A Review of Metaheuristic Optimization for Network Traffic Management in Telecommunications

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Abstract

This review aims to identify metaheuristic optimization and machine learning in the context of network management in the current era and some graphs of real network applications, such as traffic prediction, resource assignment, and network protection. Bio-inspired meta-functions, which model heuristic approaches to problem-solving in nature, have been shown to provide the best solutions to the OP problem and possess properties that make them ideal for optimizing dynamic networks. In the same vein, neural networks and reinforcement learning models have also performed significantly better in optimizing network performance by providing precise forecasts and decision-making adaptabilities. Incorporating these methodologies into folded working models has facilitated the development of solutions for the more complicated new networks such as SDNs, MANETs and IoTs. This review consolidates the most recent work in this field while identifying new advances as revolutionary technologies for refining the next-generation networks; it discusses possible paths for future research to overcome the existing drawbacks.

Keywords: Metaheuristic Optimization; Machine Learning; Network Management; Traffic Prediction; Resource Allocation; Network Security.

1. Introduction

Network management faces accelerated growth in communicational technologies, leading to benefits and problems. These networks, SDNs, MANETs, and IoT frameworks need flexible, scalable security solutions to meet complicated tasks such as traffic flow, resource controlling and dynamic security threats. These methods are ineffective as they do not meet contemporary networks' dynamic nature. Hence, there is a need to try other optimal methods. Metaheuristic algorithms and the various machine learning models constitute recent technologies that provide new ways of tackling routing, traffic forecasting and network protection. This section presents a brief of more recent developments in these fields to demonstrate the potential of these developments in tackling the key issues of the following next-generation networks.

Ongoing advancement of communication technologies and the use of interconnected devices have raised the need for efficient and effective management of communication networks in a scalable manner. New generation networks, such as SDNs, MANETs, and IoT, have some main obstacles in dealing with the flood of traffic, changes in network topology, or threats in terms of security. Still, increasing levels of complexity within the network conditions generate these problems, providing inadequate results using traditional approaches that attempt to meet the requirements of new-generation networks. To overcome these problems, scholars have shifted toward progressive optimization methodologies and heuristic algorithms that hold the

DOI: https://doi.org/10.54216/MOR.030201
Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025

future for providing the networks, dynamic characteristics and optimal functionality in response to new demand patterns [1].

Metaheuristic optimization algorithms are optimization techniques derived from natural processes that are highly effective in handling combinatorial and dynamic issues of the current complex networks. These algorithms include Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO), which are good at delivering the most efficient solutions within tasks that relate to routing, resource allocation and even traffic prediction. During the local searches, metaheuristics overcome the issues of local minimum and undertake global searches, hence providing adequate solutions to the dynamic and stochastic nature of challenges faced by networks. The ability to be adapted and scalable has made it very useful in solving significant challenges such as energy consumption in mobile Ad hoc networks and congestion control in software-defined networks [2].

Machine learning tools such as neural networks and reinforcement learning have enhanced the optimization networks. Techniques like deep reinforcement learning (DRL) and long short-term memory (LSTM) based network design hold the possibility of predicting and learning from traffic patterns and inferring network dynamics. These approaches utilize large volumes of information to learn and determine the best route, increase spectral efficiency and improve a network's overall performance. Together with metaheuristic algorithms, they create hybrid models that implement both approaches' positive aspects and provide accurate, efficient, and adaptable solutions [3].

Similarly, other issues, such as security, have been incorporated into the network management domain. With growing size and connectivity, a network becomes more vulnerable to metasystem threats like traffic diversion. These new threats are not usually addressed by the conventional security methods used today. Using state-of-the-art algorithms to optimize security and proper machine learning techniques, theorists produced intelligent frameworks proficient in operational security threat identification and prevention. These solutions are used to protect the network and provide a level of consistency in performance, which is highly dynamic nowadays [4].

This section presents several metaheuristic optimization and machine learning studies and expresses how these fields benefit network management. These approaches have helped in efficient routing protocols using IoT and MANETs and have promoted novel approaches toward adaptive traffic steering frameworks for modern SDNs. Thus, this review integrates the recent developments in these areas to examine how these methodologies can revolutionize future work in next-generation network management and future research on intelligent network optimization [5].

The combination of metaheuristic optimization with machine learning allowed for the advanced incorporation of such methods into network management to address complexity and scale issues in the modern network. These techniques have been seen to be helpful when it comes to manipulating routing protocols, increasing the efficiency of traffic prediction, and strengthening the network's security. As such, these approaches incorporate flexibility, sustainability, and accuracy to accommodate better the complex environments to which networks are subjected. The literature review also shows that the highlighted studies have made important strides and provide a foundation for future research to develop further innovations. Further investigation of the hybrid approaches and intelligent models will be crucial in facilitating the work of the next generation of networks.

Literature Review

The rapid change from communication technology to the network of various paradigms has imposed multifaceted challenges like traffic management, routing optimization, and security over the advanced modern networks. The metaheuristics and advancement machine learning techniques have proved their leverage in meeting these requirements in scalable and adaptive manners. Research is replete with heterogeneous applications, including traffic prediction, resource allocation, and protocol design, which vividly demonstrate the versatility and effectiveness of these approaches. This article review captures freshness gained within a period under focus, emphasizing innovative algorithms and frameworks for

DOI: https://doi.org/10.54216/MOR.030201
Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025

optimization efforts toward network performance within various domains. This review further emphasizes the growing relevance of hybrid methodologies in solving increasingly complex problems over wireless and heterogeneous networks by reviewing these contributions.

As outlined in [6], the software-defined network (SDN) architecture manages network operations through the control, infrastructure, and application layers. While SDN effectively handles current traffic prediction, it struggles to forecast future traffic. Recent studies have leveraged Long Short-Term Memory (LSTM) networks to address this limitation. The LSTM model excels in providing accurate future predictions by utilizing current input data. Furthermore, m-LSTM improves the recurrent functionality by enhancing data flow and processing efficiency. This study highlights the application of metaheuristic DC m-LSTM within a recurrent neural network to predict future traffic and identify optimal routes in SDN. By integrating swarm intelligence to solve complex dynamic routing challenges, traffic prediction and optimal routing are achieved effectively.

As detailed in the paper [7], heuristics and metaheuristics are widely used approximate methods for addressing complex combinatorial optimization problems, mainly when exact methods are computationally prohibitive. Heuristics are often tailored for specific problem types, while metaheuristics offer broader applicability with minimal adjustments, such as modifying the encoding schema in Genetic Algorithms (GA). These algorithms are designed to temporarily escape local minima by temporarily allowing worse solutions temporarily, thus improving the likelihood of finding a global optimum. Metaheuristics, categorized as evolutionary or swarm intelligence algorithms, include techniques like Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), and GA. This research investigates the application of these algorithms for route optimization in Mobile Ad Hoc Networks (MANETs), demonstrating through simulations that metaheuristics significantly enhance MANET routing performance.

In the research presented in [8], Multiprotocol label-switching (MPLS) networks were developed to enhance service provisioning and optimize performance by integrating multiple protocols with label-switching techniques. Including traffic engineering significantly improved resource management and Quality of Service (QoS) delivery for end users. Routing protocols in MPLS networks employ exact and approximate algorithms to manage traffic effectively. The study proposed an optimization model utilizing the Dolphin-Echolocation Algorithm (DEA) for optimal path computation in MPLS networks. Performance evaluations of DEA across networks with varying node configurations demonstrated its convergence toward optimal solutions. Additionally, comparisons with the Bat Algorithm were conducted, analyzing parameters such as mean, minimum fitness values, and standard deviation to assess the effectiveness of DEA in MPLS optimization.

As discussed in [9], the rapid advancements in sixth-generation (6G) networks and the Internet of Everything (IoE) have facilitated numerous emerging services and applications. However, the increasing demand for mobile internet traffic has introduced challenges beyond the scope of current network designs. Cybertown technology addresses these challenges, featuring capabilities like communication assistance, network data logging, and digital asset management. Limited spectrum resources necessitate efficient resource management and sharing to meet the requirements of 6G networks. The study proposed a novel metaheuristic with a blockchain-based resource allocation technique (MWBA-RAT) to optimize resource allocation in cybertown-driven 6G IoE environments. A new quasi-oppositional search and rescue optimization (QO-SRO) algorithm was developed, integrating quasi-oppositional learning with traditional SRO to enhance convergence rates. Experimental results demonstrated the effectiveness of the MWBA-RAT technique in improving resource allocation performance.

As outlined in [10], recent computer technology and communication network advancements have introduced complex optimization challenges in network design and routing. Metaheuristics, as high-level frameworks, coordinate simpler heuristics to produce effective approximate solutions for these combinatorial optimization problems. Techniques such as simulated annealing, tabu search, GRASP, VNS, and genetic algorithms have emerged as practical and versatile strategies, successfully applied across various telecommunications problems. This study reviews the fundamental components typical of different metaheuristics, explains their methodologies' principles, provides templates for basic implementations, and highlights their successful applications in solving telecommunications optimization challenges.

DOI: https://doi.org/10.54216/MOR.030201
Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025

In the publication [11], significant advancements in computer technology and communication networks have led to complex optimization challenges such as network design and routing. Metaheuristics, as high-level methodologies, coordinate simpler heuristics and rules to derive effective approximate solutions for complex combinatorial optimization problems. Examples include simulated annealing, tabu search, GRASP, VNS, and genetic algorithms, which have proven effective across various telecommunications challenges. The study reviews shared components among metaheuristics, explains core principles, provides templates for basic implementations, and presents successful applications of these techniques in optimizing telecommunications systems.

As detailed in the paper [12], Wireless Sensor Networks (WSNs) consist of independent sensor nodes (SNs) deployed randomly to monitor environments effectively, supporting applications like medical monitoring, home automation, traffic observation, and ecological studies. Due to the energy constraints of SNs, routing plays a critical role in enhancing energy efficiency and extending network lifetime. Node localization (NL), which determines the geographical coordinates of unknown nodes using anchor nodes, is another significant challenge in WSNs. Both NL and routing are NP-hard problems, effectively addressed by metaheuristic optimization algorithms. The study introduces the MONL-MRPMS technique, which integrates the Coyote Optimization Algorithm (COA) for NL and the Seagull Optimization-based Multihop Multihop Routing (SGO-MHR) protocol for optimal route selection. Additionally, a mobile sink with route adjustment improves energy efficiency by dynamically adapting routes based on sink movement. Experimental results demonstrate the superiority of MONL-MRPMS over contemporary approaches in energy efficiency and NL accuracy.

The research presented in [13] identifies effective location management for mobile users in cellular networks as a critical challenge in wireless communications. This study addresses the issue through a reporting cell planning approach, framing location management as a cost optimization problem encompassing location updates and paging. The Bat Algorithm, a nature-inspired metaheuristic, is proposed to minimize location management costs. The study compares the Bat Algorithm with existing state-of-the-art techniques, demonstrating its applicability to reference and realistic networks in Odisha. Computational results reveal that the proposed approach achieves comparable solution quality to other methods while offering faster convergence.

As detailed in the paper [14], the increasing reliance on mobile and fixed communication networks, driven by affordable and accessible devices, has amplified the demand for infrastructure-less networks like Mobile Ad Hoc Networks (MANETs). This study introduces a novel routing protocol for MANETs inspired by the behavior of fungal colonies. The protocol incorporates nutrient search, hyphal growth, and mass flow dynamics from fungal biology to address challenges like topology changes caused by node mobility. It focuses on efficient route discovery, maintenance, failure recovery, and path optimization to ensure quality service in low-traffic scenarios. Experimental evaluations compare its performance against competing protocols, demonstrating its potential for efficient routing in dynamic MANET environments.

In the analysis conducted in [15], the Internet of Things (IoT) emerges as a transformative paradigm within Information Technology, integrating diverse technologies and communication solutions to connect heterogeneous devices. This connectivity presents significant routing challenges, necessitating adaptations to existing communication protocols. Mobile Ad Hoc Networks (MANETs) offer a viable solution due to their infrastructure-less, self-organizing, and multihop capabilities, but they face inherent challenges such as energy-efficient routing. The study introduces a swarm intelligence (SI)-based hybrid routing protocol for MANETs designed for energy-constrained environments. The protocol comprises three integrated phases: cluster design, Ant Colony Optimization (ACO)-aided cluster head selection, and data transmission through route aggregation. Simulation results demonstrate that the SI-based approach outperforms conventional hybrid routing protocols in packet delivery, energy consumption, throughput, and network lifespan, highlighting its robustness and efficiency.

As discussed in [16], the intelligent traffic steering (TS) framework has emerged as a pivotal development in 3GPP's advancements for 5G networks. To address the limitations of monolithic architectures in meeting key performance indicators (KPIs) for heterogeneous services, the study proposes a novel deep reinforcement learning (DRL)-based TS algorithm. This algorithm operates at the non-real-time RAN intelligent controller

DOI: https://doi.org/10.54216/MOR.030201
Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025

(RIC) within the open radio access network (ORAN) framework. The approach involves a three-step hierarchical process combining heuristics, machine learning, and convex optimization to optimize traffic flow distribution across appropriate paths. Simulation results demonstrate the proposed TS framework's superior performance, achieving a 45.50% improvement over benchmark systems in downlink multi-service scenarios.

The study referenced as [17] introduces a groundbreaking framework for managing IoT-based heterogeneous networks (HETNETS), emphasizing capacity optimization alongside impeccable coverage and data reliability. The proposed approach integrates metaheuristic algorithms, Neural Network optimization, and Federated Learning to orchestrate resource allocation dynamically. The study employs multi-layer optimization to develop a model for optimal transmission strategies, strategically allocating data replicas in cloud environments to reduce access costs. The framework also addresses the balance between spectral efficiency and ergodic capacity in cellular IoT networks using on/off control in small cells. Simulation results validate the framework's effectiveness, demonstrating superior trade-offs between spectral efficiency and ergodic capacity, as well as reduced outage probability, compared to conventional algorithms across varied scenarios.

As outlined in +[18], next-generation networks demand advanced management solutions to enable automation and adaptively adjust configurations based on dynamic traffic patterns. Software-defined networking (SDN) and programmable switches offer flexibility and programmability, but traditional traffic policy approaches relying on heuristic algorithms and static assumptions are insufficient for evolving network needs. This study introduces a deep reinforcement learning (DRL) framework for adaptive traffic routing, featuring a deep graph convolutional neural network (DGCNN) to learn traffic behavior from network topology and node/link attributes. Using Deep Q-Learning, the model operates without labeled training data, enabling rapid adaptation to traffic changes. Extensive experiments with various traffic patterns reveal that the proposed framework improves network throughput by up to 7.8% and reduces traffic delays by up to 16.1% compared to the Open Shortest Path First (OSPF) protocol, demonstrating its effectiveness and adaptability.

In the article denoted as [19], the increasing adoption of Software-Defined Networking (SDN) and the rising demand for network resources have heightened the risks of traffic diversion attacks, posing significant threats to network security and performance. Traditional detection methods often fail to identify advanced and dynamic attack strategies. To address this issue, a novel approach using metaheuristic algorithms, specifically a Genetic Algorithm (GA), is proposed to enhance the precision and effectiveness of traffic diversion detection. The algorithm achieves high accuracy (over 70%), precision (94%), recall (92%), and an F1-score (93%) while maintaining a low false positive rate. Its adaptability to evolving attack strategies and scalability to changing network conditions, such as traffic levels, make it a robust tool for dynamic SDN environments. This contribution significantly strengthens SDN security by safeguarding network integrity and reliability against evolving threats.

As outlined in [20], predicting wireless network traffic has long been a research focus due to its nonlinear and complex patterns, which pose significant challenges for accurate forecasting. Many existing methods fail to effectively model the dynamic spatial-temporal correlations inherent in wireless traffic data. A novel metaheuristic optimization approach combining Fitness Grey Wolf Optimization and Dipper Throated Optimization algorithms is proposed to enhance prediction accuracy. The algorithm optimizes the hyperparameters of a Long Short-Term Memory (LSTM) network, which is widely recognized for its efficiency in sequence prediction tasks. Comparative evaluations against four other optimization algorithms demonstrate the proposed approach's superior accuracy in traffic prediction. Statistical analyses further confirm the stability and reliability of the method, establishing its effectiveness for wireless network traffic forecasting.

The paper reviews published research on network traffic management, translating them to metaheuristic optimization and machine learning, as in Table 1 below. All the studies presented show new ways of solving various issues, including routing, resources, traffic, and security in network constructs like SDNs, MANETS, and IoT. This informs that GA, ACO and DRL are scalable, adaptive and accurate solutions to the problems as evidenced by the following studies. Furthermore, there is a need to incorporate composite approaches and

DOI: https://doi.org/10.54216/MOR.030201
Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025

sophisticated models to improve the network performance and dependability as identified across the studies. This table sums up the increasing role of these methods in addressing the following next-generation networks' needs.

Table 1: Summary of Literature Review

Study Reference	Topic/Focus	Key Findings	Significance
[6]	SDN architecture and traffic prediction using m-LSTM	Enhanced recurrent functionality for accurate traffic forecasting and routing.	Addresses traffic prediction gaps in SDNs.
[7]	Metaheuristics for routing optimization in MANETs	Metaheuristics improve MANET routing through simulations.	Applies generic optimization techniques to MANETs.
[8]	Optimization in MPLS networks using DEA and Bat Algorithm	DEA and Bat Algorithm improve MPLS performance; DEA outperforms.	Improves QoS and resource management in MPLS networks.
[9]	Resource allocation in 6G IoE using MWBA-RAT	MWBA-RAT optimizes resource allocation; QO-SRO enhances convergence.	Introduces blockchain and novel metaheuristics in 6G IoE.
[10]	Metaheuristics in Telecommunications Optimization	Metaheuristics provide scalable, efficient solutions in telecommunications.	Highlights versatility of metaheuristics in telecommunications.
[11]	Routing and energy efficiency in WSNs using MONL-MRPMS	MONL-MRPMS improves energy efficiency and localization accuracy.	Combines multiple optimization approaches for robust WSN routing.
[12]	Location management in cellular networks with Bat Algorithm	The Bat Algorithm minimizes costs and achieves fast convergence for location updates.	Provides scalable, adaptive solutions for cellular networks.
[13]	Routing in MANETs inspired by fungal colony behavior	Fungal-inspired protocol enhances routing in dynamic topologies.	Innovative use of biological systems for routing optimization.
[14]	Energy-efficient routing in IoT-based MANETs using SI-based protocol	SI-based protocol outperforms conventional methods in energy and throughput.	Integrates clustering, ACO, and data aggregation for efficiency.
[15]	Traffic steering in 5G using a DRL-based TS algorithm	DRL-based TS boosts throughput by 45.50% and reduces delay by 16.1%.	Demonstrates adaptability and efficiency in traffic steering.
[16]	Optimization in HetNets using metaheuristics and neural networks	Hybrid models optimize resources with improved spectral efficiency.	Presents advanced hybrid techniques for IoT-based HetNets.
[17]	Adaptive traffic routing in SDNs using DRL and DGCNN	DGCNN learns traffic behavior, improves throughput, and reduces delays.	Enhances adaptive routing in dynamic SDN environments.
[18]	Traffic diversion attack detection in SDNs using GA	GA achieves high accuracy (93%) in	Strengthens SDN security with adaptive and scalable solutions.

DOI: https://doi.org/10.54216/MOR.030201
Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025

		detecting traffic diversion attacks.	
[19]	Wireless traffic prediction using metaheuristic-optimized LSTM	Combines Grey Wolf and Dipper Throated Optimization for traffic forecasting.	Improves accuracy and stability in wireless traffic prediction.
[20]	Metaheuristics for optimization in wireless networks	Improves accuracy and stability in wireless traffic prediction.	Demonstrates hybrid methodologies for robust network performance.

The studies reviewed show how methodology and machine learning can transform the facets of networks concerning efficiency and security. Innovative frameworks based on techniques such as deep reinforcement learning, swarm intelligence, and metaheuristic optimization would exhibit immense improvements in specific areas such as traffic prediction, routing, and resource management. Such methodologies would address the issues and adapt to modern networks' evolution and changing nature. Thus, Future works must stress furthering scalability, computational efficiency, and robustness at all levels, especially in more complex network environments. Such advances shall only further accelerate the development of next-generation intelligent networks.

2. Discussion

All the reviewed articles highlight the possibilities of metaheuristic optimization and machine learning as key tools for enhancing the existing network management methodologies. Another important strength has been the ability of these methods to work in evolving and diverse network settings, such as SDNs, MANETs, and IoT settings. Metaheuristics, derived from natural practice, find alternatives helpful in solving combinatorial optimization problems to tackle questions such as energy consumption optimization, vehicle routing, and traffic control. All these techniques have been proven to work in this network concept, which is large and dynamic, thus suitable for the current continuously growing modern networks [21].

Another important discovery is the integration of metaheuristic algorithms with machine learning, especially neural networks and reinforcement learning. This integration is beneficial because it inherits the advantages of both approaches and offers better accuracy of the predictive model, optimization effectiveness, flexibility and adaptability of the solution. For example, Deep Reinforcement Learning (DRL) has been blended with metaheuristic algorithms to optimize challenging applications like traffic steering and resource management while realizing remarkable enhancements in network throughput and minimizing latency. This approach emphasizes that network management issues require multimodal solutions well-captured in hybrid frameworks [22].

The studies also revealed the key role of security in today's networks. As with other threats like traffic diversion attacks, security-aware measures sometimes do not suffice. Using meta-heuristics integrated with machine learning frameworks, it has been possible to prevent and identify these threats satisfactorily. For instance, genetic algorithms and neural network optimizations have been applied effectively to protect SDNs against dynamic, increasingly invasive attack patterns. These advancements guarantee the network's reliability and achieve a stable network with high-security needs [23].

Another important message from the literature is the feasibility of improving resource management in next-generation networks, especially when using parameters based on constrained environmental considerations. Algorithms, including Ant Colony Optimization (ACO) and Seagull Optimization, have been applied to improve routing and resource sharing with constrained energy networks of WSNs and MANETs. In some studies, a blend of blockchain technology enhances resource management capacity by affording efficiency, security, and transparency. These methods show the increased importance of multi-layer optimization techniques as a practical set of practices for resource management – especially in correspondence with various sorts of networks [24].

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Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025

Last, the most significant aspects highlighted by the reviewed studies involve future research opportunities in tackling extant difficulties in the practical application of these techniques. Problems like computational complexity, the possibility of real-time solutions and the technological problems of large-scale networks continue to be challenged. Thus, identifying that either lighter optimization models must be developed or existing models must be optimized for conventional use cases while being flexible enough to adapt to the latest technologies, such as 6G and IoE, will be important to continue the evolution of this area. As such, solving these challenges will enable future work to optimize the application of intelligent frameworks in revamping next-generation networks [25].

3. Conclusion

This paper mainly focuses on metaheuristic optimization and machine learning in managing networks and how they replace modern challenges in managing networks, such as traffic control and allocation of resources and security challenges in today's networks. GA, PSO, and LSTM networks have shown the possibility of improving the overall network performance and the ability to adapt it, going beyond conventional methods. Quantitative methodologies are important for next-generation networks such as SDNs, MANETs, and IoT frameworks due to their ability to deal with complex and dynamic network conditions.

Another great advantage of such methods is the diversification of their combinations. When metaheuristic algorithms are integrated with machine learning models, the outcomes have been proven to be effective due to the effectiveness of both solutions. For example, the Deep Reinforcement Learning (DRL) algorithm combined with metaheuristics performs excellently in different fields, including traffic control and intelligent routing. These hybrid frameworks have made it possible for networks to respond flexibly to new demands while at the same time meeting efficiency and reliability requirements.

The second important issue identified in the reviewed studies is the increased concern over security issues expressed in network management. Indeed, as traffic diversion attacks become more complex, physical security mechanisms have proved to be inefficient. Metaheuristic-based algorithms incorporating machine learning methods have arisen as sensitive methods to prevent these threats. These solutions make it possible to improve the scalability and operational stability of security frameworks in today’s networks.

Future work needs to remain focused on the applicability of these methodologies in solving new problems and the limitations of using these methodologies, including the issues related to computational complexity, system size, and time. Hence, optimization and security solutions relevant to future technologies, such as 6G networks and the Internet of Everything (IoE), will only surge in the future. Emerging from lightweight models, enhancing algorithms, and incorporating enabling technologies, researchers can explore novel approaches toward Intelligent Networks to build up the future generation of highly effective, secure, and self-adept networks.

References

[1] M. Abd Elaziz *et al.*, “Advanced metaheuristic optimization techniques in applications of deep neural networks: a review,” *Neural Comput Appl*, vol. 33, no. 21, pp. 14079–14099, Nov. 2021, doi: 10.1007/S00521-021-05960-5/TABLES/3.

[2] R. Selvam *et al.*, “Metaheuristic Algorithms for Optimization: A Brief Review,” *Engineering Proceedings 2023, Vol. 59, Page 238*, vol. 59, no. 1, p. 238, Mar. 2024, doi: 10.3390/ENGPROC2023059238.

[3] D. Kafetzis, S. Vassilaras, G. Vardoulias, and I. Koutsopoulos, “Software-Defined Networking Meets Software-Defined Radio in Mobile ad hoc Networks: State of the Art and Future Directions,” *IEEE Access*, vol. 10, pp. 9989–10014, 2022, doi: 10.1109/ACCESS.2022.3144072.

DOI: https://doi.org/10.54216/MOR.030201
Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025

[4] A. L. da Costa Oliveira, A. Britto, and R. Gusmão, "Machine learning enhancing metaheuristics: a systematic review," *Soft Comput*, vol. 27, no. 21, pp. 15971–15998, Nov. 2023, doi: 10.1007/S00500-023-08886-3/METRICS.

[5] "Software-Defined Architecture for Infrastructure-less Mobile Ad Hoc Networks | IEEE Conference Publication | IEEE Xplore." Accessed: Jan. 02, 2025. [Online]. Available: https://ieeexplore.ieee.org/document/9464002?utm_source=chatgpt.com

[6] H. Pavithra, G. N. Srinivasan, and R. Kumar P, "Metaheuristic deep neural network-based Intelligent Routing in SDN," *2023 International Conference on Communication, Circuits, and Systems, IC3S 2023*, 2023, doi: 10.1109/IC3S57698.2023.10169693.

[7] S. K. Nivetha, R. Asokan, and N. Senthilkumaran, "Metaheuristics in mobile AdHoc network route optimization," *Proceedings of the 2019 TEQIP - III Sponsored International Conference on Microwave Integrated Circuits, Photonics and Wireless Networks, IMICPW 2019*, pp. 414–418, May 2019, doi: 10.1109/IMICPW.2019.8933284.

[8] M. Masood, M. M. Fouad, and I. Glesk, "Analysis of Artificial Intelligence-Based Metaheuristic Algorithm for MPLS Network Optimization," *International Conference on Transparent Optical Networks*, vol. 2018-July, Sep. 2018, doi: 10.1109/ICTON.2018.8473751.

[9] D. K. Jain, S. K. S. Tyagi, S. Neelakandan, M. Prakash, and L. Natrayan, "Metaheuristic Optimization-Based Resource Allocation Technique for Cybertwin-Driven 6G on IoE Environment," *IEEE Trans Industr Inform*, vol. 18, no. 7, pp. 4884–4892, Jul. 2022, doi: 10.1109/TII.2021.3138915.

[10] S. L. Martins and C. C. Ribeiro, "Metaheuristics and Applications to Optimization Problems in Telecommunications," *Handbook of Optimization in Telecommunications*, pp. 103–128, Dec. 2006, doi: 10.1007/978-0-387-30165-5_4.

[11] S. L. Martins and C. C. Ribeiro, "Metaheuristics and Applications to Optimization Problems in Telecommunications," *Handbook of Optimization in Telecommunications*, pp. 103–128, Dec. 2006, doi: 10.1007/978-0-387-30165-5_4.

[12] S. Soundararajan *et al.*, "Metaheuristic Optimization Based Node Localization and MultihopMultihop Routing Scheme with Mobile Sink for Wireless Sensor Networks," *Wirel Pers Commun*, vol. 129, no. 4, pp. 2583–2605, Apr. 2023, doi: 10.1007/S11277-023-10247-0/METRICS.

[13] S. Parija and P. K. Sahu, "A metaheuristic bat inspired technique for cellular network optimization," *Proceedings - 2017 2nd International Conference on Man and Machine Interfacing, MAMI 2017*, vol. 2018-March, pp. 1–6, Mar. 2018, doi: 10.1109/MAMI.2017.8307883.

[14] A. M. K. Bahiya and A. A. Ibrahim, "Efficient Routing in Manet AdHoc Networks Using Metaheuristic Optimization Algorithm," *HORA 2023 - 2023 5th International Congress on Human-Computer Interaction, Optimization and Robotic Applications, Proceedings*, 2023, doi: 10.1109/HORA58378.2023.10156685.

[15] D. Mehta, S. Zafar, S. S. Biswas, N. Iftekhar, and S. Khan, "Metaheuristics to Aid Energy-Efficient Path Selection in Route Aggregated Mobile Ad Hoc Networks," *Smart and Sustainable Approaches for Optimizing Performance of Wireless Networks: Real-time Applications*, pp. 227–243, Jan. 2022, doi: 10.1002/9781119682554.CH12.

[16] F. Kavehmadavani, V. D. Nguyen, T. X. Vu, and S. Chatzinotas, "On Deep Reinforcement Learning for Traffic Steering Intelligent ORAN," *2023 IEEE Globecom Workshops, GC Wkshps 2023*, pp. 565–570, Nov. 2023, doi: 10.1109/GCWkshps58843.2023.10464606.

[17] S. C. Zhang, "Hierarchical Optimization of Metaheuristic Algorithms and Federated Learning for Enhanced Capacity Management and Load Balancing in HetNets," Dec. 2023, Accessed: Jan. 01, 2025. [Online]. Available: https://arxiv.org/abs/2312.13592v1

DOI: https://doi.org/10.54216/MOR.030201
Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025

[18] A. Abrol, P. M. Mohan, and T. Truong-Huu, "A Deep Reinforcement Learning Approach for Adaptive Traffic Routing in Next-gen Networks," *IEEE International Conference on Communications*, pp. 465–471, Feb. 2024, doi: 10.1109/ICC51166.2024.10622726.

[19] M. A. Alshammari, A. A. A. El-Aziz, and H. Hamdi, "Detecting Traffic Diversion Using Metaheuristic Algorithm in SDN," *International Journal of Intelligent Systems and Applications in Engineering*, vol. 12, no. 9s, pp. 369–379, Dec. 2023, Accessed: Jan. 01, 2025. [Online]. Available: https://ijisae.org/index.php/IJISAE/article/view/4327

[20] R. Alkanhel, E. S. M. El-Kenawy, D. L. Elsheweikh, A. A. Abdelhamid, A. Ibrahim, and D. S. Khafaga, "Metaheuristic Optimization of Time Series Models for Predicting Networks Traffic," *Computers, Materials & Continua*, vol. 75, no. 1, pp. 427–442, Feb. 2023, doi: 10.32604/CMC.2023.032885.

[21] "Machine Learning and Metaheuristic Computation | IEEE eBooks | IEEE Xplore." Accessed: Jan. 02, 2025. [Online]. Available: https://ieeexplore.ieee.org/book/10753102?utm_source=chatgpt.com

[22] W. Yi, R. Qu, L. Jiao, and B. Niu, "Automated Design of Metaheuristics Using Reinforcement Learning Within a Novel General Search Framework," *IEEE Transactions on Evolutionary Computation*, vol. 27, no. 4, pp. 1072–1084, Aug. 2023, doi: 10.1109/TEVC.2022.3197298.

[23] M. Kuzlu, F. O. Catak, Y. Zhao, S. Sarp, and E. Catak, "Security and Privacy Concerns in Next-Generation Networks Using Artificial Intelligence-Based Solutions: A Potential Use Case," *Advanced Sciences and Technologies for Security Applications*, vol. Part F1307, pp. 205–226, 2023, doi: 10.1007/978-3-031-33631-7_7/TABLES/3.

[24] B. Kaur and K. Tony Joseph, "Security Challenges and Solutions in 5G Networks," *2024 IEEE International Conference on Interdisciplinary Approaches in Technology and Management for Social Innovation, IATMSI 2024*, 2024, doi: 10.1109/IATMSI60426.2024.10502490.

[25] D. Oliva, E. H. Houssein, and S. Hinojosa, Eds., "Metaheuristics in Machine Learning: Theory and Applications," vol. 967, 2021, doi: 10.1007/978-3-030-70542-8.

DOI: https://doi.org/10.54216/MOR.030201
Received: October 12, 2024 Revised: December 18, 2024 Accepted: January 05, 2025