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NETWORK ENERGY MINIMIZATION AND AI-BASED EFFICIENT LEACH PROTOCOL DESIGN

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ABSTRACT

Wireless sensor networks (WSNs) are becoming increasingly important, providing pervasive real-time applications that have been used to enhance smart environments in various fields such as smart cities, manufacturing, and the Internet of Things (IoT). This survey reviews and analyzes the research trends related to the utilized Artificial Intelligence (AI) methods for WSN and the potential enhancement of WSNs using these methods. We highlight the routing challenge in WSN and present a comprehensive discussion on the recent studies that utilized various AI methods in addressing the routing challenge to meet specific objectives of WSN, during the span of 2010 to 2020. This would guide the reader towards an understanding of up-to-date applications of AI methods with respect to routing challenge in WSN. In addition, a general evaluation is provided along with a comparison of utilized AI methods in WSNs, which guides the reader in identifying the most appropriate AI methods that can be utilized for solving the routing challenge. Finally, we conclude the paper by stating the open research issues and new directions for future research.

Keywords Artificial intelligence, Data aggregation, Internet of Things, Data collection, Data dissemination, Challenges, Wireless Sensor Networks, Routing

I. INTRODUCTION

WSNs are systems of internationally spread and customized systems that detect and collect atmospheric factors and transmit the data to a centralised location. WSNs may detect warmth, sounds, particulate emissions, moisture, and weather, between other factors. In order to communicate sensor data electronically, these systems are comparable to mobile ad hoc networking include that the rely on mobile connections and spontaneously system development. WSNs detect external atmospheric parameters such as warmth [1-4], vibration, and humidity. Wired versions are reversible, collecting information and permitting management of sensing action. The construction of those connections was spurred by tactical applications such as combat surveillance. Such systems are used in both corporate and commercial purposes, such as processes industry measurement and controlling and equipment condition checking [5].

II. WIRELESS SENSOR NETWORK (WSN) PROTOCOLS TYPES

Wireless Sensor Network (WSN) protocols are designed to manage communication and data transfer in sensor networks. They are typically categorized based on the network layers and tasks they address. Here are some common types of WSN protocols organized by layer:

1. **Physical Layer Protocols**

- **Energy-efficient Protocols:** Focus on minimizing energy consumption by controlling transmission power, sleep cycles, and data rate. Examples include **Low Energy Adaptive Clustering Hierarchy (LEACH)** and **S-MAC (Sensor-Medium Access Control)**.
- **Modulation Techniques:** Involve techniques like Frequency Shift Keying (FSK) and Phase Shift Keying (PSK), which help to optimize power and bandwidth.

2. Data Link Layer Protocols

- **Medium Access Control (MAC) Protocols:** Govern how sensor nodes access shared communication media. Examples include **TDMA (Time Division Multiple Access)**, **CDMA (Code Division Multiple Access)**, and protocols like **B-MAC (Berkeley MAC)** and **S-MAC**.
- **Error Control Protocols:** Manage error detection and correction to maintain reliable data transfer.

3. Network Layer Protocols

- **Routing Protocols:** Handle data transmission across the network. Routing protocols can be classified into:
  - **Flat-based Routing:** All nodes are treated equally, as in protocols like **Directed Diffusion** and **SPIN (Sensor Protocols for Information via Negotiation)**.
  - **Hierarchical-based Routing:** Nodes are grouped into clusters to optimize energy use and scalability, like in **LEACH** and **TEEN (Threshold sensitive Energy Efficient sensor Network protocol)**.
  - **Location-based Routing:** Nodes are aware of their position to route data, with examples like **GPSR (Greedy Perimeter Stateless Routing)**.

4. Transport Layer Protocols

- **Congestion Control Protocols:** Ensure that data is transferred smoothly without network congestion. Examples include **CODA (Congestion Detection and Avoidance)**.
- **Reliable Transmission Protocols:** Provide mechanisms for data retransmission in case of packet loss, as seen in **STCP (Sensor Transmission Control Protocol)**.

5. Application Layer Protocols

- **Query-based Protocols:** Nodes send data upon receiving a request. **Directed Diffusion** is an example.
- **Data-centric Protocols:** Data is communicated based on its characteristics. **COUGAR** and **ACQUIRE** are examples.
- **Event-driven Protocols:** Nodes transmit data when certain events occur, which is common in monitoring and surveillance applications.

Each of these protocol types is optimized to manage energy, reliability, and data delivery efficiently in WSN environments based on specific application needs.

III. AI ROLE IN WSN

Artificial Intelligence (AI) plays a crucial role in enhancing the functionality and efficiency of Wireless Sensor Networks (WSNs). AI techniques help address WSN challenges such as limited energy resources, dynamic topology, and data accuracy. Here are some key roles of AI in WSNs:

1. Energy Management and Optimization

- AI algorithms, especially machine learning (ML), optimize power consumption by predicting node usage patterns, enabling energy-efficient routing, and dynamically adjusting node activity. This extends the lifespan of the network, which is vital in energy-constrained WSNs.

2. Data Processing and Aggregation

- AI techniques are used to process and analyze vast sensor data locally to reduce the amount of data transmitted. This includes filtering, compression, and anomaly detection, which reduces bandwidth use and conserves energy.

3. Fault Detection and Recovery

- AI methods can detect sensor faults, misbehaviors, and hardware failures by analyzing data patterns or node performance. AI can also enable self-repair capabilities, where nodes reconfigure themselves to maintain network functionality despite failures.

4. Routing and Communication Optimization

- AI-based algorithms (e.g., genetic algorithms, neural networks) assist in identifying optimal routing paths based on factors like energy efficiency, node density, and network load, providing adaptive and robust routing protocols.

5. Security and Intrusion Detection

- AI enhances security in WSNs by detecting unusual patterns that may signify an attack. Machine learning models, such as anomaly detection algorithms, can identify unauthorized access or data breaches, helping to secure data integrity and network reliability.

6. Event Prediction and Detection

- Using AI, WSNs can predict events based on historical data patterns. This is beneficial for applications like environmental monitoring, where AI models can predict conditions like temperature surges, flooding, or forest fires, allowing for proactive responses.

7. Localization and Tracking

- AI algorithms, including deep learning, improve node localization accuracy and tracking, especially in dynamic environments. AI can refine location estimates even when GPS is not available, aiding applications like object tracking or environmental monitoring.

8. Self-Organization and Adaptive Topology Control

- AI enables WSNs to autonomously adapt to environmental changes and manage node behavior based on network conditions. This allows WSNs to self-organize, optimizing topology for improved efficiency and resilience.

9. Quality of Service (QoS) Management

- AI can balance load distribution and prioritize critical data transmissions to ensure Quality of Service. AI-based scheduling and resource allocation algorithms improve network responsiveness, which is critical for applications with real-time requirements.

In summary, AI enhances WSNs by providing intelligent solutions that improve their energy efficiency, reliability, adaptability, and security, which are essential for the diverse applications of WSNs.

IV. LITERATURE REVIWE

Manar M. Aldaseen et al. [1] The Wireless Sensor Networks (WSNs) are characterized by their widespread deployment due to low cost, but the WSNs are vulnerable to various types of attacks. To defend against the attacks, an effective security solution is required. However, the limits of these networks' battery-based energy to the sensor are the most critical impediments to selecting cryptographic techniques. Consequently, finding a suitable algorithm that achieves the least energy consumption in data encryption and decryption and providing a highly protected system for data remains the fundamental problem. In this research, the main objective is to obtain data security during transmission by proposing a robust and low-power encryption algorithm, in addition, to examining security algorithms such as ECC and MD5 based on previous studies. In this research, the Energy Saving and Securing Data algorithm (ESSD) algorithm is introduced, which provides the Message Digest 5 (MD5) computation simplicity by modifying the Elliptic Curve Cryptography (ECC) under the primary condition of power consumption. These three algorithms, ECC, MD5, and ESSD, are applied to Low Energy Adaptive Clustering Hierarchy (LEACH) and Threshold-sensitive Energy Efficient Sensor Network Protocol (TEEN) hierarchical routing algorithms which are considered the most widely used in WSNs. The results of security methods under the LEACH protocol show that all nodes are dead at 456, 496, and 496, respectively, to ECC, MD5, and ESSD. The results of security methods under the TEEN protocol show that the test ends at 3743, 4815, and 4889, respectively, to ECC, MD5, and ESSD. Based on these results, the ESSD outperforms better in terms of increased security and less power consumption. In addition, it is advantageous when applied to TEEN protocol.

Amal Almasri et al. [2] Wireless Sensor Networks (WSNs) are generally deployed with low-cost devices that have low power consumption and small-size sensor nodes. They can be used in several monitoring and control applications such as; health, agriculture, and environment. With the advent of Industry 4.0 and Artificial Intelligence (AI), WSNs attracted many industrial applications and specific implementation scenarios. In general, the sensor nodes compromising of WSNs consume vast energy during tracking and monitoring. This poses a challenge especially since most of WSNs are battery-operated and have very limited energy sources. Therefore, it is important to optimize power consumption and prolong the lifetime of WSNs. Many protocols have been proposed with emphasis on data forwarding and routing. These protocols, however, have not been designed to address interference and transmissions issues, such as communication link instability and packet drops. In addition, a quiet substantial amount of energy would be consumed during transmission, which leads to a degradation in network performance. In this research, an effective solution is proposed based on Spiral Clustering Based on Selective Activation Protocol (SCSAP). The objective is to enhance energy consumption and improve network performance, which makes it a good candidate for several Industrial tailored WSNs. In this solution, the network nodes are classified into two types; super and normal. Super nodes have a significant power source and are utilized to construct clusters and act as Cluster Heads (CHs).

Fahad Razaque et al. [3] Mughal Wireless sensor networks (WSNs) have received a lot of attention due to numerous advancements, especially in smartphones, smart watches, smart homes, and even smart cities. Aside from WSNs progression, they are affected by a combination of factors, including network efficiency, link asymmetry, and energy loopholes. This paper introduces a novel approach, particularly useful for challenging receiver-initiated asynchronous heterogeneous networks, which are competitive due to low energy consumption. In WSNs, inefficient energy consumption is a widespread issue that drastically decreases the lifetime of each deployment network. To overcome these challenges, we proposed an intelligent Asymmetry link Quality Routing (ALQR) protocol for WSNs with a low energy consumption clustering protocol. Additionally, If there is no cross-channel traffic, ALQR provides adequate connection control at a low cost, making it more advantageous to WSN applications. We investigated the effectiveness of our proposed protocol compare to multiple state-of-the-art clustering-based protocols. According to the findings, ALQR outperforms in terms of region and lifetime, while ALQR ensures overall throughput.

R.M. Bhavadharini et al. [4] An adaptive metaheuristic optimization-based QoS-aware, Energy-balancing, Secure Routing Protocol (AQoS-ESRP) is proposed in this article. The network is modelled as a biconcentric hexagon (BiCon-HexA), and the clusters are formed within the BiCon-HexA network. The BiCon-HexA is divided into six sectors to support effective data aggregation, and then clusters are formed within all sectors. The optimal cluster head (CH) selection mechanism is modelled by an Adaptive Hunter-Prey Optimization (AdapH-PO) algorithm considering QoS parameters. Data aggregation is then done securely with an enhanced encryption approach. Here, upgraded elliptic curve cryptography (UEllip-CC) is used to encode data in CH. This UEllip-CC approach provides security improvements in data transmission. Furthermore, in this study, CHs are combined in the multi-hop routing of data packets to reduce the power consumption problems of wireless sensor networks (WSN). To determine the optimal route for data transmission, an energy-balanced multi-path routing algorithm called improved convolutional osprey network (ICON) is presented. Nevertheless, the data transmission nodes can be overloaded in the data routing phase.

Pradeep Bedi et al. [5] Wireless sensor networks (WSNs) are designed to sense, collect, and transmit information from the environment to the base station. Under applications such as the Internet of Things and mobile WSNs, intelligent routing is important for achieving better quality of service (QoS) performance of the network. The real-time scenario is dynamic and contains heterogeneous nodes (especially in terms of energy) for a prolonged lifetime of the WSN. Despite these recent advancements in WSNs, energy efficiency is still an essential component that needs researchers to focus their efforts to increase the lifetime of the network. Many researchers have presented their contributions with the integration of optimization algorithms with cluster-based routing protocols to enhance such energy constraints in real-time applications. The objective of this chapter is to review existing energy-efficient routing protocols for homogeneous as well as heterogeneous WSNs. However, these existing algorithms have shown limitations in terms of dynamic, mobile, and heterogeneous network scenarios. Further, this chapter proposes the application of machine learning, swarm optimization, and an evolutionary approach to compensate for these limitations and to make routing decisions more cost-effective in terms of energy.

Hina Gul et al. [6] The seamless integration of intelligent Internet of Things devices with conventional wireless sensor networks has revolutionized data communication for different applications, such as remote health monitoring, industrial monitoring, transportation, and smart agriculture. Efficient and reliable data routing is one of the major challenges in the Internet of Things network due to the heterogeneity of nodes. This paper presents a traffic-aware, cluster-based, and energy-efficient routing protocol that employs traffic-aware and cluster-based techniques to improve the data delivery in such networks. The proposed protocol divides the network into clusters where optimal cluster heads are selected among super and normal nodes based on their residual energies. The protocol considers multi-criteria attributes, i.e., energy, traffic load, and distance parameters to select the next hop for data delivery towards the base station. The performance of the proposed protocol is evaluated through the network simulator NS3.40. For different traffic rates, number of nodes, and different packet sizes, the proposed protocol outperformed LoRaWAN in terms of end-to-end packet delivery ratio, energy consumption, end-to-end delay, and network lifetime. For 100 nodes, the proposed protocol achieved a 13% improvement in packet delivery ratio, 10 ms improvement in delay, and 10 mJ improvement in average energy consumption over LoRaWAN.

R.M. Bhavadharini et al. [7] Due to the resource constraint nature of WSN, ensuring secured communication in WSN is a challenging problem. Moreover, enhancing the network lifetime is one of the major issues faced by the existing studies. So, in order to secure the communication between WSNs and achieve improved network lifetime, a novel trust enabled routing protocol is proposed in this study. Initially, the clusters are constructed using Direct, Indirect, and Total Trust evaluations, which helps to identify the faulty nodes. After, an Improved Fuzzy-based Balanced Cost Cluster Head Selection (IFBECS) method is used to choose the cluster head (CH). Finally, to determine the best path from source to destination, a hybrid bionic energy-efficient routing model known as an Energy Efficient Rider Remora Routing (EERRR) protocol is introduced.

Rajesh Arunachalam et al. [8] In Wireless Sensor Networks (WSNs), one of the most significant threats is vampire attacks in sensor nodes. These attacks are marked by malicious behaviors within sensor nodes, often exploiting vulnerabilities inherent in routing protocols. These attacks can disrupt the connectivity of the network and significantly impact the energy resources. However, these intermediate nodes can introduce security vulnerabilities, making network security in WSN is challenging task. To address this issue, a novel deep learning-based vampire attack detection model is proposed. The developed deep learning-based vampire attack detection model is performed by following steps like data collection, attack detection, mitigation, and optimal path selection. Initially, the data attributes for all sensor nodes in the WSN system are collected. Further, the vampire attack detection is carried out by a Weighted Recurrent Neural Network (WRNN), here the weight values are optimized using Enhanced Golf Optimization Algorithm (EGOA).

K. Phani Rama Krishna et al. [9] Wireless sensor network (WSN) technique has advanced in several applications, however, the environment has significant energy and security challenges. Therefore, this research proposes a Multi-Hop, Trivial, as well as Protected Routing Solution for Constrained Wireless Sensor Networks. The Chaotic Particle-swarm Krill Herd (CPKH) method, which includes chaotic theory with accelerated PSO (APSO) as a mutation operator into the krill herd method, is used to first choose the energy-efficient cluster heads. Then, to select the optimal path this research proposed a novel Self-Adaptive Step Glow Worm Swarm Optimization (SASGWS) Algorithm.

KH Vijayendra Prasad et al. [10] Wireless Sensor Networks (WSN) faces numerous problems. The deployment of the sensor nodes in faraway places makes battery replacement a difficult process. As a result, there are energy constraints and security issues. So, the fusion of SDN with WSN is SDWSN, which flexibly brings network management. The main issue here is controller placement, which has an impact on communication dependability, latency, and throughput. The major drawbacks in existing work include high energy consumption, inefficient data collection, increased response time, and poor packet delivery ratio. This paper presents a unique Artificial Intelligence-based method for adaptive quorum-based scheduling and interference-free routing in edge-enabled UAV-assisted Software-Defined Wireless Sensor Networks (SDWSNs). It combines energy-efficient clustering with E-DBSCAN, multiple attribute-based software node authentication, and interference-free routing with the IDEE algorithm. The NS-3 tool was utilized to conduct simulations using a setup consisting of 4 edge-assisted UAVs, 4 SDN controllers, and 100 wireless sensor nodes.

V. CONCLUSION

WSNs have a wide range of potential applications. The use of these networks in the context of Big Data demonstrates their capacity to overcome inherent limitations in order to fulfil specific objectives. We anticipate a heterogeneous dataset that is constantly generated by the IoT to the point that it cannot be collected, managed, or analyzed by conventional methods in Big Data. Given their features, such data provide an intriguing challenge for LS-WSNs to acquire and analyze. We performed a thorough evaluation in this article and suggest a better method to Big Data gathering. To better address the problem of collecting Big Data, we provided horizontal overviews of WSNs and Big Data in this context. Then we looked at Big Data collecting structures and data transmission methods. Furthermore, the difficulties of collecting Big Data in LS-WSNs have been addressed. We presented a comprehensive overview of the outstanding problems with their related difficulties based on a systematic study of different writers' perspectives on Big Data gathering in LS-WSNs in order to inspire and guide future researchers.

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