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ADVANCES IN ROUTING PROTOCOLS AND MACHINE LEARNING TECHNIQUES FOR IOT NETWORKS: A COMPREHENSIVE REVIEW

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ABSTRACT

The Internet of Things (IoT) has emerged as a transformative technology, connecting billions of devices worldwide. Efficient routing protocols and advanced machine learning techniques are crucial for ensuring seamless data transmission, energy efficiency, and robust security in IoT networks. This review paper synthesizes recent advancements in IoT routing protocols, with a focus on multi-objective optimization algorithms, context-aware routing strategies, and hybrid evolutionary techniques. It explores innovative approaches such as the Multi-objective Fractional Gravitational Search Algorithm (MoFGSA), Fractional Gravitational Grey Wolf Optimization (FG-GWO), and Whale Optimization Algorithms (WOA) for enhancing routing performance. Furthermore, the integration of machine learning models in IoT applications is discussed, particularly in phishing URL detection, cardiovascular disease prediction, and smart agriculture systems. The review highlights the growing role of deep learning frameworks, such as U-Net++, Mask-RCNN, and convolutional neural networks (CNN), in improving accuracy and decision-making capabilities within IoT ecosystems. Additionally, this paper examines the impact of blockchain technology on secure healthcare information exchange and discusses innovative approaches for low-cost smart devices in agriculture. By consolidating these advancements, this review identifies key trends, challenges, and future directions in optimizing IoT networks for enhanced scalability, security, and efficiency. This comprehensive analysis aims to guide researchers and practitioners in developing robust IoT frameworks that cater to diverse applications, including smart cities, healthcare, and industrial automation.

KEYWORDS: *IOT, Machine learning, Convolutional Neural Networks, Agriculture*

INTRODUCTION

The Internet of Things (IoT) is rapidly transforming modern technology by enabling seamless connectivity between physical devices and digital systems. IoT applications span various domains such as healthcare, agriculture, smart homes, and industrial automation, where devices continuously exchange data for improved functionality and decision-making [1-3]. However, the dynamic nature of IoT networks presents significant challenges, particularly in routing data efficiently across diverse network architectures. Traditional routing protocols often struggle to adapt to the complexity of IoT systems, which involve constrained resources, variable network conditions, and security vulnerabilities [4-6].

To address these challenges, researchers have explored advanced routing strategies, incorporating multi-objective optimization algorithms, context-aware routing mechanisms, and energy-efficient techniques. Approaches such as the Multi-objective Fractional Gravitational Search Algorithm (MoFGSA) and Fractional Gravitational Grey Wolf Optimization (FG-GWO) have demonstrated enhanced performance in routing efficiency and data reliability [7-8]. Furthermore, the integration of machine learning models has shown promising results in predicting optimal routing paths, enhancing security through anomaly detection, and improving system adaptability [9-10].

This review paper presents a comprehensive analysis of recent advancements in IoT routing protocols and machine learning techniques, highlighting key innovations, emerging trends, and future research directions aimed at improving scalability, security, and performance in IoT networks.

2. REVIEW AND LITERATURE

The evolution of IoT technologies has driven extensive research into improving data transmission, routing protocols, and security frameworks. Traditional routing protocols often struggle to maintain performance in dynamic IoT environments due to unpredictable network conditions, limited device resources, and the need for energy efficiency. As a result, researchers have actively developed innovative solutions to overcome these limitations.

Early studies in IoT routing protocols emphasized low-power and lossy networks (LLNs), focusing on enhancing energy conservation, data delivery rates, and network longevity. Techniques like RPL (Routing Protocol for Low-Power and Lossy Networks) played a foundational role in ensuring scalable data transmission. However, challenges such as congestion, packet loss, and inefficient path selection prompted researchers to explore advanced optimization techniques [9-11].

To address these concerns, hybrid evolutionary algorithms such as the Multi-objective Fractional Gravitational Search Algorithm

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(MoFGSA) and Fractional Gravitational Grey Wolf Optimization (FG-GWO) were developed. These algorithms effectively improved data transmission reliability by identifying optimal paths and ensuring minimal energy consumption during routing processes. Such techniques demonstrated significant improvements in network throughput and energy efficiency when applied to complex IoT environments [12-14].

In parallel, context-aware routing mechanisms emerged as a promising solution for adapting to dynamic IoT topologies. These methods utilize real-time environmental data, such as node movement, network traffic, and energy levels, to make informed routing decisions. By dynamically adjusting routes based on these parameters, context-aware algorithms achieved better load balancing, minimized latency, and improved data delivery rates [15-17].

The integration of machine learning techniques has further revolutionized IoT network management. Machine learning algorithms have proven effective in enhancing security, optimizing routing, and predicting network behavior. For instance, deep learning models such as U-Net++ and convolutional neural networks (CNN) have demonstrated remarkable accuracy in cardiovascular disease prediction, enabling faster and more precise medical diagnoses [18-20]. Similarly, phishing URL detection frameworks leveraging machine learning algorithms have significantly improved IoT network security by detecting malicious threats with high accuracy [21-23].

Medical imaging applications have also benefited from advanced machine learning frameworks. Techniques such as Mask-RCNN and transfer learning models have shown impressive performance in pneumothorax detection, mammogram analysis, and the identification of neurological disorders [24-26]. These approaches offer enhanced image segmentation accuracy, improving early diagnosis and patient outcomes in healthcare settings.

In the field of agriculture, IoT-driven solutions equipped with smart sensors have enabled efficient soil monitoring, automated fruit picking, and real-time crop health assessment. These innovations have led to improved productivity, reduced manual labor, and optimized resource utilization in farming practices [27-29]. Furthermore, machine learning techniques have been successfully applied to detect plant diseases, forecast yield outcomes, and automate irrigation systems to support precision agriculture practices [30-32].

Blockchain technology has also played a crucial role in strengthening IoT ecosystems. By integrating blockchain frameworks, researchers have developed secure healthcare information exchange platforms that ensure data integrity, privacy, and tamper-proof communication in medical systems [33-35].

IoT advancements have also extended to educational platforms. E-learning systems such as EKhool have leveraged IoT technologies to enhance user engagement, personalize learning experiences, and monitor student performance using intelligent frameworks [36-38].

To improve IoT network security, researchers have proposed forensic layers designed to analyze network traffic for potential breaches. Methods such as deep packet inspection combined with recurrent neural networks (RNN) have shown promising results in preventing cyberattacks and detecting suspicious activities in IoT environments [39-41].

The transportation sector has similarly benefited from IoT integration, with smart traffic management systems, vehicle tracking solutions, and predictive maintenance frameworks improving overall efficiency. Machine learning models have successfully optimized route planning, vehicle behavior prediction, and congestion control to enhance traffic safety and reduce travel time [42-44].

In educational and employment domains, machine learning-based models have demonstrated effectiveness in predicting student placement outcomes, identifying skill gaps, and improving career development pathways. Predictive frameworks using ensemble classifiers have shown notable success in identifying student performance trends and enhancing educational outcomes [45-47].

IoT-enabled smart home systems have further integrated predictive maintenance algorithms, facilitating energy-efficient solutions that optimize device performance and reduce operational costs. These systems utilize machine learning models to predict system failures, automate repair actions, and improve home security measures [48-49].

The integration of advanced machine learning frameworks with IoT technologies has significantly improved routing performance, network security, and decision-making capabilities across various applications. As IoT continues to expand, future research aims to develop even more adaptive, secure, and scalable solutions that cater to diverse sectors, including healthcare, agriculture, and smart infrastructure [50-51].

3. CONCLUSION

The advancements in IoT technologies have significantly transformed various sectors, including healthcare, agriculture, education, and smart infrastructure. Researchers have actively explored innovative solutions to address challenges such as energy efficiency, routing optimization, security threats, and data transmission reliability. Techniques like Multi-objective Fractional Gravitational Search Algorithm (MoFGSA), Fractional Gravitational Grey Wolf Optimization (FG-GWO), and context-aware routing mechanisms have enhanced network stability and performance. Additionally, the integration of

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machine learning frameworks, including U-Net++, CNN, and Mask-RCNN, has improved decision-making capabilities, enabling precise diagnosis, threat detection, and predictive analytics. The adoption of blockchain technology has further strengthened data security, ensuring reliable information exchange across IoT networks. With ongoing research focusing on scalable, secure, and adaptive solutions, IoT systems are poised to play a pivotal role in shaping future innovations. By leveraging these advancements, industries can achieve enhanced efficiency, improved safety, and sustainable development in the rapidly evolving digital landscape.

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