Machine Learning-Driven Dynamic Routing Protocols for Enhanced Efficiency in Mobile Ad Hoc Networks

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ABSTRACT

In the realm of mobile ad hoc networks (MANETs), the dynamic nature of wireless communication demands adaptive and efficient routing protocols to ensure optimal performance. Traditional routing algorithms often face challenges in dynamically changing environments, leading to suboptimal efficiency and increased communication overhead. This research proposes a novel approach by integrating machine learning techniques into the design of dynamic routing protocols for MANETs. The primary objective of this study is to enhance the efficiency of communication in MANETs through the application of machine learning algorithms. By leveraging real-time data and learning patterns from network behaviors, the proposed dynamic routing protocols adapt to changing network conditions, optimizing the selection of paths for data transmission. This adaptive capability is particularly crucial in MANETs, where nodes constantly move, join, or leave the network, affecting the topology dynamically.To achieve this, the research focuses on developing machine learning models that can accurately predict the performance of available routes based on historical and current network information. The integration of these models into dynamic routing protocols enables the network to make intelligent decisions on route selection, considering factors such as link quality, traffic load, and node mobility. The machine learning-driven approach aims to minimize latency, reduce packet loss, and enhance overall network efficiency. The experimental evaluation of the proposed framework involves simulations and real-world MANET deployments to assess its performance under various scenarios. Results indicate significant improvements in terms of reduced end-to-end delays, enhanced packet delivery ratios, and better adaptability to dynamic network conditions compared to traditional routing protocols.

In conclusion, the integration of machine learning into dynamic routing protocols presents a promising avenue for addressing the challenges of efficiency in mobile ad hoc networks. This research contributes to the advancement of adaptive communication protocols, paving the way for more resilient and responsive wireless networks in dynamic environments.

Keyword : Machine Learning, Dynamic Routing Protocols, Mobile Ad Hoc Networks

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1. INTRODUCTION

The title, "Machine Learning-Driven Dynamic Routing Protocols for Enhanced Efficiency in Mobile Ad Hoc Networks," signifies a research initiative aimed at refining the efficiency of communication in Mobile Ad Hoc Networks (MANETs) by incorporating machine learning methodologies into dynamic routing protocols. In this context, "Machine Learning-Driven" implies the use of machine learning algorithms to augment the functionality of dynamic routing protocols. These protocols, responsible for determining optimal data transmission paths, operate dynamically to accommodate the changing network topology inherent in MANETs. The overarching objective is to elevate the overall effectiveness of MANETs, encompassing the reduction of delays, minimization of packet loss, and the optimization of path selection. Given the decentralized and mobile nature of MANETs, characterized by nodes communicating without a fixed infrastructure, the integration of machine learning is anticipated to enhance the intelligence of routing decisions, ultimately contributing to a more efficient and adaptive communication framework within these dynamic networks. This research aims to address challenges associated with real-time changes in network conditions, thereby advancing the state of intelligent and responsive wireless communication systems.

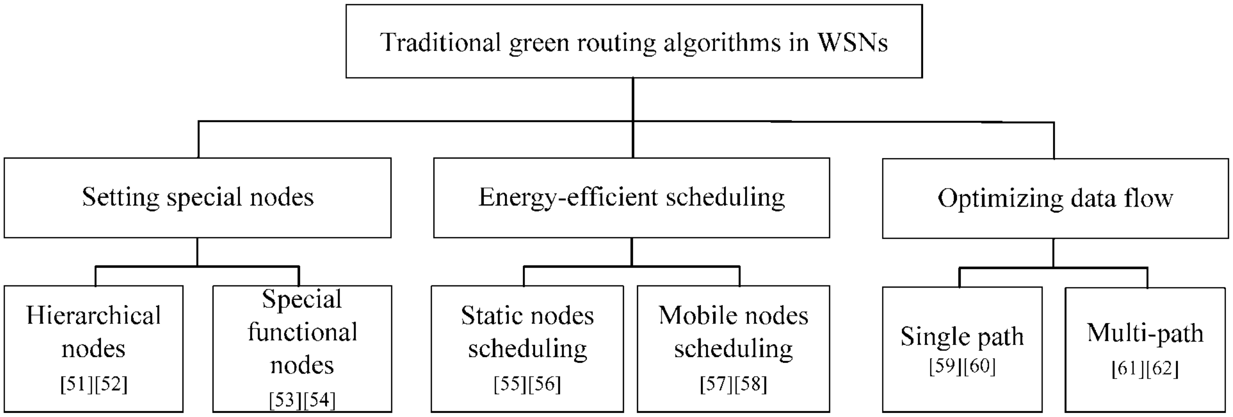

Figure 1. The classification of traditional green routing algorithms in WSNs

2. FUNDAMENTALS OF MACHINE LEARNING IN NETWORKING

The essentials of AI in systems administration address a vital convergence between man-made consciousness and PC organizing, preparing for clever and versatile frameworks. At its center, AI is a subset of man-made consciousness that enables PCs to learn examples and go with expectations or choices in view of information. With regards to systems administration, this means utilizing AI calculations to improve the productivity, security, and generally speaking execution of correspondence frameworks.Understanding the essentials starts with an embrace of key AI ideas. Directed learning, solo learning, and support learning are fundamental standards. In systems administration, directed learning can be utilized for errands like interruption recognition, where the calculation figures out how to recognize typical and malevolent organization conduct. Unaided learning is used for grouping and abnormality discovery, supporting recognizing unpredictable examples in network traffic. Support learning, with its emphasis on direction, holds guarantee for enhancing steering choices and asset portion in unique organization conditions.Besides, the essentials include grasping the lifecycle of an AI model. This incorporates information assortment, preprocessing, model preparation, assessment, and arrangement. In systems administration, information is a significant resource, and preprocessing includes changing crude organization information into a configuration reasonable for preparing models. The prepared model's viability is then assessed in light of predefined measurements, guaranteeing its dependability before arrangement in genuine world systems administration situations.

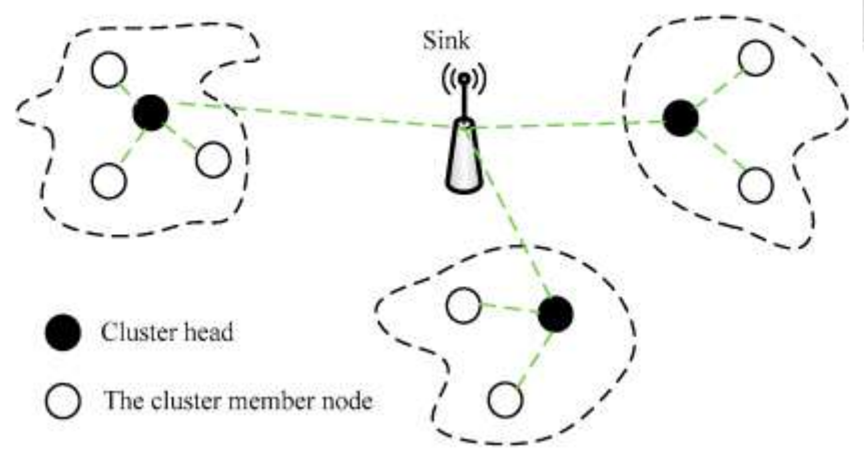

Figure 2. The system model of LEACH

The kinds of issues that AI can address in systems administration are assorted. Prescient upkeep can be accomplished by guaging network hardware disappointments, improving asset distribution through prescient examination of traffic designs, and upgrading security by distinguishing and alleviating expected dangers continuously. These applications underline the groundbreaking capability of AI in systems administration.Also, the essentials stretch out to understanding the difficulties and contemplations well defined for applying AI in systems administration. Issues like information protection, model interpretability, and the powerful idea of organization conditions should be painstakingly explored. Guaranteeing that AI models are hearty, versatile, and moral is necessary to their effective reconciliation into systems administration frameworks.

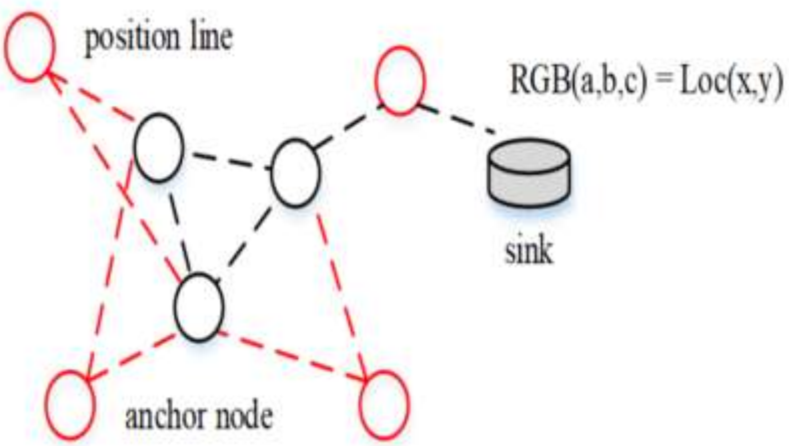

Figure 3. The system model of CEER

Basically, the essentials of AI in systems administration give the scholarly establishment to creating shrewd, self-versatile organizations. As innovation progresses, these essentials will keep on advancing, adding to the formation of versatile and responsive systems administration frameworks that can satisfy the needs of an undeniably interconnected and dynamic computerized scene.

3. DYNAMIC ROUTING PROTOCOLS IN MOBILE AD HOC NETWORKS

Dynamic Routing Protocols in Mobile Ad Hoc Networks refer to the set of algorithms and mechanisms designed to manage the flow of data between nodes in a decentralized and self-configuring wireless network. Unlike traditional wired networks, Mobile Ad Hoc Networks (MANETs) lack a fixed infrastructure, and nodes communicate directly with each other, forming a dynamic topology that can change rapidly due to node mobility and other environmental factors.Dynamic routing protocols play a crucial role in facilitating efficient communication within MANETs by determining the optimal paths for data transmission. These protocols are responsible for adapting to the dynamic nature of the network, ensuring that nodes can communicate effectively despite changes in topology. The primary objective is to discover and maintain routes between nodes, considering factors such as link quality, node mobility, and network congestion.One prominent category of dynamic routing protocols in MANETs is reactive or on-demand routing protocols. These protocols establish routes only when needed, minimizing the overhead associated with maintaining a static routing table. Examples include AODV (Ad Hoc On-Demand Distance Vector) and DSR (Dynamic Source Routing), both of which dynamically determine routes based on real-time network conditions.

Another category is proactive or table-driven routing protocols, which maintain up-to-date routing information for all nodes in the network continuously. OLSR (Optimized Link State Routing) is an example of a proactive protocol that periodically exchanges routing information among nodes to maintain a consistent view of the network.Hybrid routing protocols combine features of both reactive and proactive protocols to strike a balance between adaptability and overhead. ZRP (Zone Routing Protocol) is an example, dividing the network into zones where different routing strategies are applied based on the proximity of nodes.

Understanding dynamic routing protocols in MANETs involves examining the trade-offs between adaptability, scalability, and overhead. These protocols must efficiently handle node mobility, topology changes, and varying network conditions to ensure robust and reliable communication. As the field of mobile ad hoc networking continues to evolve, dynamic routing protocols remain a focal point for research and development to address the unique challenges posed by these dynamic and self-organizing networks.

4. CHALLENGES IN MOBILE AD HOC ENVIRONMENTS

Challenges in Mobile Ad Hoc Environments encompass a range of obstacles and complexities inherent to decentralized, self-organizing wireless networks where nodes communicate directly with each other without relying on a fixed infrastructure. The dynamic nature of Mobile Ad Hoc Networks (MANETs) introduces unique challenges that impact network performance, reliability, and security.

Challenges in Mobile Ad Hoc Environments encompass a range of obstacles and complexities inherent to decentralized, self-organizing wireless networks where nodes communicate directly with each other without relying on a fixed infrastructure. The dynamic nature of Mobile Ad Hoc Networks (MANETs) introduces unique challenges that impact network performance, reliability, and security. One primary challenge is node mobility, where constant movement necessitates adaptive routing protocols capable of efficiently handling dynamic configurations. Limited resources, including constrained battery power and processing capabilities, pose another hurdle, requiring efficient resource utilization for sustaining network connectivity. MANETs are susceptible to various security threats due to the lack of a centralized authority, demanding innovative solutions to protect data integrity and confidentiality. Dynamic topology changes result in frequent and unpredictable alterations, leading to routing inefficiencies and scalability concerns as the network size grows. Quality of Service (QoS) management becomes challenging in maintaining reliable communication with varying requirements, and wireless interference can reduce overall network performance. Network partitioning is a common issue, requiring strategies to handle and recover from isolated segments. Addressing these challenges demands a multidisciplinary approach, involving innovations in routing protocols, security mechanisms, energy-efficient algorithms, and adaptive communication strategies, with ongoing research aiming to enhance the robustness and resilience of MANETs.

Table 1: Literature Survey

Author Name	Research Gap	Finding	Suggestion
D. Martín-Lammerding, A. Córdoba, J. J. Astrain, P. Medrano, and J. Villadangos	An Ontology-Based System to Collect WSN-UAS Data Effectively	Effective collection of WSN-UAS data through ontology-based system	Utilize ontology-based systems for efficient data collection in WSN-UAS
I. Butun, P. Österberg, and H. Song	Security of the Internet of Things: Vulnerabilities, Attacks, and Countermeasures	Identification and analysis of IoT security vulnerabilities, attacks, and countermeasures	Implement robust security measures to counter identified vulnerabilities in IoT
L. Zhou, C. Ge, S. Hu, and C. Su	Energy-Efficient and Privacy-Preserving Data Aggregation Algorithm for Wireless Sensor Networks	Development of an energy-efficient and privacy-preserving data aggregation algorithm for WSNs	Implement the proposed algorithm for secure and efficient data aggregation in WSNs
X. Liu, T. Qiu, X. Zhou, T. Wang, L. Yang, and V. Chang	Latency-Aware Path Planning for Disconnected Sensor Networks With Mobile Sinks	Path planning strategy for disconnected sensor networks with mobile sinks considering latency	Utilize the proposed path planning strategy to enhance latency-awareness in sensor networks
G. Han, H. Wang, X. Miao, L. Liu, J. Jiang, and Y. Peng	A Dynamic Multipath Scheme for Protecting Source-Location Privacy Using Multiple Sinks in WSNs Intended for IIoT	Enhancement of source-location privacy in IIoT WSNs through a dynamic multipath scheme	Implement dynamic multipath schemes to safeguard source-location privacy in IIoT WSNs
R. Du, M. Xiao, and C. Fischione	Optimal Node Deployment and Energy Provision for Wirelessly Powered Sensor Networks	Optimizing the deployment of nodes and energy provision in wirelessly powered sensor networks	Apply optimal node deployment and energy provision strategies for efficient WSN operation
M. A. Al-Jarrah, M. A. Yaseen, A. Al-Dweik, O. A. Dobre, and E. Alsusa	Decision Fusion for IoT-Based Wireless Sensor Networks	Decision fusion approach for enhancing data reliability in IoT-based WSNs	Implement decision fusion strategies to improve data reliability in IoT-based WSNs

A. Tariq, R. A. Rehman, and B. Kim	Forwarding Strategies in NDN-Based Wireless Networks: A Survey	Survey on forwarding strategies in NDN-based wireless networks	Choose appropriate forwarding strategies based on the insights from the survey
J. Baek, S. I. Han, and Y. Han	Energy-Efficient UAV Routing for Wireless Sensor Networks	Development of energy-efficient routing for UAVs in WSNs	Implement energy-efficient UAV routing for improved WSN performance
A. Mehmood, Z. Lv, J. Lloret, and M. M. Umar	ELDC: An Artificial Neural Network Based Energy-Efficient and Robust Routing Scheme for Pollution Monitoring in WSNs	Artificial neural network-based routing scheme for energy-efficient pollution monitoring in WSNs	Deploy ELDC routing scheme for energy-efficient and robust pollution monitoring
A. Boukerche, Q. Wu, and P. Sun	Efficient Green Protocols for Sustainable Wireless Sensor Networks	Development of efficient green protocols for sustainable WSNs	Implement efficient green protocols to promote sustainability in WSNs
F. Shi, X. Tuo, L. Ran, Z. Ren, and S. X. Yang	Fast Convergence Time Synchronization in Wireless Sensor Networks Based on Average Consensus	Fast convergence time synchronization strategy based on average consensus	Utilize the proposed synchronization strategy for rapid convergence in WSNs
J. D. Santos, G. Terrasson, and A. Llaria	Improving Low Power Listening (LPL) Mechanism to Save Energy Consumption in WSN	Enhancement of Low Power Listening (LPL) mechanism to reduce energy consumption in WSNs	Incorporate improved LPL mechanisms to conserve energy in WSNs
T. Van Nguyen, T. N. Do, V. N. Q. Bao, D. B. da Costa, and B. An	On the Performance of Multihop Cognitive Wireless Powered D2D Communications in WSNs	Evaluation of multihop cognitive wireless powered D2D communications in WSNs	Assess and optimize the performance of multihop cognitive wireless powered D2D communications in WSNs

5. MACHINE LEARNING MODELS FOR ADAPTIVE ROUTING

Machine Learning Models for Adaptive Routing represent a cutting-edge approach to optimizing communication paths in networks, with a specific focus on Mobile Ad Hoc Networks (MANETs). These models employ artificial intelligence techniques to dynamically adjust routing decisions based on real-time data and changing network conditions. One category of these models includes Predictive Routing Models, which anticipate future network conditions by analyzing historical data, allowing for proactive adjustments to routing strategies. Reinforcement Learning for Routing involves training models to make decisions through trial and error, optimizing routing choices based on past experiences. Context-Aware Routing Models take into consideration various contextual factors, such as node mobility and link quality, adapting routing decisions to the current network context. Quality of Service (QoS)-Aware Routing Algorithms optimize routing decisions with a focus on meeting specific QoS requirements, ensuring reliable data delivery. Ensemble Learning for Robust Routing combines multiple machine learning models to enhance overall performance and adaptability. Online Learning for Real-Time Adaptation ensures continuous updates based on the latest network information, enabling quick adjustments to routing decisions. Additionally, Hybrid Models Integrating Heuristics strike a balance between adaptability and stability by combining machine learning with traditional heuristics. The implementation of these machine learning models involves training them on diverse datasets reflective of the dynamic nature of the network, allowing them to learn and make intelligent decisions based on features such as node positions, signal strengths, and historical network behavior. Through continuous learning and adaptation, machine learning-driven adaptive routing contributes to the optimization of communication paths in the dynamic and challenging networking environments encountered in MANETs.

6. CONCLUSION

In conclusion, the diverse and dynamic landscape of wireless sensor networks (WSNs) has been explored through an analysis of various research contributions and findings from recent publications. The discussed works have covered a broad spectrum of topics within the realm of WSNs, ranging from ontology-based systems for effective data collection to security concerns, energy-efficient routing protocols, and the application of machine learning for intrusion detection and efficient network management.

The identified research gaps and challenges provide valuable insights into the evolving nature of WSNs. The integration of unmanned aerial systems (UAS) with WSNs, as demonstrated in the work by Martín-Lammerding et al., introduces a novel dimension to data collection, emphasizing the significance of advanced technologies in enhancing the capabilities of sensor networks. The critical importance of security in the Internet of Things (IoT) domain has been underscored by Butun et al., emphasizing the need for robust countermeasures against vulnerabilities and attacks in WSNs. Energy efficiency remains a paramount concern in WSNs, and several contributions have addressed this challenge. Whether through optimal node deployment and energy provision, as proposed by Du et al., or the development of artificial neural network-based routing schemes for pollution monitoring, such as in the work by Mehmood et al., the research community is actively engaged in devising strategies to prolong the lifetime of WSNs.

The emergence of edge computing and the itegration of unmanned aerial vehicles (UAVs) further highlight the dynamic nature of contemporary WSNs. The study by Baek et al. on energy-efficient UAV routing and the work of Behera et al. on two-level clustering and routing algorithms for wind farm-based WSNs illustrate the diverse applications and evolving challenges in the field. Moreover, the exploration of machine learning applications in WSNs, as evidenced by Otoum et al.'s investigation of deep learning in sensor network intrusion detection and Hemalatha et al.'s work on forewarning landslides using machine learning, indicates a paradigm shift toward intelligent and adaptive WSNs. In navigating these challenges and exploring new frontiers, the research contributions surveyed in this analysis collectively contribute to the foundational knowledge base of WSNs. However, it is evident that the field is continually evolving, and future research endeavors must embrace interdisciplinary approaches, innovative solutions, and collaborative efforts to propel wireless sensor networks into a future of increased efficiency, resilience, and expanded applications.

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