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Artificial Intelligence And Its Applications In Wireless Mesh Networks (WMN)

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Abstract

Wireless Mesh Networks (WMNs) have emerged as a robust and scalable solution for providing broadband wireless connectivity. However, challenges such as dynamic topology, interference, routing complexity, and scalability persist. Artificial Intelligence (AI), with its capabilities in learning, prediction, and optimization, offers novel solutions to enhance the performance of WMNs. This article reviews the integration of AI techniques—such as machine learning, deep learning, reinforcement learning, and fuzzy logic—into various layers of WMNs, including routing, channel allocation, traffic prediction, security, and fault management. In the field of Computer Networks, a Mesh Network is one of the revolutionary concepts for communication and data transmission in a set of various nodes. The Mesh Network is a decentralized communication system that is used for data transmission and data collection In this approach the nodes are directly connected, where there is the dynamic web interconnections among them, and the transmission takes place.

Keywords: WMN, GEN-AI,WSN, ML, DL, Fuzzy Logic, K-NN etc

1. Introduction:

Wireless Mesh Networks are multi-hop wireless networks consisting of mesh routers and mesh clients. They provide self-configuring, self-healing, and reliable networking infrastructure. Despite their benefits, WMNs suffer from key challenges such as:

- **Dynamic topology changes**
- **Interference and congestion**
- **Routing inefficiencies**
- **Limited Quality of Service (QoS)**

Artificial Intelligence (AI), particularly Machine Learning (ML), has demonstrated success in optimizing complex, non-linear systems. AI can dynamically adapt to network changes, predict failures, and optimize performance parameters.

1.1 AI & ITS APPLICATIONS

AI and its applications performed the efficiency of routing metrics with different structure of topology efficiency and resilience. Generative AI (GenAI) refers to artificial intelligence systems capable of creating new content, including text, images, audio, and video, based on learned patterns from existing data. It's a subfield of AI focused on generating novel outputs rather than simply analysing or classifying existing data. The Topology structure changes in the mesh routing with node to define the path between two nodes.

Which the efficiency is challenges to overcome the Propagation Delay and improve the Packet delivery ratio.

1.2. AI TECHNIQUES USED IN WMNS

1.2.1. Machine Learning

1.2.2. Deep Learning

1.2.3. Re-enforcement Learning

1.2.4. Fuzzy Logic

1.2.1. Machine Learning

The Machine Learning described the Decision Trees to prevent the mechanisms such as Support Vector Machine to study the performance of the routing in the form of

1. Intrusion Detection

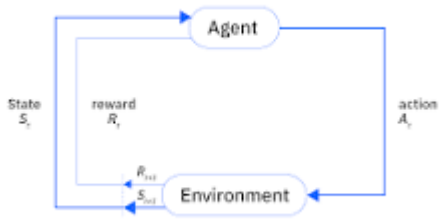
2. Traffic Classification

3. Network Traffic Allocation

1.2.2. Deep Learning

Deep learning can significantly enhance wireless mesh networks (WMNs) by improving various aspects like routing, resource allocation, and network management. By leveraging the power of deep learning models, such as Convolutional Neural Networks (CNNs) and Graph Neural Networks (GNNs), WMNs can become more efficient, adaptive, and resilient.

1.2.3. Re-enforcement Learning



Reinforcement learning (RL) is a type of machine learning process that focuses on decision making by autonomous agents. An autonomous agent is any system that can make decisions and act in response to its environment independent of direct instruction by a human user.

RL is used for decision-making in uncertain environments. Applications include:

- Adaptive routing (e.g., Q-routing)
- Spectrum management
- Load balancing

1.2.4. Fuzzy Logic

This techniques have been implemented in the routing strategy of Link Quality between nodes and the Routing Metric Evaluation of the nodes based on the Signal Strength, Residual Energy, Bandwidth and performance of the node.

Fuzzy logic systems can handle imprecision in decision-making to calculate the Routing metric evaluation by using the **ETX (Estimated Transmission Time) TOA – Time of Arrival of Packets.**

- Link quality estimation

3.APPLICATIONS OF AI IN WMN'S

3.1 Intelligent Routing

AI algorithms adapt to changing topologies and optimize routes based on latency, packet loss, and bandwidth. For example:

- Q-learning for dynamic path selection
- Neural networks for delay prediction

3.2 Channel Allocation

AI models minimize interference and optimize spectrum use by learning traffic patterns and environmental parameters.

3.3 Load Balancing

ML techniques predict congestion and balance traffic across multiple paths, improving throughput and latency.

3.4 Security & Intrusion Detection

AI detects malicious behaviours using classification models like Random Forests, Deep Learning, and anomaly detection frameworks.

3.5 Fault Detection and Self-Healing

Predictive ML models monitor network parameters to identify potential failures and trigger proactive maintenance.

4. BENFITS OF AI IN WMN'S

4.1.Improved Performance:

AI-powered WMNs can achieve higher throughput, lower latency, and better packet delivery ratios compared to traditional methods.

Which improves the efficiency and overcome the propagation delay and over relay of packets

4.2.Enhanced Efficiency:

AI algorithms can optimize resource utilization, leading to more efficient network operation and reduced energy consumption.

4.3. Increased Reliability:

AI can enhance network resilience by detecting and mitigating faults, ensuring continuous operation even in challenging environments.

4.4.Reduced Complexity:

AI can automate many network management tasks, reducing the need for manual intervention and simplifying network administration. It helps to deal in the innovation of the technology in the mesh networks enhancing the routing metrices with allocation of the cost efficiency and frequency distribution.

4.5. Cost-Effectiveness:

By optimizing resource usage and automating management tasks, AI can contribute to lower operational costs for WMNs.

5. CHALLENGES AND FUTURE DECISIONS

Despite its promise, applying AI in WMNs involves challenges:

- **Data scarcity**: Training AI models requires labelled data.
- **Computational overhead**: Many nodes have limited resources.
- **Interpretability**: Black-box models can be hard to trust in critical systems.
- **Security of AI models**: Adversarial attacks can mislead learning systems.

6. CONCLUSION

AI has the potential to significantly enhance the performance, reliability, and intelligence of Wireless Mesh Networks. From routing optimization to predictive maintenance and secure communication, AI-driven solutions are shaping the future of WMNs. Continued research is essential to address current limitations and unlock the full potential of intelligent wireless networking. The integration of AI into WMNs is an ongoing trend, with continuous research and development efforts focused on enhancing network performance, security, and adaptability. Future research will likely explore more sophisticated AI techniques, including deep learning and reinforcement learning, to address the evolving challenges of wireless mesh networking.

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