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REVIEW ARTICLE

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

Metaheuristic optimization algorithms are optimization tech-

niques 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 review 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].

2. LITERATURE REVIEW

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.

As detailed in [7], heuristics and metaheuristics are widely used approximate methods for addressing complex combinatorial optimization problems, mainly when exact methods are computationally prohibitive. 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. 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. Comparisons with the Bat Algorithm were conducted, analyzing parameters such as mean, minimum fitness values, and standard deviation.

As discussed in [9], rapid advancements in sixth-generation (6G) networks and the Internet of Everything (IoE) have facilitated numerous emerging services and applications. 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 cybertwin-driven 6G IoE environments. A quasi-oppositional search and rescue optimization algorithm was developed to enhance convergence rates.

As outlined in [10, 11], recent computer technology and communication network advancements have introduced complex optimization challenges in network design and routing. Metaheuristics act as high-level frameworks that coordinate simpler heuristics to produce effective approximate solutions for combinatorial optimization problems. Techniques such as simulated annealing, tabu search, GRASP, VNS, and genetic algorithms have emerged as practical strategies across telecommunications problems.

As detailed in [12], Wireless Sensor Networks (WSNs) consist of independent sensor nodes deployed randomly to monitor environments effectively, supporting applications like medical monitoring, home automation, traffic observation, and ecological studies. Due to the energy constraints of sensor nodes, routing plays a critical role in enhancing energy efficiency and extending network lifetime. The proposed multihop routing scheme with a mobile sink combines metaheuristic optimization techniques to improve energy efficiency and localization accuracy.

As described in [13], a bat-inspired technique was developed for cellular network optimization. The Bat Algorithm minimizes costs and achieves fast convergence for location updates, providing scalable and adaptive solutions for cellular networks. In [14], a novel routing protocol for MANETs inspired by fungal colony behavior incorporates nutrient search, hyphal growth, and mass-flow dynamics to address topology

changes caused by node mobility.

In the analysis conducted in [15], the Internet of Things emerges as a transformative paradigm within Information Technology, integrating diverse technologies and communication solutions to connect heterogeneous devices. The study introduces a swarm-intelligence-based hybrid routing protocol for MANETs designed for energy-constrained environments. The protocol includes cluster design, ACO-aided cluster-head selection, and data transmission through route aggregation.

As discussed in [16], the intelligent traffic steering framework has emerged as a pivotal development in 3GPP's advancements for 5G networks. The study proposes a deep reinforcement learning based traffic-steering algorithm operating at the non-real-time RAN intelligent controller within the ORAN framework. Simulation results demonstrate superior performance, achieving a 45.50% improvement over benchmark systems in downlink multi-service scenarios.

The study referenced as [17] introduces a framework for managing IoT-based heterogeneous networks, emphasizing capacity optimization, coverage and data reliability. The proposed approach integrates metaheuristic algorithms, neural-network optimization, and federated learning to orchestrate resource allocation dynamically. As outlined in [18], next-generation networks demand advanced management solutions that enable automation and adaptive configuration based on dynamic traffic patterns. A DRL framework with a deep graph convolutional neural network learns traffic behavior from network topology and link attributes, improving throughput and reducing traffic delays.

In [19], increasing adoption of SDN and rising demand for network resources have heightened the risks of traffic diversion attacks. A novel approach using a Genetic Algorithm enhances the precision and effectiveness of traffic-diversion detection. As outlined in [20], wireless network traffic prediction is addressed through a metaheuristic optimization approach combining Fitness Grey Wolf Optimization and Dipper Throated Optimization algorithms to optimize LSTM hyperparameters.

The paper reviews published research on network traffic management, translating them to metaheuristic optimization and machine learning, as in Table 1. 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 evidenced by these studies.

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 exhibit improvements in traffic prediction, routing, and resource management. Such methodologies address the issues and adapt to modern networks' evolution and changing nature. Future works must stress further scalability, computational efficiency, and robustness at all levels, especially in more complex network environments.

3. DISCUSSION

All the reviewed articles highlight the possibilities of metaheuristic optimization and machine learning as key tools for enhancing 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 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 [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 metaheuristics 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 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 [24].

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 lighter optimization models or optimizing existing models 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 [25].

4. 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 con-

Table 1. Summary of Literature Review

Study	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.
[12]	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.
[13]	Location management in cellular networks with Bat Algorithm	The Bat Algorithm minimizes costs and achieves fast convergence.	Provides scalable, adaptive solutions for cellular networks.
[14]	Routing in MANETs inspired by fungal colony behavior	Fungal-inspired protocol enhances routing in dynamic topologies.	Innovative use of biological systems for routing optimization.
[15]	Energy-efficient routing in IoT-based MANETs	SI-based protocol outperforms conventional methods in energy and throughput.	Integrates clustering, ACO, and data aggregation for efficiency.
[16]	Traffic steering in 5G using DRL	DRL-based traffic steering boosts throughput and reduces delay.	Demonstrates adaptability and efficiency in traffic steering.
[17]	Optimization in HetNets using metaheuristics and neural networks	Hybrid models optimize resources with improved spectral efficiency.	Presents advanced hybrid techniques for IoT-based HetNets.
[18]	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.
[19]	Traffic diversion attack detection in SDNs using GA	GA achieves high accuracy in detecting traffic-diversion attacks.	Strengthens SDN security with adaptive and scalable solutions.
[20]	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.

trol, allocation of resources and security challenges in today's networks. GA, PSO, and LSTM networks have shown the possibility of improving overall network performance and the ability to adapt it, going beyond conventional techniques. Combining metaheuristic algorithms with machine learning models improves traffic prediction, routing, and resource assignment, and the reviewed studies show that these solutions are suitable for SDNs, MANETs, IoT, 5G, 6G and IoE environments.

The review also stresses that security and resource management remain central issues in next-generation networks. Intelligent frameworks based on genetic algorithms, reinforcement learning, graph neural models, blockchain support and hybrid optimization can improve reliability, scalability, and resilience against traffic-diversion attacks and other threats. Future research should focus on computationally efficient real-time models, robustness in large-scale heterogeneous networks, and practical deployment under dynamic operating conditions.

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