the supervised type of the learning [1] the agent can observe a few input-output pair examples and can learn a function specifying from the input to the output. The methods comprise the logistic regression, linear regression, ANNs, decision trees, SVMs and nearest neighbor models. In addition to that, various models may be included in the group learning, aiming at the improvement of the results. The supervised type of learning was utilized, for example, to monitor visual performance [33], for the estimation of transmission quality (QoT) in the optical networks [34, 35, 36, 37, 38] and to allocate resources in data centers [39]. In the unsupervised learning [1], the agent can learn the patterns from inputs despite not providing clear outputs. For example, methods of principal group and component analysis, belonging to this learning type, were utilized to monitor visual performance, recognize modulation coordination, and mitigate vulnerability [40, 41, 42]. Ultimately, in the reinforcement can learning [43] the agent can learn an ideal (or near-ideal) strategy from a group of the rewards (i.e. reinforcements) or punishments that have been received from their interactions with their environment. Some of the approaches include the dynamic, adaptive, and time-lag programming Q-mastering, a common method of the latter type, has the aim to find the optimum (Q-value) to cover choice of action for any specific (limited) Markov selection process [44]. For example, knowledge acquisition of Q was utilized to select path and wave-length in optical switching networks (OBS) context [45].

2.1. Artificial intelligence applications in optical transmissions

Here, we have described the application of artificial intelligence methods in the optical network's physical layer, that is, in issues related to optical transmission. Artificial intelligence technologies may be helpful in improving the network hardware configuration and operation, monitor optical performances, recognize modulation coordination, mitigate nonlinear fibers, and estimate transmission quality (QoT). These applications are summarized in Table 1.

Table 1. Artificial intelligence applications in optical transmissions

Applications	Artificial Intelligence Methods	Literature
Transmitter	Bayes filtering and expectation-maximizations ML (approaches of pattern learning) and GAs Simulated annealing	[46]: characterized phase noise and laser amplitude. [47]: determined optimum settings for optic comb sources for the ultra-dense WDM passive optic networks. [48]: mechanism of self-tuning for the mode-locked fiber laser.
Optical amplification control	Kernelized linear regression Multilayer perceptron Linear/logistic regression	[49]: defined model of regression for the purpose of studying the power excursions in the multi-span networks of the EDFA [50]: used model of ridge regression for coping with discrepancy amongst the post-EDFA channel power. [51]: autonomous adjustments of operating point of the amplifiers in the EDFA cascade.
Linear impairments identification	Kalman filter Neural networks Principal component analysis	[21]: tracking of carrier phase, estimating 1 st -order PMD, and polarization tracking. [33]: identified DGD and CD [41]: monitored the DGD and the CD in an independent manner.

Applications	Artificial Intelligence Methods	Literature
OSNR monitoring	Deep neural networks (DNN) NNs	[52]: used the DNN, trained with asynchronously sampled raw data, for the monitoring of the OSNR. [53]: used the NN-based non-linear regression for estimating the OSNR.
Modulation format recognition	PCA Clustering k- means SVMs	[40]: identified the formats of the modulation on the basis of the amount of the levels and the clusters in the diagram of the constellation. [41]: identified the bit rates/modulation formats/ from a known dataset. [53]: classified the formats of the modulation with the use of eye opening width variances.
Non-linearity mitigation, Receivers	Maximal a posteriori Maximal-likelihood Maximal-likelihood and Bayesian filtering and expectation-maximization Maximal a posteriori Non-linear SVMs KNNs	[30]: looked for the phase estimates feasible for the calculation in real-time. [31]: proposed a variety of the methods of the equalization for the WDM interconnects of high capacity. [32]: proposed a variety of the estimators for recovering phase in Offset-QAM-based filter-bank multi-carrier systems. [54]: Maximal-likelihood detection for the phase-modulated systems that have linear and non-linear phase noise. [55]: proposed state-space models for the cross-polarization mitigation, symbol detection and carrier synchronization. [56]: SVMs have been applied for the creation of the decision boundaries for avoiding the errors that are induced by the non-linear impairments. [57]: proposed algo. Which learns the link characteristics and produce boundaries of the non-linear decision for The maximization of the distance of the transmission and enhancing the non-linear tolerances. Clustering k-mean [42]: suggests an approach of the mitigation of the effects of the time-varying impairments, for example, the phase noise. The non-linear SVMs and Newton approach [58]: utilizes Newton-method (N-SVM) for the reduction of the inter-sub-carrier non-linear crosstalk influences.
QoT estimation	Case-Based Reasoning (CBRs) CBR + learning/forgetting CBRs + learning/forgetting Linear regression SVMs Random forests	[34]: presented an estimator of the QoT for deciding whether or not the light-path fulfils the requirements of the QoT. [35]: optimized previous method of the CBR for estimating the QoT with the learning and forgetting methods. [36]: experimentally demonstrated estimator of the QoT [35] in a WDM80 Gb/s PDM-QPSK testbed. Classifier [37]: predicted probability that a candidate light-path BER will not exceed a certain value of the threshold.

Applications	Artificial Intelligence Methods	Literature
		[38]: used the monitoring of the BER information and a process of learning (based upon the LR) for the purpose of estimating BER of every one of the new service requests. [59]: proposed accurate and fast light-path QoT estimators that have been based upon the SVMs for deciding whether or not the light-path can fulfil the requirements of the QoT

2.2. Applications of AI in the optical networks

Artificial intelligence provides many advantages for the automation of the processes and introduction of the intelligent decision-making into the planning of the network and in the dynamic management as well as the regulations of the community resources, which include the establishment of the connections, self-optimizations and self configuration, by predicting and appreciating the use of the current and historical data. These applications are summarized in Tables 2.

Table 2. Applications of AI in the Optical Networks

Application	Artificial intelligence methods	Literature
Survivable optical networks	GA Ant colony optimization	[7]: guaranteed the underlying network survivability at the same time as reducing the number of the re-generators. [69]: designed physical topology of network, ensuring the survivability.
Regenerator placement	Genetic algorithms Ant colony optimization	[6]: minimized the number of the all-optical regenerators for the purpose of minimizing the cost of the network. [7]: guaranteed the survivability of underlying network while simultaneously reducing number of re-generators. [70]: optimized selection of the re-generators, routing, code rate and spectrum allocation in the flex-grid code-rate adaptive optic networks.
Resource allocation	GA PSO Ant colony optimization K-means clustering MDP	[72]: proposed an approach for the joint routing and the dimensioning of the dynamic WDM ring networks. [71]: proposed an innovative network model that interconnects a group of the IP/MPLS areas, performing routing and flow aggregation, via flex-grid optical core. [26]: modeled resource allocation the issue as MDP for optimizing an objective that has been defined randomly by the network operator. [74]: allocation of the transmitted power for the energy efficient optic WDM/OCDM networks. [73]: solved resource allocation issue under the restrictions of the QoS and problem of energy efficiency constraint. [75]: proposed an approach of message scheduling, which addressed message sequencing as well as channel evaluation problems for WDM star network.
Establishment of the Connection	Swarm intelligence Case-based reasoning GA ACO	[6]: solved RWA issue while also ensuring QoT of the unestablished light-paths.

Application	Artificial intelligence methods	Literature
	Simulated annealing Back-propagation NN Tabu search Q-learning Neural networks and principal components analysis Kalman filters Game theory Markov decision processes	[76]: proposed multi-objective methods that are based upon the swarm intelligence for solving the problem of the RWA. [8]: solved Impairment Aware static RWA issue. [79]: solved RSA problem in the flex-grid networking that produced useful insights about the design of the network. [77]: solved problem of RMLSA. [78]: considered multi-cast flows for the RSA with the use of a variety of the cross-over and selection strategies. [9]: the RWA solution with a very high robustness and adaptability to a variety of the traffic and network conditions. [11]: solved the problem of the RSA through the proper balancing of spectrum utilizations and security-level of the domain in the multi-domain EONs. [24]: derived optimum establishment policy of the light-path for every one of the service classed with the use of an MDP. [80]: solved RSA problem with the joint unicast and anycast demands. [81]: reduced the energy footprint of the network's by finding most energy-efficient routes. [82]: introduced a heuristic on the way ants chose a request from the demand space for the purpose of finding minimal path. [85]: solved problem of RMCSA in the elastic networks with the SDM. [45]: solved wave-length and path selection in the networks of the OBS. [83]: reduced the complexity of the computing in the case of solving conventional RWA problem in dynamic WRONs. [22]: reduced the ratio of the blocking through the estimation of wave-length occupancy before RWA decision. [84]: solved RMLSA problem in the elastic networks. [86] & [87]: solved the problem of RSA providing dedicated path protection as well. [88]: predicted arrival and holding times of the future connections through the consideration of the past experiences. [89]: estimated feature of connection blocking probability. [25]: proposed using a sufficient dynamic-preemption

3. New opportunities and challenges for using artificial intelligence in optical network types

The following sections include a description of some of the recent possibilities and challenging situations that we have envisioned in place of the optical systems and networks. We have envisioned an increasing number of challenging roles for AI use within the physical layer, as it will remain a beneficial tool, in the simplest

framework of the increasing technologies of the optical transmissions, as well as in helping increasing the security with the use of the intrusion or attack detection and positioning. We additionally described the related position of the area of the Artificial Intelligence in the automation of the processes of the network management, and in assisting emerging network models.

- 1. Optical transmission systems and intrusion and attack detections:** Several community control options are made based on correct dimensions or an estimate of physical parameters. Thus, we assume that AI will continue to play a critical function in assisting emerging technologies of the transmission such as space-division multiplexing, constellation modulation and multi-mode / multi-core fibers and super-modulation formats. We assume as well, that additional progress has been made within using the AI methods to estimate the QoT and monitor the performance. None-the-less, the main place closely associated with the surveillance where it has been seen that there has been a tremendous opportunity for the technologies of the Artificial Intelligence but not appear (to first degree of our knowledge) within the visual field, is the detection of intrusions and attacks.
- 2. Automating network management processes:** at a photovoltaic network operating site, heterogeneous community devices (multi-age and multi-vendor) make the operation, management and renewal of optical networks a complicated and difficult approach. That results because the societal country information, for example, topology, crowding, failure detection, and so on., which have been drawn from exclusive devices have exclusive and restricted information about the state, and that constitutes a mega enterprise in collecting records, processing them and making decisions. Which is why, the system automation was recognized as one of the major enablers to reduce operation costs, in addition to helping the flow of human intelligence away from the repetitive assignments.
- 3. Sufficient Joint Operations of the Computing Resources and Networks:** some of the emerging concepts, such as IoT, Industry (4.0) or tactile Internet, are imposing the stringent requirements on the networks, in combination with the excessive bandwidth and low latency, security and availability, thereby presenting massive challenges. The mix of the 5-G cell communication system with the high-speed fault-tolerance fiber backhaul infrastructures can be considered as the key that enables the technologies for these types of the networks. The end-to-end latency for a small number of the applications may be limited to few milliseconds (such as, 1ms for the tactile internet).

3.1. Network automation using AI and ML

Creating totally autonomous networks for communications service providers (CSPs) will be a long process of incrementally automating processes, domains, services, and eventually networks, after that protecting and controlling them with ML and AI. This will enable operators to do more than just compete; it is going to also supply them with the agility they require to reclaim enterprise customers, a lot of them have switched to digital-native suppliers for cloud-based services. Small adjustments can help CSPs get started on the road to autonomous networks, yet they must be part of a larger strategy. Various companies are already implementing automation in areas like IT operations, network operations, and other business units. Automation, on the other hand, is more and more being viewed as an enterprise-wide transformation project that should be integrated to reach an end-to-end result [35]. Some of the nodes communicate via algorithms that is based on linear algorithm or nonlinear algorithm such as (Dynamic evolving neural fuzzy inference (Dy-NFIS)) and (Recursive least squares (RLS)) [90], where other mainly use optical code division multiple access (optical-CDMA) [91] while in [92] authors try minimizing the undesirable noise among channels using fuzzy logic, Laguerre-Gaussian (LG) is used in [93] for division multiplexing,

3.2. Deep learning in optical communications

Generally, DL is a DNN with several of the nonlinear layers which are made up of many neurons, each of them is described (mathematically) as an activation function. Various algorithms that have distinct structures have been appropriate for a variety of the challenges and specialized in many types of data in DL communities. CNNs, recurrent neural networks (RNNs), generative adversarial networks (GANs), deep reinforcement learning (DRL), end-to-end learning depending on autoencoders, and their variants have all made significant contributions to some of the areas, like the NLP, machine vision, genomics, drug discovery, information retrieval, speech identification, automatic deriving, and affective computing (Deng, 2014). Advancement

from the ML to the DL is making significant progress in wide range of applications in network as well as physical layers, promoting the development of AI in optical communication [94]

From ML to DL, AI has progressed in optical communication. Dissimilar to other review papers that focus on traditional ML algorithms, this one focuses on cutting-edge DL methods and tries to emphasize the DL contributions to the optical communication at the physical as well as the network layers. We briefly discuss numerous DL-enabled optical communication applications by studying the properties of distinct DL algorithms and data types. To begin, CNN is presented as a very prominent DL algorithm for image recognition, processing 7 types of common image data from optical communication to perform many activities. After that, to handle network traffic data, digital signal waveforms, and equipment status information, RNN is used for sequential data analysis. Furthermore, a data-driven channel modeling approach depending on DL has been offered as an additional option to traditional block-based modelling, with the potential to increase end-to-end learning performance. GAN is a new data augmentation technology that is used to extend image data and network traffic data. Lastly, DRL has been taken into account for a variety of tasks of decision-making such as resource allocation, routing, and automatic configuration. [94].

3.3. CNNs for image data

DL is one of the ML branches that mostly refers to the NN faction. The term "neural network" comes from efforts for finding mathematical representations of the information processing in the biological systems that are made up of many inter-connected neurons. Each one of the neurons in a NN might be described as activation function in order to mimic the information transfer process in a practical biological system. NNs are classified as feedback networks or feedforward networks based on their network structure. A CNN is a sort of feedforward network that is used to analyze the image data and could be thought of as a 2-D grid of pixels (Le Cun *et al.*, 2015). Convolution, pooling, and activation are the three steps of CNN's operation.

3.4. Recurrent neural network for sequential data

Dissimilar to CNNs, which are developed for the image data, RNNs have been developed for sequential data, in which there are temporal correlations over a wide range of timescales. RNNs with cyclic connections, unlike feedforward neural networks, add memory to NNs, indicating that the outputs are related not just to the present inputs, yet also to previously available information [95]. As a result, the RNNs have excelled at sequence modeling and prediction applications like handwriting identification, speech recognition, stock price forecasting, and language translation. Figure 3 shows the RNN principle. The input vector can be defined as a set of the sequential data $X = \{\dots x_{t-1}, x_t, x_{t+1} \dots\}$, and neurons in hidden layer get the inputs from not only x_t of input layer but also the output h_{t-1} of hidden layer at previous time steps. Passing through a number of the hidden layers, an input sequence x_t may be mapped to output sequence y_t , involving some of the previously stated information. Traditional RNNs, on the other hand, have a hard time learning long-term dependencies from sequential data. Long short-term memory (LSTM) has been created for overcoming such flaw in RNNs by learning long-range temporal correlations amongst sequential data and remembering inputs for a long time [96] The memory cell that might carry information via time steps, and structures that are referred to as gates, applied for removing or adding information to the memory cell, are the key ideas of LSTM, which is one of the most well-known RNN variants, as illustrated in Figure 3B. The LSTM's functioning method could be characterized as forgetting the old state and memorizing the new one in order to pass on the valuable information in the cell while discarding the useless information. As a result, the LSTM not just allows for the accumulation of data over a lengthy period of time, yet it also forgets the previous state through setting it to 0 and starting anew. Apart from image data, the majority of the data in the age of big data is sequential, like language, speech, and words. The mutual impact and the experienced impairments from process of transmission might be represented in temporal signal wave-forms, and optical signals could be thought of as a series of time-domain data. RNN might pre-distort signals prior to transmission for resisting the transmitter imperfection and post-compensate signals after receiving to mitigate the impairments of the system, or find crosstalk between adjacent symbols to cancel ISI, owing to its higher performance for such data [94] Based day-to-day statistics, traffic loads fluctuate irregularly or regularly over time for network traffic data. With regard to temporal analysis, RNN might develop a model of prediction for large-scale network traffic prediction, depending on prior scenes, which is critical for network planning and load balancing [93] Because a failure of the optical network might lead to a significant financial loss, network operators are more and more relying on

proactive protection and early warning. The equipment state characteristics, which vary over time, might reflect the working conditions related to the network equipment. RNN might learn the trend of the variation regarding the state parameters and develop a mechanism of failure prediction for preventing risks in advance by evaluating a large amount of historical data [97].

4. Deep reinforcement learning for automation of the network

Reinforcement Learning (RL) made significant progress in solving complex control problems using environment-aware methods. As can be seen in Figure 6, DL is of high importance in perception because it could gather information from observations of environment and deliver current state information, whereas RL is of critical in decision-making because it could sense complex system states and learn the optimal policies via repeated the interactions with environment. Furthermore, DRL combines DL's perception and RL's decision to develop a policy for maximizing the cumulative rewards for a variety of tasks, such as Go, robotics control, and competitive video games [94].

4.1. Convolution

The kernel convolves with the pixel points over the input image's height and width, evaluating the dot product between input entries and the kernel. Also, the kernel functions like a filter, scanning input image for informative features which could be used for recognition. In face images, the extracted features, like nose, eyes, and mouth, are explainable and visible. To enhance image the recognition performance, convolution uses sparse interaction, equivariant representations, and parameter sharing [95].

4.2. Pooling: Down-Sampling operation

At a given location, the convolution layer's output is substituted by a summary statistic of surrounding outputs. Calculating the maximum or average value of a small local area in certain feature map to down-sample feature map's dimensions; thus, drastically lowering the parameter size as well as generating invariance to small input translations, is a common pooling technique [96].

5. Activation: Non-linear operation

The nonlinear mapping between the adjacent layers improves the network's overall representation capacity. Softmax, ReLU, Sigmoid, and Softplus are examples of major activation functions. CNN is extremely excellent at analyzing image data, such as objection detection, image recognition, video translation, and image understanding, because of the aforementioned features [95]. Images frequently responsible for a substantial share of different data types. As a result, CNN is considered as one of the most effective image processing techniques in deep learning. The majority of data in optical communication is represented via a digital signal, whereas a few other types of information are represented by images, as illustrated in Figure 2. One significant benefit of image formats over digital vector data formats is that they allow different digital data of various sizes to be presented integrally and thoroughly in an image with fixed pixel size. As a result, image data with a given size might be containing a variety of information, critical for DL and ML to establish the stability of their structures [97].

6. Conclusion

This scientific paper has presented a detailed survey on the latest researches in the domain of AI Technologies Program in the Optical Networks, in addition to an overview of emerging possibilities and issues in such context. For the purpose of providing the readers with a comprehensive, generalized imagination and insight into many strategies and approaches making up this clinical discipline, we have initially identified these sub-fields of artificial intelligence which were effectively utilized in the optical networks: (a) theoretical research and improvement techniques, (b) recreation theory, (c) methods. Knowledge-based inference and planning, (d) statistical model, (e) algorithms of decision-making, (f) mastery of techniques, later, we radically revised the

applications of those strategies to enhance the visual transmission performance (Table1), as well as the network design Visual and its processing (Tables 2). Specifically, with regard to the optical transmissions, we have addressed AI technology suitability in the case of dealing with transmitters' characterizations and operations, and estimating QoT, which is of particular interest in the visual community process.

References

- [1] S. Russell, P. Norvig, "Artificial Intelligence: A Modern Approach", 3rd Edition, Prentice Hall Press, Upper Saddle River, NJ, USA, 2009.
- [2] B. Mukherjee, Optical WDM Networks, Springer-Verlag New York, Inc., Secaucus, NJ, USA, 2006.
- [3] J. M. Simmons, "Optical Network Design and Planning", Optical Networks, Springer International Publishing, 2014.
- [4] R.V. Rao, V.J. Savsani and, D.P. Vakharia, Teaching-learning-based optimization: an optimization method for continuous non-linear large scale problems. Information sciences, vol.183, no.1, pp.1-15, 2012
- [5] K.-L. Du, M. N. S. Swamy, Search and Optimization by Metaheuristics, Springer International Publishing, 2016.
- [6] F. Martinelli, N. Andriolli, P. Castoldi and I. Cerutti, Genetic approach for optimizing the placement of all-optical regenerators in WSON. Journal of Optical Communications and Networking, vol.6, no.11, pp.1028-1037, 2014.
- [7] M. Morgan, "An ant colony approach to regenerator placement with fault tolerance in optical networks", In 2015 7th International Workshop on Reliable Networks Design and Modeling (RNDM), pp. 85-91. IEEE. 2015
- [8] D. Monoyios and K. Vlachos, Multiobjective genetic algorithms for solving the impairment-aware routing and wavelength assignment problem. Journal of optical communications and networking, vol.3, no.1, pp.40-47. 2011
- [9] Wang, X., Brandt-Pearce, M. and Subramaniam, S. Distributed grooming, routing, and wavelength assignment for dynamic optical networks using ant colony optimization. Journal of Optical Communications and Networking, 6(6), pp.578-589. 2014
- [10] O. Awwad, A. Al-Fuqaha, B. Khan, D. Benhaddou, M. Guizani, A. Rayes, Bayesian-based game theoretic model to guarantee cooperativeness in hybrid RF/FSO mesh networks, in: IEEE Global Telecommunications Conference, 2009. GLOBECOM 2009, pp. 1-7 2009.
- [11] J. Zhu, B. Zhao and Z.. Zhu, Leveraging game theory to achieve efficient attack-aware service provisioning in EONs. Journal of Lightwave Technology, 35(10), pp.1785-1796. 2017
- [12] L. Pavel, Game Theory for Control of Optical Networks, Birkh"auser Basel, 2012.
- [13] I. De Miguel, R.J. Durán, T. Jiménez, N. Fernández, et al., "Cognitive dynamic optical networks. Journal of Optical Communications and Networking", vol.5, no.10, pp.A107-A118. 2013
- [14] R. Borkowski, et al., "Cognitive optical network testbed: EU project CHRON. Journal of Optical Communications and Networking", vol. 7, no.2, pp.A344-A355. 2015
- [15] G.S. Zervas and D. Simeonidou, "Cognitive optical networks: Need, requirements and architecture", In 2010 12th International Conference on Transparent Optical Networks, pp. 1-4, 2010
- [16] W. Wei, C. Wang and J. Yu, "Cognitive optical networks: key drivers, enabling techniques, and adaptive bandwidth services", IEEE Communications magazine, vol.50, no.1, pp.106-113.2012
- [17] S.J.B. Yoo, " Multi-domain cognitive optical software defined networks with market-driven brokers", In 2014 The European Conference on Optical Communication (ECOC) (pp. 1-3). IEEE. 2014
- [18] V.W. Chan and E. Jang, "Cognitive all-optical fiber network architecture", In 2017 19th International Conference on Transparent Optical Networks (ICTON) (pp. 1-4). IEEE.2017
- [19] S. Gosselin, J. L. Courant, S. R. Tembo, S. Vaton, Application of probabilistic modeling and machine learning to the diagnosis of FTTH GPON networks, in: 2017 International Conference on Optical Network Design and Modeling (ONDM), pp. 1-3. 2017
- [20] K. Chitra, M. R. Senkumar, Hidden Markov model based lightpath establishment technique for improving QoS in opticalWDM networks, in: Second International Conference on Current Trends In Engineering and Technology - ICCTET 2014, pp. 53-62. 2014
- [21] B. Szafraniec, T.S. Marshall and B. Nebendahl, "Performance monitoring and measurement techniques for coherent optical systems", Journal of Lightwave Technology, vol.31, no.4, pp.648-663. 2012

- [22] M. Yannuzzi, X. Masip-Bruin, S. Sanchez-Lopez, E. M. Tordera, J. Sole- Pareta, J. Domingo-Pascual, Interdomain RWA Based on Stochastic Estimation Methods and Adaptive Filtering for Optical Networks, in: IEEE Globecom, pp. 1–6. 2006
- [23] A. Jayaraj, T. Venkatesh and C.S.R. Murthy, " Loss classification in optical burst switching networks using machine learning techniques: improving the performance of tcp", IEEE Journal on Selected Areas in Communications, vol.26, no.6, pp.45-54. 2008
- [24] T. Tachibana and I. Koyanagi, "MDP-based lighpath establishment for service differentiation in all-optical WDM networks with wavelength conversion capability", Photonic Network Communications, vol.20, no.2, pp.183-192. 2010
- [25] C.C. Sue, Y.B. Hsu and P.J. Ho, "Dynamic preemption call admission control scheme based on Markov decision process in traffic groomed optical networks", Journal of Optical Communications and Networking, vol.3, no.4, pp.300-311. 2011
- [26] R.R. Reyes and T. Bauschert, "Adaptive and state-dependent online resource allocation in dynamic optical networks", Journal of Optical Communications and Networking, vol.9, no.3, pp.B64-B77. 2017
- [27] Z. Ghahramani, " Probabilistic machine learning and artificial intelligence", Nature, vol.521, no.7553, pp.452-459. 2015
- [28] K. P. Murphy, Machine Learning: A Probabilistic Perspective, The MIT Press, 2012.
- [29] C. M. Bishop, Pattern recognition and machine learning, springer, 2006.
- [30] Taylor, M.G. Phase estimation methods for optical coherent detection using digital signal processing. Journal of Lightwave Technology, 27(7), pp.901-914.2009
- [31] Karinou, F., Stojanovic, N., Prodaniuc, C., Agustin, M., Kropp, J. and Ledentsov, N.N. Solutions for 100/400-Gb/s ethernet systems based on multimode photonic technologies. Journal of Lightwave Technology, 35(15), pp.3214-3222. 2016
- [32] F. Rottenberg, T. H. Nguyen, S. P. Gorza, F. Horlin, J. Louveaux, ML and MAP phase noise estimators for optical fiber FBMC-OQAM systems, in: 2017 IEEE International Conference on Communications (ICC) , pp. 1–6., 2017
- [33] X. Wu, J.A. Jargon, et al., "Applications of artificial neural networks in optical performance monitoring", Journal of Lightwave Technology, vol.27, no.16, pp.3580-3589. 2009
- [34] T. Jiménez, J. C. Aguado, I. de Miguel, R. J. Durán, N. Fernandez, M. Angelou, D. Sa´nchez, N. Merayo, P. Fern´andez, N. Atallah, et al., A cognitive system for fast quality of transmission estimation in core optical networks, in: Optical Fiber Communication Conference and Exposition (OFC/NFOEC), 2012 and the National Fiber Optic Engineers Conference, IEEE, pp. 1–3. 2012
- [35] T. Jiménez, J.C. Aguado, I. de Miguel, et al., " A cognitive quality of transmission estimator for core optical networks", Journal of Lightwave Technology, vol.31, no.6, pp.942-951. 2013
- [36] Caballero, A., Aguado, J.C., Borkowski, R., Saldaña, S., Jiménez, T., de Miguel, I., Arlunno, V., Durán, R.J., Zibar, D., Jensen, J.B. and Lorenzo, R.M.. Experimental demonstration of a cognitive quality of transmission estimator for optical communication systems. Optics express, 20(26), pp.B64-B70. 2012
- [37] L. Barletta, A. Giusti, C. Rottondi, M. Tornatore, QoT estimation for unestablished lighpaths using machine learning, in: Optical Fiber Communications Conference and Exhibition (OFC), pp. 1–3. 2017
- [38] S. Oda, M. Miyabe, S. Yoshida, T. Katagiri, Y. Aoki, T. Hoshida, J.C. Rasmussen, et al. , "A learning living network with open ROADMs", Journal of Lightwave Technology, vol. 35, no.8, pp.1350-1356. 2017
- [39] H. Rastegarfar, M. Glick, N. Viljoen, M. Yang, J. Wissinger, et al., "TCP flow classification and bandwidth aggregation in optically interconnected data center networks", Journal of Optical Communications and Networking, vol.8, no.10, pp.777-786. 2016
- [40] N. G. Gonzalez, D. Zibar, I. T. Monroy, Cognitive digital receiver for burst mode phase modulated radio over fiber links, in: Optical Communication (ECOC), 2010 36th European Conference and Exhibition on, IEEE, pp. 1–3. 2010
- [41] M. C. Tan, F. N. Khan, W. H. Al-Arashi, Y. Zhou, A. P. T. Lau, Si1240 multaneous optical performance monitoring and modulation format/bitrates identification using principal component analysis, Journal of Optical Communications and Networking 6 (5) pp.441–448. 2014
- [42] J. J. G. Torres, A. Chiuchiarelli, V. A. Thomas, S. E. Ralph, A. M. C. Soto, N. G. González, Adaptive nonsymmetrical demodulation based on machine learning to mitigate time-varying impairments, in: Avionics and Vehicle Fiber-Optics and Photonics Conference (AVFOP), 2016 IEEE, IEEE, , pp. 289–290. 2016

- [43] L. P. Kaelbling, M. L. Littman, A. W. Moore, Reinforcement learning: A survey, *Journal of artificial intelligence research* 4 pp.237–285. 1996
- [44] C.J. Watkins and P. Dayan, Q-learning. *Machine learning*, 8(3-4), pp.279-292. 1992
- [45] Y.V. Kiran, T. Venkatesh and C.S.R. Murthy, "A reinforcement learning framework for path selection and wavelength selection in optical burst switched networks", *IEEE Journal on Selected Areas in Communications*, vol.25, no.9, pp.18-26. 2007
- [46] D. Zibar, L.H.H. de Carvalho, M. Piels, et al., "Application of machine learning techniques for amplitude and phase noise characterization", *Journal of Lightwave Technology*, vol.33, no.7, pp.1333-1343. 2015
- [47] A. Hraghi, M.E. Chaibi, M. Menif and D. Erasme, "Demonstration of 16QAM-OFDM UDWDM transmission using a tunable optical flat comb source", *Journal Of Lightwave Technology*, vol.35, no.2, pp.238-245. 2016
- [48] S.L. Brunton, X. Fu and J.N. Kutz, "Self-tuning fiber lasers", *IEEE Journal of Selected Topics in Quantum Electronics*, vol.20, no.5, pp.464-471.2014
- [49] Y. Huang, W. Samoud, C. L. Gutterman, C. Ware, M. Lourdiane, G. Zussman, P. Samadi, K. Bergman, A machine learning approach for dynamic optical channel add/drop strategies that minimize edfa power excursions, in: *Proceedings of ECOC 2016; 42nd European Conference on Optical Communication*, VDE, , pp. 1–3. 2016
- [50] Y. Huang, P.B. Cho, P. Samadi and K. Bergman, "Dynamic power pre-adjustments with machine learning that mitigate EDFA excursions during defragmentation", In *2017 Optical Fiber Communications Conference and Exhibition (OFC)* (pp. 1-3), 2017
- [51] E. d. A. Barboza, C. J. Bastos-Filho, J. F.Martins-Filho, U. C. deMoura, J. R. de Oliveira, Self-adaptive erbium-doped fiber amplifiers using machine learning, in: *Microwave & Optoelectronics Conference (IMOC), 2013 SBMO/IEEE MTT-S International*, IEEE, , pp. 1–5. 2013
- [52] T. Tanimura, T. Hoshida, J. C. Rasmussen, M. Suzuki, H. Morikawa, OSNR monitoring by deep neural networks trained with asynchronously sampled data, in: *2016 21st OptoElectronics and Communications Conference (OECC) held jointly with 2016 International Conference on Photonics in Switching (PS)*, IEEE, , pp. 1–3. 2016
- [53] J. Thrane, et al., "Machine learning techniques for optical performance monitoring from directly detected PDM-QAM signals", *Journal of Lightwave Technology*, vol.35, no.4, pp.868-875.2016
- [54] A.P.T. Lau and J.M. Kahn, "Signal design and detection in presence of nonlinear phase noise", *Journal of Lightwave Technology*, vol.25, no.10, pp.3008-3016. 2007
- [55] D. Zibar, M. Piels, R. Jones and C.G. Schaeffer, "Machine learning techniques in optical communication", *Journal of Lightwave Technology*, vol.34, no.6, pp.1442-1452. 2015
- [56] D. Wang, M. Zhang, Z. Li, Y. Cui, J. Liu, Y. Yang, H. Wang, Nonlinear decision boundary created by a machine learning-based classifier to mitigate nonlinear phase noise, in: *Optical Communication (ECOC), 2015 European Conference on*, IEEE, , pp. 1–3. 2015
- [57] D. Wang, M. Zhang, M. Fu, Z. Cai, Z. Li, Y. Cui, B. Luo, KNN-based detector for coherent optical systems in presence of nonlinear phase noise, in: *2016 21st OptoElectronics and Communications Conference (OECC) held jointly with 2016 International Conference on Photonics in Switching (PS)*, IEEE, , pp. 1–3. 2016
- [58] E. Giacomidis, J. Wei, S. Mhatli, M. F. Stephens, N. J. Doran, A. D. Ellis, B. J. Eggleton, Nonlinear inter-subcarrier intermixing reduction in coherent optical OFDM using fast machine learning equalization, in: *Optical Fiber Communications Conference and Exhibition (OFC), 2017*, IEEE, , pp. 1–3. 2017
- [59] J. Mata, I. de Miguel, R. J. Dur´an, J. C. Aguado, N. Merayo, L. Ruiz, P. Fern´andez, R. M. Lorenzo, E. J. Abril, A SVM approach for lightpath QoT estimation in optical transport networks, in: *2017 IEEE International Conference on Big Data (IEEE BigData)*, pp. 4713–4715. 2017
- [60] T. Duthel, et al., "Laser linewidth estimation by means of coherent detection. *IEEE Photonics Technology Letters*, vol.21, no.20, pp.1568-1570. 2009
- [61] I. Fatadin, D. Ives, and S. J. Savory. "Laser linewidth tolerance for 16-QAM coherent optical systems using QPSK partitioning", *IEEE Photonics Technology Letters*, vol. 22, no. 9, pp. 631-633, 2010.
- [62] Z. Dong, et al., "Optical performance monitoring: A review of current and future technologies", *Journal of Lightwave Technology*, vol.34, no.2, pp.525-543, 2016.
- [63] Z. Li, et al., "Signed chromatic dispersion monitoring of 100Gbit/s CS-RZ DQPSK signal by evaluating the asymmetry ratio of delay tap sampling", *Optics express*, vol.18, no.3, pp.3149-3157, 2010.

- [64] F.N. Khan, et al., "OSNR monitoring for RZ-DQPSK systems using half-symbol delay-tap sampling technique", *IEEE Photonics Technology Letters*, vol.22, no.11, pp.823-825, 2010.
- [65] A. Napoli, et al., "Reduced complexity digital back-propagation methods for optical communication systems", *Journal of lightwave technology*, vol.32, no.7, pp.1351-1362, 2014.
- [66] N.V. Irukulapati, et al., "Stochastic digital backpropagation with residual memory compensation", *Journal of Lightwave Technology*, vol.34, no.2, pp.566-572, 2016.
- [67] S. Azodolmolky, et al., "Experimental demonstration of an impairment aware network planning and operation tool for transparent/translucent optical networks", *Journal of Lightwave Technology*, vol.29, no.4, pp.439-448, 2011.
- [68] A. Aamodt and E. Plaza, "Case-based reasoning: Foundational issues, methodological variations, and system approaches", *AI communications*, vol.7, no.1, pp.39-59, 1994.
- [69] R.M. Morais, C. Pavan, A.N. Pinto and C. Requejo, "Genetic algorithm for the topological design of survivable optical transport networks", *Journal of optical communications and networking*, vol.3, no.1, pp.17-26.
- [70] I. Cerutti, et al., "Trading regeneration and spectrum utilization in code-rate adaptive flexi-grid networks", *Journal of Lightwave Technology*, vol.32, no.23, pp.3894-3901, 2014.
- [71] L. Velasco, et al., "Saving CAPEX by extending flexgrid-based core optical networks toward the edges", *Journal of Optical Communications and Networking*, vol.5, no.10, pp.A171-A183, 2013.
- [72] I. de Miguel, et al., "Genetic algorithm for joint routing and dimensioning of dynamic WDM networks", *Journal of Optical Communications and Networking*, vol.1, no.7, pp.608-621, 2009.
- [73] F.R. Durand and T. Abrão, "Energy-efficient power allocation for WDM/OCDM networks with particle swarm optimization", *Journal of Optical Communications and Networking*, vol.5, no.5, pp.512-523, 2013.
- [74] M. de Paula Marques, F.R. Durand and T. Abrão, "WDM/OCDM energy-efficient networks based on heuristic ant colony optimization", *IEEE Systems Journal*, vol.10, no.4, pp.1482-1493, 2014.
- [75] S.G. Petridou, P.G. Sarigiannidis, G.I. Papadimitriou and A.S. Pomportsis, "On the use of clustering algorithms for message scheduling in WDM star networks", *Journal of Lightwave Technology*, vol.26, no.17, pp.2999-3010, 2008.
- [76] A. Rubio-Largo, et al., "A comparative study on multiobjective swarm intelligence for the routing and wavelength assignment problem", *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, vol.42, no.6, pp.1644-1655, 2012.
- [77] L. Gong, et al., "A two-population based evolutionary approach for optimizing routing, modulation and spectrum assignments (RMSA) in O-OFDM networks", *IEEE Communications letters*, vol.16, no.9, pp.1520-1523, 2012.
- [78] P. Lechowicz, K. Walkowiak, Genetic algorithm for routing and spectrum allocation in elastic optical networks, in: *Network Intelligence Conference (ENIC), 2016 Third European*, IEEE, 2016, pp. 273–280.
- [79] P. Wright, M.C. Parker and A. Lord, "Minimum-and maximum-entropy routing and spectrum assignment for flexgrid elastic optical networking", *Journal of Optical Communications and Networking*, vol.7, no.1, pp.A66-A72, 2015.
- [80] M. Przewoźniczek, et al., "Towards solving practical problems of large solution space using a novel pattern searching hybrid evolutionary algorithm—an elastic optical network optimization case study", *Expert Systems with Applications*, vol.42, no.21, pp.7781-7796, 2015.
- [81] C.A. Kyriakopoulos, et al., "Energy-efficient lightpath establishment in backbone optical networks based on ant colony optimization", *Journal of Lightwave Technology*, vol.34, no.23, pp.5534-5541, 2016.
- [82] Y. Sun, J. Yuan, M. Zhai, An optimized RWA method with services selection based on ACO in optical network, in: *2016 15th International Conference on Optical Communications and Networks (ICOON)*, pp. 1–3, 2016.
- [83] Z. Chen, S. Wang, H. Zhang, Y. Liu, Y. Peng, Cognitive routing and wavelength assignment algorithm for dynamic optical networks, in: *2014 12th International Conference on Optical Internet 2014 (COIN)*, pp. 1–3, 2014.
- [84] K. Christodouloupoulos, I. Tomkos and E.A. Varvarigos, "Elastic bandwidth allocation in flexible OFDM-based optical networks", *Journal of Lightwave Technology*, vol.29, no.9, pp.1354-1366, 2011.

- [85] J. Perelló, J.M. Gené, et al., "Flex-grid/SDM backbone network design with inter-core XT-limited transmission reach", *Journal of Optical Communications and Networking*, vol.8, no.8, pp.540-552, 2016.
- [86] K. Walkowiak, et al., "Routing and spectrum allocation algorithms for elastic optical networks with dedicated path protection", *Optical Switching and Networking*, vol.13, pp.63-75, 2014.
- [87] Goścień, R., Walkowiak, K. and Klinkowski, M., 2015. Tabu search algorithm for routing, modulation and spectrum allocation in elastic optical network with anycast and unicast traffic. *Computer Networks*, 79, pp.148-165.
- [88] W. B. Jia, Z. Q. Xu, Z. Ding, K. Wang, An efficient routing and spectrum assignment algorithm using prediction for elastic optical networks, in: 2016 International Conference on Information System and Artificial Intelligence (ISAI), pp. 89–93, 2016.
- [89] D.R. de Araújo, et al., "Methodology to obtain a fast and accurate estimator for blocking probability of optical networks", *Journal of Optical Communications and Networking*, vol.7, no.5, pp.380-391, 2015.
- [90] A. Ghazi, et al., "Hybrid Dy-NFIS & RLS equalization for ZCC code in optical-CDMA over multi-mode optical fiber", *Periodicals of Engineering and Natural Sciences (PEN)*, vol.9, no.1, pp.253-276, 2021.
- [91] A. Ghazi, et al., "A Systematic review of Multi-Mode Fiber based on Dimensional Code in Optical-CDMA", In *Journal of Physics: Conference Series*, vol. 1860, No. 1, p. 012016, 2021.
- [92] A. Ghazi, et al., "Hybrid Dy-NFIS & RLS equalization for ZCC code in optical-CDMA over multi-mode optical fiber", *Periodicals of Engineering and Natural Sciences (PEN)*, vol.9, no.1, pp.253-276, 2021.
- [93] A. Amphawan, A. Ghazi and A. Al-dawoodi, "Free-space optics mode-wavelength division multiplexing system using LG modes based on decision feedback equalization", In *EPJ Web of Conferences*, Vol. 162, p. 01009, 2017.
- [94] C. Häger and H.D. Pfister, "Nonlinear interference mitigation via deep neural networks", In 2018 Optical Fiber Communications Conference and Exposition (OFC), pp. 1-3, 2018
- [95] T. Mikolov, et al., "Recurrent neural network based language model". In *Interspeech*, Vol. 2, No. 3, pp. 1045-1048, 2010.
- [96] T. Zia and U. Zahid, "Long short-term memory recurrent neural network architectures for Urdu acoustic modeling" *International Journal of Speech Technology*, vol.22, no.1, pp.21-30, 2019.
- [97] C. Li, "Analogue signal and image processing with large memristor crossbars", *Nature electronics*, vol.1, no.1, pp.52-59, 2018.