AI Techniques used for Improvement in Communication Protocols of Wireless Sensor Networks

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Abstract:
Wireless Sensor Networks (WSNs) are a cutting-edge technology finding applications in diverse fields like environmental monitoring, industrial automation, and healthcare. Composed of numerous sensor nodes with limited processing power and battery life, WSNs aggregate data and sent to a central base-station for further analysis. Routing protocol determines how data packets are forwarded between sensor nodes, impacting network performance and resource utilization. Efficient data routing protocols are crucial for WSNs to optimize energy consumption, network lifetime, and data delivery reliability. This paper delves deeper into the world of WSN routing protocols, exploring various options and analysing their strengths, weaknesses, and suitability for different applications. This paper also investigates the application of Artificial Intelligence (AI) techniques to enhance communication protocols for WSNs. The study explores different communication protocols commonly employed in WSNs, analysing their strengths and limitations. Particular focus is placed on factors critical to WSN performance, including energy consumption, network lifetime, and data delivery reliability. The paper then examines how AI techniques can be leveraged to improve these communication protocols.

Keywords: WSN, AI techniques, Sensor Network, Wireless Communication System, Applications of WSN etc.

1. Introduction

The name Wireless Sensor Networks (WSNs) cleared the meaning very well in which sensor nodes form the network for transmitting data over wireless communication channel. WSN deployed in a self-organizing manner in the particular area limited by the topology of connection and configuration of physical layer. Each node is equipped with on board processors, sensors, and wireless communication capabilities, allowing them to collect data from their surroundings and transmit it to other nodes or a central base station. With advent of 5G network, the various algorithm is studied to utilized the advancement in techniques and used for load management [1].

In figure 1, the physical WSN Architecture is illustrated. The end user is connected to all sensor node though Intranet or though internet. These are the fundamental units of a WSN called sensor node. Each sensor node is equipped with sensors to measure physical or environmental parameters (e.g., temperature, humidity, light, pressure, vibration, etc.). The onboard processor collects and processes data from the sensors. Sensor nodes communicate with each other and with the base station using wireless technologies like Bluetooth, Wi-Fi, Zig Bee, or cellular networks. The base station acts as the central control point of the WSN. It collects data from the sensor nodes, processes it, and may transmit it to a larger network or system for further analysis.

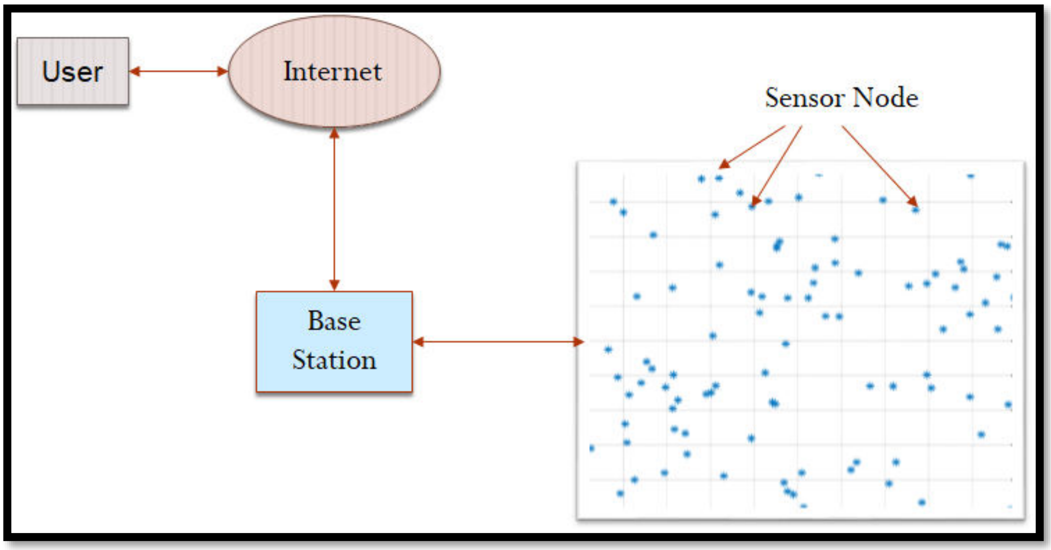

Figure 1: Typical architecture of Wireless Sensor network

WSNs are typically deployed in a distributed manner, with sensor nodes scattered throughout the area of interest. They form a self-organizing network, meaning they can automatically configure themselves and establish communication links without human intervention. This self-organization capability makes WSNs highly adaptable to changing environments. WSN have numerous benefits. Some are listed below.

- Low Cost: They are generally cost-effective compared to wired networks.
- Wireless Communication: They provide flexibility and ease of deployment.
- Energy Efficiency: Recent advancements have improved energy efficiency.
- Scalability: They can be easily expanded to accommodate more nodes.
- Real-time Monitoring: They enable real-time data collection and analysis.

WSN is utilized for transmitting, processing and storing the data. Applications of WSN are illustrated in figure 2.

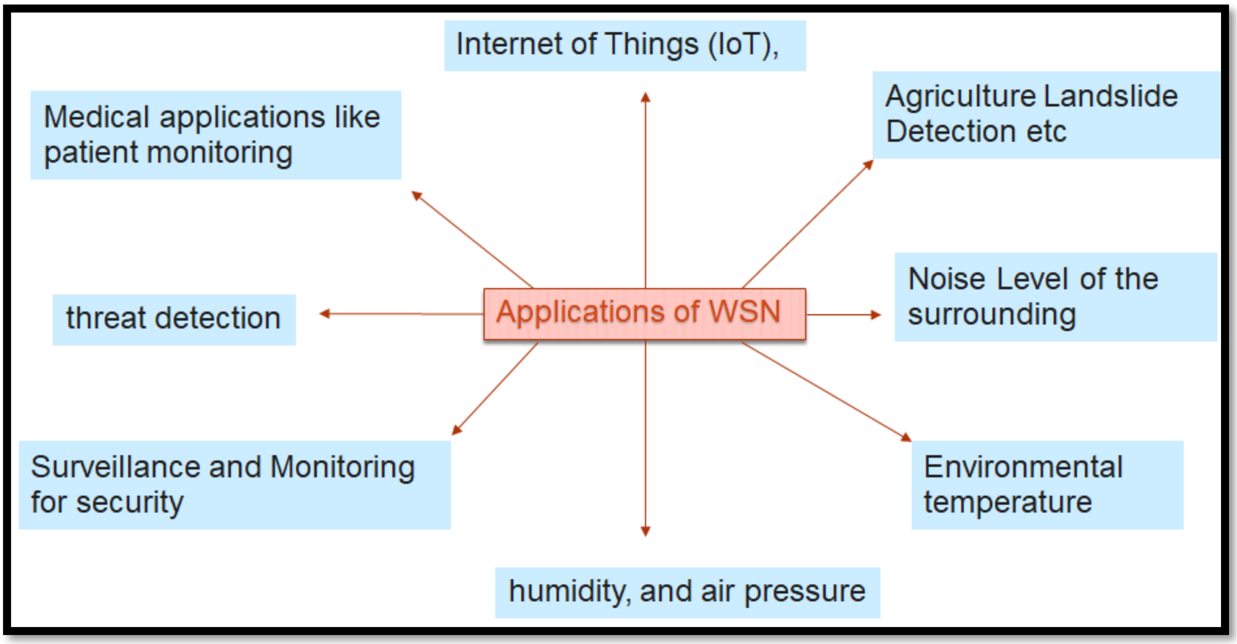

Figure 2: Applications of WSN

While WSNs provide many advantages, their limitations and challenges must be taken seriously while developing the real-world applications. Wireless Sensor Networks (WSNs) face several challenges, including:

- Quality of Service (QoS): Ensuring reliable data transmission and timely response.
- Energy Efficiency: Optimizing power consumption due to limited battery life.
- Network Throughput: Handling large volumes of data efficiently.
- Scalability: Supporting a huge sensor nodes and handling increasing data loads.
- Limited Energy Resources: Battery-powered sensor nodes often have limited energy, making it difficult to sustain long-term operation.

The effective data transmission in dynamic environment is the key point for developing many wireless routing protocol. This paper discusses different routing protocol for WSN and then need and use of AI technique for this.

2. WSN Routing Protocols

In WSN, various routing protocols are in use which can be classified based on several factors. On basis of network Structure, WSN can be classified as flat or hierarchical. In flat routing, all nodes have equal roles and capabilities. Protocols like flooding are simple but inefficient for large networks. In hierarchical routing, nodes are organized into tiers, with cluster heads aggregating data from lower-level nodes and forwarding it upwards. LEACH (Low-Energy Adaptive Clustering Hierarchy) is a popular example.

WSN routing protocols can also be classified based on operation as proactive or reactive routing. In proactive protocol, nodes maintain routing tables with pre-defined paths to the BS. This offers fast data delivery but consumes more energy for route maintenance. In reactive routing, nodes dynamically discover routes when needed. This is energy-efficient but can experience delays during initial route discovery.

2.1 Classical WSN Routing Protocols

This section delves into some prominent WSN routing protocols:

- **LEACH (Low-Energy Adaptive Clustering Hierarchy):** LEACH divides nodes into clusters with cluster heads aggregating data and transmitting it to the BS. This reduces long-distance data transmission, saving energy [2].
- **TEEN (Threshold-sensitive Energy Efficient Sensor Network):** TEEN allows nodes to define thresholds for data transmission. Nodes only transmit data exceeding a certain threshold or when a specific type of event occurs, conserving energy [3].
- **Directed Diffusion:** This data-centric protocol allows the BS to specify data interests by sending queries. Nodes only forward data relevant to the queries, reducing unnecessary traffic [4].
- **Geographic Routing:** Nodes utilize location information to forward data towards the BS. This simplifies routing decisions but requires nodes to be aware of their location [5].

The choice of WSN routing protocol depends on various factors like network size, data traffic patterns, and application requirements. The table below summarizes key considerations:

Protocol	Strengths	Weaknesses	Suitable for Applications
LEACH	Energy-efficient, Scalable	Cluster head selection overhead	Environmental monitoring, Industrial automation
TEEN	Adaptable data transmission	Complex threshold setting	Event-driven applications
Directed Diffusion	Efficient data delivery based on interest	Increased control message overhead	Query-based data collection

Geographic Routing	Simple routing decisions	Requires location awareness	Location-based monitoring

3. Use of AI for Communication Protocols in WSNs

While traditional routing protocols have served WSNs well, the growing complexity and evolving demands of these networks necessitate exploring new solutions. Artificial intelligence (AI) techniques offer promising avenues for enhancing communication protocols in WSNs. Here's a look at how AI can be leveraged in this domain:

3.1. Machine Learning for Adaptive Routing:

Traditional protocols often rely on static rules or assumptions about network behavior. Machine learning (ML) algorithms can analyze network data (traffic patterns, node status, energy levels) to learn and adapt routing decisions dynamically. This allows for routing paths can be chosen based on remaining energy levels, optimizing network lifetime. ML can predict and avoid congested areas, ensuring smooth data flow. The network can adjust routing in case of node failures or changes in the environment. Reinforcement learning algorithms can be used to learn optimal routing strategies through trial and error, while supervised learning can be used to classify data and make informed routing decisions based on specific network conditions.

3.2. Deep Learning for Complex Network Management:

Deep learning, a powerful subset of ML using artificial neural networks, can handle even more intricate data patterns. In WSNs, deep learning can be used for context-aware routing (consider various factors like node location, data type, and environmental conditions to make context-aware routing decisions for improved performance), intrusion detection (used to analyse network traffic and identify potential security threats) etc.

3.3. AI-powered Resource Management:

WSNs have limited resources like battery life and processing power. AI algorithms can optimize resource allocation for tasks like data transmission, sensing, and computation, ensuring efficient utilization.AI can predict potential node failures based on sensor data, allowing for proactive maintenance and resource optimization.

3.4. Challenges and Considerations:

- **Limited processing power:** Implementing complex AI algorithms on resource-constrained sensor nodes might require distributed processing or offloading tasks to more powerful edge devices.

- **Data security and privacy:** AI models rely on data for training and operation. Ensuring data security and privacy within the network is crucial.
- **Explainability of AI decisions:** Understanding how AI algorithms make routing decisions is essential for ensuring network reliability and troubleshooting potential issues.

4. WSN protocol with AI techniques

Various research papers presented in the table 2, focus on improving the energy efficiency and network lifetime of Wireless Sensor Networks (WSNs). This is a critical challenge due to the limited battery life of sensor nodes. The papers explore various approaches to address these challenges, including Routing Mechanisms, Machine Learning: Gaussian Regression Models, Fuzzy Logic, Genetic Algorithms, Metaheuristics etc. The proposed methods in these papers generally demonstrate better performance in terms of energy efficiency, network lifetime, load balancing, and other metrics compared to existing protocols like LEACH. The increasing use of AI techniques, such as machine learning, fuzzy logic, and genetic algorithms, is a significant trend in WSN research. These techniques offer greater flexibility and adaptability in optimizing network performance.

S.no	Author Name	Title	Methods	Result
1.	**"W.R. Heinzelman, A.Chandrakasan, and H. Balakrishnan (2000)"**	"Energy Efficient Communication Protocol for Wireless Micro Sensor Networks."	In this work, an efficient routing mechanism EEMCS is developed for WSNs to prolong the network lifetime and reduce energy consumption in a dynamic environment.	EEMCS performs better as compared to the existing algorithms CRPD, LEACH, and MODLEACH in terms of load balancing, network stability, energy depletion, and throughput [6].
2.	**"Anna Merina George, S.Y. Kulkarni, and Ciji Pearl Kurian (2022)"**	"Gaussian Regression Models for Evaluation of Network Lifetime and Cluster Head Selection in Wireless Sensor	The paper introduces a model predictive method that assesses network lifetime and optimizes cluster head selection in wireless sensor	The paper evaluates and compares various machine learning models for predicting network lifetime and selects the best performing models against traditional tools like Smart Mesh

		Devices."	networks (WSNs).	IP and ANFIS-based models [7].
3.	**"S. Murugaanandam and VelappaGanapathy (2019)"**	"Reliability-Based Cluster Head Selection Methodology Using Fuzzy Logic for Performance Improvement in WSNs"	The paper introduces a new method called "Reliability-based Enhanced Technique for the Ordering of Preference by Similarity to Ideal Solution (RE-TOPSIS)," which integrates with fuzzy logic to enhance cluster head (CH) selection in wireless sensor networks (WSNs).	Simulation results demonstrate that RE-TOPSIS significantly extends network lifespan, reduces energy consumption, and decreases the frequency of CH selections by about 20%-25% compared to existing fuzzy-TOPSIS and LEACH protocols, highlighting the effectiveness of the proposed scheme [8].
4.	**"Eyman F. Ahmed, MohdAdib Omar, Tat-Chee Wan, AltahirAbdallaAltahir(2020)"**	"Energy Efficient Scalable Routing Algorithm for Wireless Sensor Networks"	This paper discusses an improvement over the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol with a focus on scalability and lifespan of large wireless sensor networks (WSNs). It introduces the Energy-Efficient	Performance comparisons through simulations show that EESRA provides better load balancing and energy efficiency for large scale WSNs, surpassing other existing WSN routing protocols [9].

			Scalable Routing Algorithm (EESRA).	
5.	**"Hassan El Alami AbdellahNajid (2019)"**	"An Enhanced Clustering Hierarchy Approach to Maximize Lifetime of Wireless Sensor Networks"	The paper presents an Enhanced Clustering Hierarchy (ECH) algorithm to increase energy efficiency and maximize the lifespan of wireless sensor networks (WSNs). Traditional clustering hierarchy methods in WSNs do not adequately address the issue of data redundancy from adjacent or overlapping sensor nodes.	The ECH algorithm has been tested in both homogeneous and heterogeneous network environments, with simulation results demonstrating its effectiveness in conserving energy and extending the network's lifetime [10].
6.	**"Xingxing Xiao Haining Huang Wei Wang (2020)"**	"An Energy-Efficient Clustering Routing Protocol Based on Data Fusion and Genetic Algorithms"	This paper discusses a new energy-efficient clustering routing protocol for underwater wireless sensor networks	Experimental results show the protocol's superior performance over existing methods in reducing energy usage, extending network life, and lowering packet loss

			(UWSNs), which is crucial due to the challenges of battery replacement in underwater environments. The protocol employs data fusion and genetic algorithms (GAs) to optimize network function.	[11].
7.	**"Jin-Gu Lee , SeyhaChim and Ho-Hyun Park (2019)"**	"Energy-Efficient Cluster-Head Selection for Wireless Sensor Networks Using Sampling-Based Spider Monkey Optimization"	The paper introduces a new approach called sampling-based spider monkey optimization (SSMOECHS) to select cluster-heads in wireless sensor networks.	SSMOECHS choosing cluster-heads from the pool of nodes themselves. This new strategy more effective, and experimental comparisons with protocols like LEACH-C, PSO-C, and SMOTECP show that SSMOECHS outperforms [12].
8.	**"J. Sengathir, A. Rajesh, Gaurav Dhiman, S. Vimal, C.A. Yogaraja & Wattana Viriyasitavat (2022)"**	"A novel cluster head selection using Hybrid Artificial Bee Colony and Firefly Algorithm for network lifetime and stability in WSNs"	The paper presents a novel Hybrid Modified Artificial Bee Colony and Firefly Algorithm (HMABCFA) designed to optimize cluster-head selection in Wireless Sensor Networks (WSNs).	The proposed method increasing network lifetime by 23.21%, energy stability by 19.84%, and also optimizing other network parameters [13].

9.	**"Huifang Chen, Hiroshi Mineno, T. Mizuno (2019)"**	"A Meta-Data-Based Data Aggregation Scheme in Clustering Wireless Sensor Networks"	This paper introduces a meta-data-based data aggregation scheme aimed at enhancing energy efficiency in clustered wireless sensor networks. It addresses redundancy issues when multiple sensor nodes detect and report the same event to the cluster head.	The effectiveness of this approach is validated through simulations comparing it to the LEACH protocol, demonstrating notable improvements in network lifetime and scalability of data aggregation [14].
10	**"Chia-Pang et al. (2014)"**	"A hybrid memetic framework for coverage optimization in wireless sensor networks"	Author proposed a novel method to optimize WSN duty cycles based on load conditions. They used linear regression and Q-learning to achieve this.	While their method effectively reduced latency, energy consumption, and Q-learning's drawbacks, its performance across various topologies and conditions remains unexplored [15].
11	**"Quinlan (1986)"**	"Induction of decision trees"	Author introduced a binary logistic regression-based intrusion detection system (IDS) for WSNs.	It successfully detected selective forward and blackhole attacks but had overhead limitations [16].
12	**"Alshinina and Elleithy (2018)"**	"A highly accurate deep learning based approach for developing wireless sensor network	Authors used a support vector machine technique (INSA) for faulty node detection in WSNs.	INSA improved various parameters like consumed energy, false positive rate, fault detection accuracy, and classification accuracy [17].

		middleware"		
14	**"El Boudani et al. (2020)"**	"Implementing deep learning techniques in 5G IoT networks for 3D indoor positioning: DELTA (DeEp learning-based co-operative architecture)"	Authors proposed a cluster-based data aggregation method using naive Bayesian classification.	It improved accuracy and energy consumption but lacked evaluation of network lifetime, throughput, and delay [18].
15	**"Wu and Yang (2018)"**	"Cooperative reinforcement learning based throughput optimization in energy harvesting wireless sensor networks"	Authors used reinforcement learning (RL) for delay-aware data fusion in WSNs.	They have optimized throughput, network lifetime, energy consumption, buffer utilization, and end-to-end delay using the RL [19].
16	**"Botao et al. (2020)"**	"Improved soft-K-means clustering algorithm for balancing energy consumption in wireless sensor networks"	The authors employed a hybrid approach combining hierarchical clustering for cluster head selection and fuzzy c-means-based routing.	The simulation results showed that this approach effectively improved energy consumption, network lifetime, coverage, and the number of clusters. However, it's important to further evaluate the energy consumption during the cluster formation phase and compare it to other existing solutions [20].

From above table, there is a clear focus on developing energy-efficient and long-lasting WSN protocols. This is required to address scalability of WSN with limited energy resources. The cluster architecture of WSN provides a complex scenario for optimization or controlling the network parameters. Hence, use of AI techniques is becoming increasingly prevalent in WSN research. Many proposed AI-based approaches demonstrate significant improvements in WSN performance metrics.AI techniques have been applied to a variety of tasks, including intrusion detection, data aggregation, cluster head selection, and optimization of various parameters. However, while AI offers great potential, it also faces challenges such as computational overhead, data requirements, and ethical considerations. In future, WSN and Mobile Adhoc network (MANET) can be use together for developing Sensor-equipped MANETs and for WSN management. MANETs can be used to manage and control WSNs, especially in dynamic environments. Many researcher works for improving the performance of MANET system [21].

5. Conclusion:

WSN routing protocols play a vital role in network performance and resource management. This paper explored various protocols, highlighting their advantages, limitations, and suitability for different applications. Selecting the appropriate protocol requires careful consideration of network characteristics and application-specific needs. The provided study comprehensively explores the application of various AI techniques in Wireless Sensor Networks (WSNs). It covers a wide range of techniques, including machine learning, deep learning, evolutionary computation, and unsupervised learning, and their applications to address challenges such as energy efficiency, network lifetime, security, and data aggregation. Overall, AI is a promising tool for enhancing WSN performance and addressing its challenges. Continued research and development in this area are likely to lead to even more innovative and effective solutions. Future research directions include exploring hybrid protocols combining features from different categories and developing protocols that adapt to dynamic network conditions. Real-time Adaptation is also required. Developing AI-based systems that can adapt to changing network conditions in real-time. Implementing AI algorithms directly on sensor nodes for more efficient and autonomous operation. It is also required to address the limitations of current AI techniques, such as computational overhead and data requirements.

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