RTET- 2K26", National Conference (June-2026)
Organized by Department of General Sciences and Engineering, AITRC Vita

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

A Comprehensive Survey on Wireless Sensor Networks: Architecture, Challenges, and Future Directions

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Abstract- Wireless Sensor Networks (WSNs) are becoming more common in today's world. They are used to collect and send data from different environments. A WSN is made up of small sensor nodes. These nodes sense data, process it, and then send it wirelessly to a base station. In this paper, we look at how WSNs actually work. Not just the theory, but the practical side too. We cover structure, communication, localization, and routing methods. There are also some problems—like limited battery, security risks, and data loss. These issues cannot be ignored. New technologies like Artificial Intelligence are slowly changing things. They help improve performance and efficiency. In the end, we also discuss what the future might look like for WSNs.

Keywords: Wireless Sensor Networks, Sensor Nodes, Energy Efficiency, Localization, Routing, Security, Artificial Intelligence, IoT

I.INTRODUCTION

Think of a situation. A farmer wants to know if his soil has enough moisture. He cannot check every part of the field manually. This is where WSNs come in.
Wireless Sensor Networks are made up of small devices called sensor nodes. These nodes collect data like temperature, humidity, light, or motion. Once the data is collected, it is sent wirelessly to a base station. Simple idea. But very powerful.

These networks are used in many areas. Agriculture. Healthcare. Security. Even environmental monitoring. Basically, anywhere data is needed from the real world.

But things are not perfect. Sensor nodes run on batteries. And batteries don't last forever. Replacing them is not always easy, especially in remote areas. Also, since everything is wireless, there is always a risk of attacks or data loss.
So the main challenge is clear. Make WSNs more efficient. More secure. And more reliable.

II. LITERATURE REVIEW

Over the years, many researchers have worked on improving WSNs.
At first, the focus was mostly on security. Attacks like Denial of Service, fake nodes, and data interception were major issues. To solve this, encryption and authentication methods were used.

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

Then researchers focused on localization. Knowing the location of data is very important. Range-based methods give high accuracy but cost more. Range-free methods are cheaper but less accurate. Some methods combine both.

Recently, the focus is on energy and performance. Traditional routing helped but was not flexible. Now, Artificial Intelligence is used. It helps in choosing better routes, saving energy, and improving network life.

III. OVERVIEW OF WIRELESS SENSOR NETWORKS

A WSN has three main parts: sensor nodes, communication links, and a base station.
Sensor nodes collect and send data. But they have limitations—low power, low memory, and low processing ability. That is why energy efficiency is very important.

WSNs use multi-hop communication. Data travels from one node to another before reaching the base station. This reduces energy usage.
Also, WSNs are self-organizing. If one node fails, others continue the work. The system adjusts automatically.

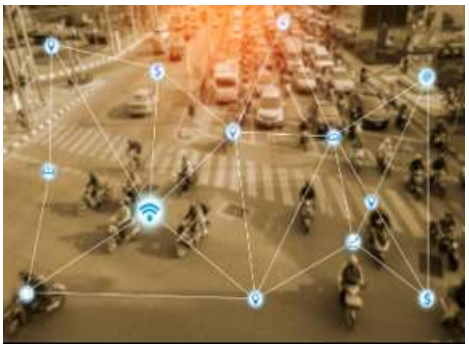

Fig. 1: Wireless Sensor Networks

IV. WORKING FLOW OF WSN

Start → Sense data → Process data → Select route → Transmit data → Base station → Analyze → End
First, nodes sense the environment. Then they process and send data through the best path. Finally, the base station receives and analyzes it.

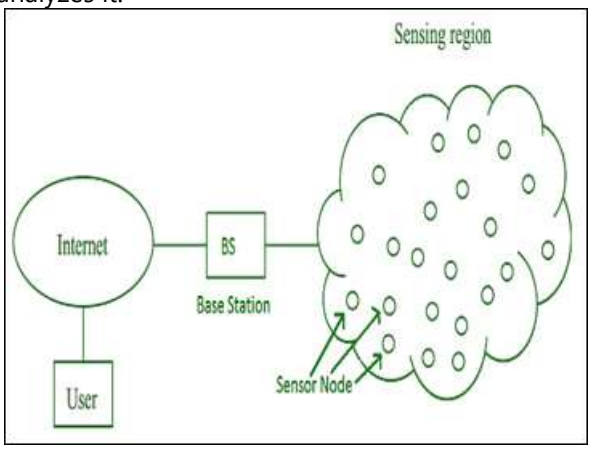

Fig. 2 : Working flow of WSN

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V. CLASSIFICATION OF WIRELESS SENSOR NETWORKS

Based on Environment

- Terrestrial WSN – used on land
- Underground WSN – used below ground
- Underwater WSN – used in water
- Multimedia WSN – handles video/audio
- Mobile WSN – nodes can move
- Based on Structure
- Flat Network – all nodes are equal
- Hierarchical Network – some nodes act as leaders

Fig. 3: Application of Wireless Sensor Network

VI. COMPARISON OF TECHNIQUES

Technique	Advantage	Disadvantage
Range-based	High accuracy	High cost
Range-free	Low cost	Less accuracy
AI-based	Saves energy	Complex system

VII. CHALLENGES IN WIRELESS SENSOR NETWORKS

Energy: Battery life is limited.
Security: Wireless networks are open to attacks.
Data Loss: Signals or nodes may fail.
Scalability: Large networks are hard to manage

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VIII. ANALYSIS (OWN UNDERSTANDING)

From this study, energy efficiency is the biggest issue. Many techniques exist, but none is perfect.
Range-based methods are accurate but costly. Simpler methods save money but reduce performance.
Artificial Intelligence improves decision-making but increases complexity.
In my opinion, combining simple and intelligent methods can give better results.

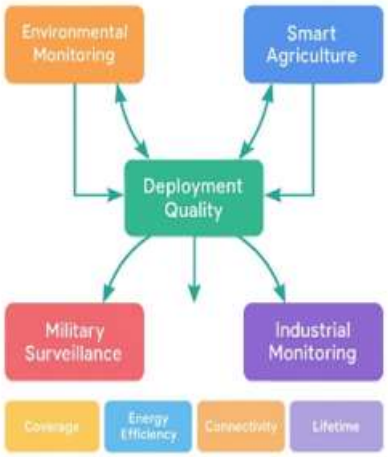

Fig. 4 : Deployment Quality

IX. FUTURE SCOPE

WSNs will grow with IoT. More devices will connect. AI will make systems smarter.
5G and 6G will improve communication. Solar power and energy harvesting will solve battery problems.
WSNs will be used more in smart cities, healthcare, and industries.

X. CONCLUSION

Wireless Sensor Networks are very useful for data collection and monitoring. This paper explained their working, types, challenges, and future improvements.
Although there are problems like energy and security, new technologies are improving WSNs. In the future, they will become more efficient and widely used.

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