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SURVEY ARTICLE

Analysis of Energy, Coverage, and Fault Issues and their Impacts on Applications of Wireless Sensor Networks: A Concise Survey

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Abstract – Energy-efficiency, Coverage-quality, and Fault-tolerance Issues (ECFI) are the three primary and crucial quality assurance standards in a Wireless Sensor Network (WSN). These three standards ensure the network design of a self-configurable and sustainable WSN. First, energy-efficiency mechanisms ensure the prolonging of the overall network lifetime. Second, the coverage quality means how well a region of interest (RoI) is covered. Third, fault-tolerance refers to the ability of a network to continue operating without interruption when one or more components fail. With rapid innovations and developments in Wireless Sensor Network (WSN) applications, many researchers' most sustainable objective is to provide an adeptly operational sensor network. A broad range of applications of WSNs can be seen in the fields of academic, military, industry, medical, and daily needs worldwide. This analysis and survey article's main objective is to highlight different promising challenges on various fundamental characteristics, designing limitations, and their impacts on applications of WSNs. The authors also highlight the energy depletion and energy-provision issues with a concise survey of coverage and fault-related issues in WSNs. The authors finally summarized with discussion and analysis of the overall impacts of ECFI and other parameters on WSNs with simulator availability and future research direction.

Index Terms – Wireless Sensor Networks, Design-Limitations, Applications, Energy-Efficiency, Coverage-Quality, Fault-Tolerance, Future Remarks.

1. INTRODUCTION

A Wireless Sensor Network (WSN) consists of several low-cost and primarily battery-dependent sensors densely deployed in a region of interest (RoI) with sensing, communicating, and processing capabilities. The latest developments in Micro-Electro-Mechanical Systems (MEMS) technology and the advancements in wireless technology and digital peripherals have contributed to the emergence of new shapes of inexpensive, energy-efficient artificial-intelligent devices. They perform more efficiently with these tiny, intelligent sensors than earlier [1]. However, energy-efficiency, coverage-quality, and fault-tolerance concerns are the significant challenges facing the widespread adoption of WSN. In [2, 3], the authors review the sensor network's architecture, applications, and processing components of a sensor node in WSNs. These components, such as sensor technology, operating systems, networking services, and communication protocols, do not discuss energy-related issues and challenges. However, sensors are primarily limited and battery-dependent, and thus, the lifetime of WSNs is limited [4, 5].

One of the critical design challenges in WSNs is energy-efficiency to prolong the operable network lifetime. With the wide range of applications of WSNs and the exact moment of facing one challenge, i.e., an energy constraint in the form of limiting the lifetime of the sensor's results network goes down or fails. In sensor networks, energy depletion is mainly due to sensing, communications, and data processing.

Another concern is the coverage-quality issue in WSNs. Coverage quality is an essential issue in WSNs, which has a significant impact on the overall performance of WSNs. It is always fundamentally concerned with coverage problems: how well an area, a target point, or a barrier or boundary is covered in WSN [6]. Generally, coverage-aware techniques are categorized into three types: area coverage, target coverage, and barrier coverage. The coverage quality depends on the different applications. For example, some applications

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expect complete coverage, which means their whole area must be covered at all times.

In contrast, the coverage quality can be slightly compromised [7-9]. In another aspect, coverage quality can be classified into 1-coverage and k-coverage problems. For a 1-coverage, each point inside the RoI is to be covered by at least one sensor. In the case of a k-coverage, where each point inside the RoI must be covered by at least k-sensors all the time (k can be 1,2,3...), respectively [9].

MEMS technology-based and equipped with small storage sensors are deployed in WSN. These sensors are deployed either randomly or pre-determined in the target region (RoI) or remote location. These sensors can fail for various reasons, e.g., harsh environmental conditions, remote areas, battery failure, and component wear-out or hazards. Since WSNs are supposed to operate unattended after deployment, failing sensors cannot be replaced or restored during field operation. Therefore, the designed network system should be capable enough to handle various failures. So, we can ensure that a wireless sensor network can perform sensing, monitoring, tracking, and other tasks even when some sensors fail in the network [10-13].

Several influencing factors affect the overall performance of a sensor network. This survey article's main objective is to provide a concise survey on several crucial and hidden characteristics, design limitations, ECFI and their impacts on applications of WSNs.

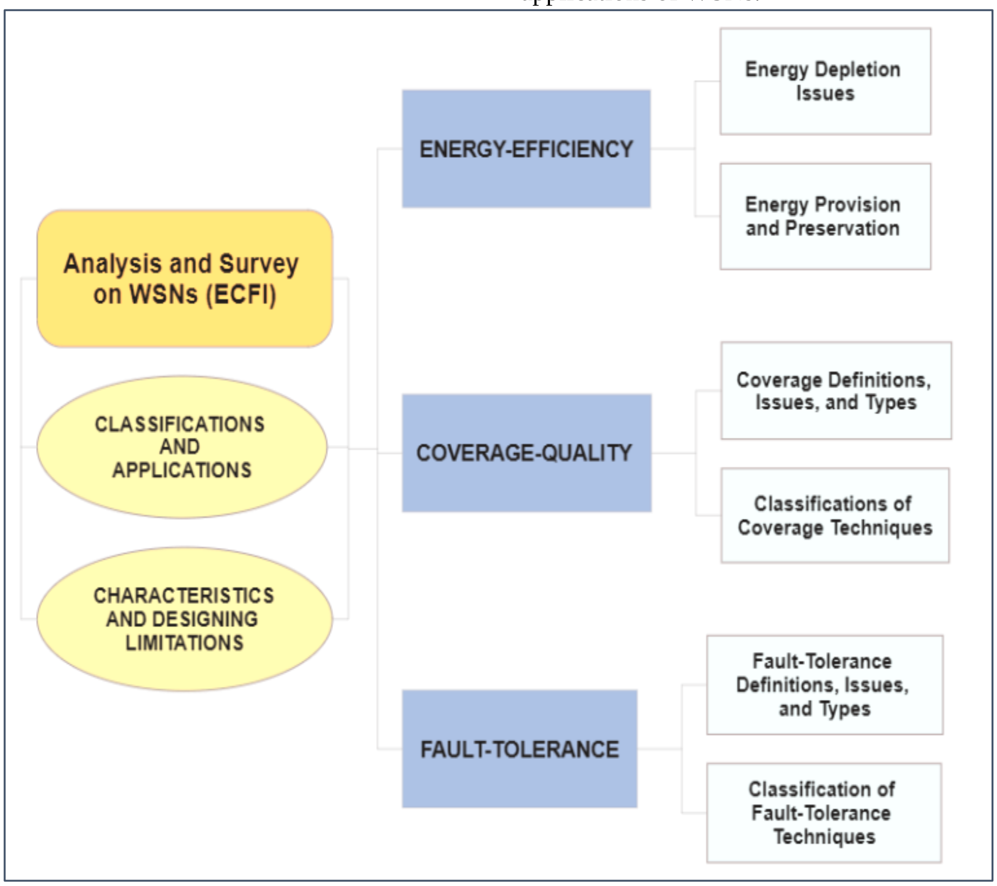

Figure 1 Summary of the Work Presented in this Article

1.1. Motivation and Objective of the Survey Article

Motivation: Several reviews and research articles related to the energy, coverage, and fault-related issues in WSNs exist in the literature. However, none of the existing studies analyze, review, and provide a clear description of all the features together yet. This article covers all the influencing factors and classifies the energy-coverage-fault issues and their impacts on applications of WSNs. Due to the excessive demands from a wide range of applications in wireless sensor networks (WSNs), we always receive multiple challenges from researchers' various considerations. Moreover, once sensors are densely randomly deployed in remote or vulnerable, or harsh locations, they are not easily replaceable or rechargeable.

Many applications often deal with multiple challenges and vulnerability concerns, such as reliability, security, quality of

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service in coverage and monitoring, limited network lifetime, sensor failures, fault-tolerant systems, and more. For example, applications have more vulnerability and sensitivity, such as forest fire detection, battlefield surveillance, medical healthcare surveillance, environmental and weather prediction zones, security-oriented monitoring in homes and industries, vehicle monitoring and tracking, and more. Therefore, prerequisites and rapid changes in WSN applications require a long-lasting network with guaranteed quality coverage with an uninterruptible network system for a sustainable and self-configurable WSN. Therefore, researchers have consistently devoted foremost concerns over the last two decades to addressing and making effective solutions.

Objectives: Because of prerequisites and rapid changes in applications of WSNs, it has been considered an attentive and prospective field of research. This analysis and survey study exclusively identifies various issues and influencing factors in WSNs. The authors focus on energy efficiency, coverage quality, and fault-tolerant issues (ECFI) and their impacts on applications of WSNs.

The main findings of the concise survey article are summarized as follows:

- Identification of components, architecture, fundamental characteristics, design limitations, and applications of WSNs.
- Discussion on significant challenges and energy, coverage, and fault-related issues (ECFI) based on the application's necessity with a complete discussion of target parameters.
- Authors study and analyze existing energy efficiency-related issues based on two deliberations: energy-depletion and energy-provisioning-related issues in WSNs.

The authors perform a concise survey on coverage issues and fault issues in WSNs with different simulators for WSNs.

1.2. Article Organization

This analysis and survey article is organized as follows: In Section-1, the introduction and motivation part of the paper with the outlines of the article are discussed. The Architecture, Classifications, and Applications of WSNs are presented in Section-2. In Section-3, Fundamental Characteristics and Design Limitations of WSNs. Section-4 provides a discussion on energy depletion and provisioning in WSNs. Section-5 discusses a concise way to solve coverage quality and fault-tolerance issues with the availability of various simulation tools for WSNs. In Section-6, the authors perform the discussion and analysis. Section-7. Finally, summarize the survey article by conclusion and future research directions. A summary of the work done in our article is shown in Figure 1.

2. ARCHITECTURE, CLASSIFICATIONS, AND APPLICATIONS OF WSN

2.1. Architecture of Wireless Sensor Network

MEMS chip-based circuitry and minimal power are required for processing. Four critical components are required for a sensor to work correctly, as seen in Figure 2. Additional application-specific utilities, such as a GPS unit or mobilizer, could also be provided. The basic subunit units in sensing units include sensors and signal converters. In short, the processing unit is involved in all the procedure processes that coordinate the sensor nodes to carry out their given responsibilities. A transceiver device links the sensor to the deployed network. The power unit is the primary energy source for any sensor device in the network. These tiny sensors are equipped with limited lifetime capacity batteries. Power supply units are supported by power harvesting units such as solar cell technology, advanced technology-based intelligent silicon batteries, etc. [1-3]. Other subunits may be required as per the needs of applications. These additional subunits must be low power, low production cost, dispensable, and autonomous from the environment. These tiny sensors are equipped with limited lifetime capacity batteries. A WSN is affected by various factors, such as energy consumption/depletion, scalability, mobility, deployment of sensors, fault-tolerance, environmental vulnerability, etc., [5].

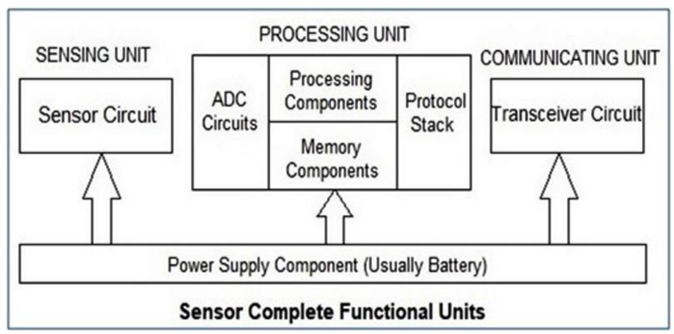

Figure 2 Sensor Components

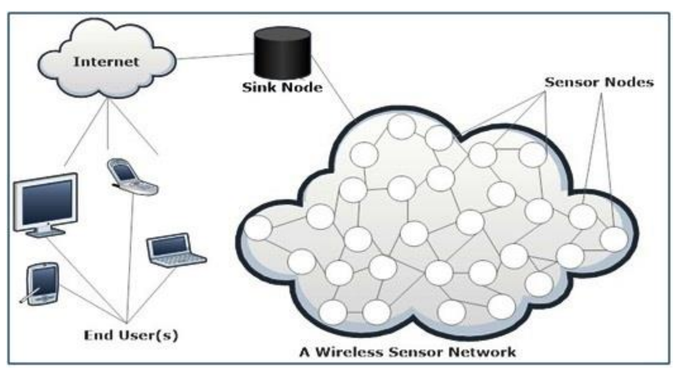

Figure 3 WSN Architecture

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A simple sketch of wireless sensor network architecture is shown in Figure 3, where a sink node is connected to the internet and an intermediate connection among sensors is called a WSN [3].

2.2. Classification of Sensors

Due to their high-sensing nature, they are deployed densely and randomly to monitor physical objects or environmental conditions cooperatively. Furthermore, each sensor can sense the monitored zone, process the collected data, and finally communicate and share processed data with other network sensors. Due to advancements in technology, pursuing all these capabilities offers various innovative and beneficial applications in WSNs [1, 2, 5] and [14-17]. Broadly, sensors are categorized as physical, chemical, biological, and environmental. There are many types of sensors used in various applications, creating more scope for spreading application variety, such as light, accelerometer, barometric pressure, humidity, temperature sensors, acoustic, magnetometers, wind speed, moisture, solar radiation sensors, and GPS modules, etc., [2, 14]. Also, the authors summarize sensor categories and ECFI impacts, as shown in Table 1.

Category	Parameter	Energy-Efficiency	Coverage-Quality	Fault-Tolerance
Physical	Temperature, Pressure, Moisture Content, Flow rate, Flow velocity	High	High	High
Chemical	Electrical Conductivity, Dissolved Oxygen, pH, Oxidation Reduction Potential	High	Moderate	High
Biological	Microorganisms, Biologically active contaminants	Low	Low	Low
Optical	Wavelengths, Longitudinal rib, Intensity	Low	Low	Low
Environmental	Sensitivity, Linearity, Selectivity	High	Moderate	High

Table 1 Sensor Categories and ECFI Impacts

2.3. Classification of WSNs

All WSNs are categorized into two classifications based on the capability and characteristics of the sensors, viz. homogeneous WSN and heterogeneous WSN [18-20]. Others, based on their functionality and approaches, adopted sensors, viz., Traditional WSN, Participatory WSN, and Two-Three Dimensional WSN.

Homogeneous WSN:

Assuming a homogeneous architecture of the WSN consists of sensors with identical sensing, communication, and processing, storage, power, and their functionalities are also quite simple.

Heterogeneous WSN:

Assuming a heterogeneous architecture of the WSN has various sensors and their different sensing and communication ranges, processing. Sensors may become unequal due to battery failure, which is also known as heterogeneity.

Traditional WSN:

Assuming a traditional architecture, the WSN is specially designed and deployed as a fully automated and stand-alone system. Such networks consist of thousands of small, fixed, and static sensors or devices with identical processing capabilities, storage, and functionalities.

Participatory WSN:

Assuming a participatory architecture of the WSN leverages available sensors or devices. The functionalities of sensors include humans in the loop, heterogeneity, and support total mobility.

Two-Dimensional or 2D-WSN:

The dimensional shape of the RoI for choosing the sensor network's appropriate architecture. 2D-WSN assumes that the sensor can only cover or detect a 2D plane. However, many applications require a 3D model to solve several problems associated with the 3D scenario. We cannot extend the existing work on 2D-WSN because of some limitations.

Three-Dimensional or 3D-WSN:

The shape (like a sphere) of the RoI plays an essential role in selecting the appropriate sensors to fulfill coverage quality requirements. The deployment of the 3D-WSNs requires additional computational geometry-based mechanisms that are very high and the need for costly sensors with memory-based protocols.

Furthermore, the types of sensor networks depend on the physical environment, decided to be deployed terrestrial, underwater, underground, mobile, multimedia, WBASNs as follows [19-21]:

Terrestrial WSNs

Terrestrial WSNs can impart base stations effectively and comprise hundreds to thousands of sensor nodes sent either in an irregular or predefined way. Deployment in the terrestrial district is one of the difficulties.

Underwater WSNs

These organizations comprise a few sensor nodes conveyed submerged. A test of submerged correspondence is an extended spread deferral and sensor failures. Such organizations have self-governing sensors which move around in the water.

Underground WSNs

Sensors are sent under the earth to screen surface exercises. The underground sensor networks are more costly than terrestrial WSNs in deployment, upkeep, and gear costs. The fundamental reason for this organization framework is to screen diverse underground clashing conditions.

Mobile WSNs

These organizations comprise an assortment of dynamic sensor nodes that can be continued forward according to guidelines and collaborate with the current climate. The dynamic conduct of sensor nodes makes an organization parcel habitually. There are several limitations due to mobility on this WSN.

Multimedia WSNs

Multimedia remote sensor networks have been proposed to empower following and checking of occasions as multimedia, like imaging, video, and sound. These networks comprise minimally expensive sensor nodes furnished with mouthpieces and cameras. Multimedia sensor networks experience the ill effects of long proliferation deferrals and high transmission capacity. Such an organization is coordinated with some canny hardware like a receiver and camera that helps convey one end client to another end client with pressure, relationship, interaction, and data recovery.

Wireless Body Area SNs

The extension of WSNs to clinical applications progressively transforms these advancements into body area sensor networks (WBASNs). The implantation of a sensor network in the human body to check wellbeing boundaries.

For example, the biosensors record electrocardiograms, electromyographs, and measure body temperature, circulatory strain, and electrodermal movement, among other medical service boundaries, e.g., heartbeat, oxygen immersion, etc., patients. Such an organization is described as a remote body area sensor organization.

2.4. WSNs Applications: Taxonomy

In this section, we review the classification of various applications and the impact analysis of the ECFI. WSNs have been resolving issues in different application areas and changing our daily lives worldwide in several diverse ways. That is why they are extensively used in a broad range of applications in WSNs. Such as military and surveillance, medical and health devices, home appliances & vehicles, public safety & emergency, industrial & automotive, agriculture & environment, transportation & logistics, entertainment & sports, etc. [1, 5]. We present a concise classification of widely used applications in WSNs, as shown in Figure 4. WSN Applications: Taxonomy. Our survey article proposes a novel way of representing a concise survey classified into eight classes. Each class has a specific range of applications, as shown in Figure 4, and summaries the WSN applications and impacts of various influencing parameters on WSNs as shown in Table 2.

Military and Surveillance:

It is the critical technology used for tracking and monitoring hostile or sensitive areas where intruders and their weapons are targeted. WSNs are a whole section of military insight, control, correspondence, figuring, observation, examination, and focusing on frameworks. WSNs have become an integral and essential part of military and surveillance systems for commanding, controlling, communication, and intelligence expert systems.

Examples: This includes early detection of the enemy's movement and vehicle tracking, monitoring friendly forces, equipment, and ammunition, biological and chemical attack detection, battlefield surveillance, soldier supervision, enabling close surveillance of opposing forces, and more [21, 22].

Medical and Health Care:

To detect physical function, doctors can install sensor nodes in a patient's home or body. The sensed parameters are passed to the medical practitioner for further analysis and diagnosis. Medical treatment and observations can be done by doctors or hospitals, even far away from each other, using sensor networks known as tele-treatment or telemedicine. A portion of the clinical and medical advantages of WSNs are in diagnostics, insight, drug organization, and executives. It upholds the debilitated, coordinates patient checking and the executive's interfaces, telemonitoring human physiological data, and follows and observes clinical specialists or patients inside the clinical office. **Examples:** include telemonitoring of human physiological data, tracking and monitoring of doctors and patients, drug administration inside a medical center, home monitoring system for elderly care, real-time monitoring of physiological signals, sensor-based ECG (cardiac monitoring), blood pressure, pulse rate monitoring, remote health care system, etc., [23, 24].

Home Appliances and Vehicles:

Nowadays, a home can be an innovative and intelligent home where we can access many appliances from remote locations. This is because it uses the home automation-based technology that emerged with sensor networks. In addition, these sensor nodes inside the gadgets can speak with one another and the outer organization through the Web or satellite correspondence. Therefore, we can monitor and keep our eyes on the home from anywhere using intelligent sensors and communication systems. Similarly, today's vehicles mostly have many in-built sensors for many purposes.

Examples: These sensors are used to track cars in the city, identify unlawful actions, and monitor congestion in the area. Examples of places such as airports, railway stations, and crowded public spaces, for example, are being used to track down stolen cars. Vehicle tracking and detection systems, vacuum cleaners with built-in threat alarms, humidity, acceleration, GPS, and temperature sensors are just a few of the sensors found in intelligent vehicles [25, 26].

Public Safety and Emergency:

From the public safety point of view, it is planting smart camera sensors in public places like roadways, traffic squares, bus stands, railway platforms, and many others to monitor and control unavoidable circumstances. It also supports the government in establishing a better management system for public safety and emergencies.

Examples: include camera sensors in traffic control, remote metering in intelligent cities, gas leakage, floods, earthquakes, fire detectors, and more [27, 28].

Industrial and Automotive:

WSN is used to monitor the condition of manufacturing equipment and manufacturing processes. Sensor network deployment can be beneficial for improving industrial factory automation and supply-chain control. Inventory management and product quality monitoring are also the main aspects of WSNs. WSNs have been progressed to "Technological Condition-based Maintenance (TCBM)" since they could offer tremendous expense decreases/speculations and permit creative functionalities.

Examples-Incorporate permitting and designing practices to screen assets distantly without essentially visiting the areas, destinations, or industrial facility zones, machine-automation process, pipeline monitoring and production control, data logging, alert alarms in case of any failure, mass airflow, fuel temperature, smart grid, etc., [29, 30].

Environmental and Agricultural:

The WSNs monitor many environmental conditions like air, water, pollution, humidity, etc. In agriculture, WSN is deployed for monitoring and observing the wetness, dryness, and fertility condition of the land. The work of WSNs has been accounted for in helping ranchers from different angles. With the support of wiring in a mind-boggling climate, water system automation helps more clever water use and waste decrease. Some other imperative viewpoints are; air pollution observing and the executives, timberland fires revelation/recognition, nursery checking and the board, and Avalanche disclosure/discovery. Sensors are bound to provide accurate environmental conditions for crop cultivation.

Examples: include monitoring weather and environmental conditions forecasting, rainfall range, water quality, monitoring of crops, soil information, and land; chemical/biological detection, precise agriculture; tracking the movements and patterns of insects, birds, or small animals; meteorological or geophysical research; flood detection; bio-complexity mapping of the environment; and pollution study, assisting farmers in various aspects, and so on [31-33].

Transportation and Logistics:

Nowadays, creating WSNs is handy for improving transportation and logistics by managing and monitoring goods, workers, and benefits. Sensor technology and real-time information can be shared with users for tracking and satisfaction. WSNs compose instantaneous traffic statistics to forage transportation models later and keep drivers alert of possible congestion and traffic difficulties. It is expected that the active RFID technology based on wireless sensor networks will have a broad application prospect in the logistics field.

Examples: include traffic monitoring and control like traffic prevention, congestion and parking systems, accident signaling, vehicle location-aware systems, RFID, IoT applications, etc., [34, 80].

Entertainment and Sports:

Another blasting area of WSN, changing the entertainment and gaming zones. The game experiences are becoming more intelligent, and real-time experiences between physical and virtual scenarios using sensor networks. In sports, the deployment of WSNs is more practical, sophisticated and overcomes existing problems. Sensors can improve athletic performance, balance the competitive landscape, create fair judgment, and increase fan interaction.

Examples: include smart and intelligent systems, mobile entertainment, TV and home gaming equipment, virtual and augmented reality, 3-D reconstruction and motion capture, and motion capture. Placing small, unobtrusive sensors into

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the clothing athletes wear to quantify their heart rate and respiration, muscle activity, and exertion as wearable sensors in sports systems [35-37].

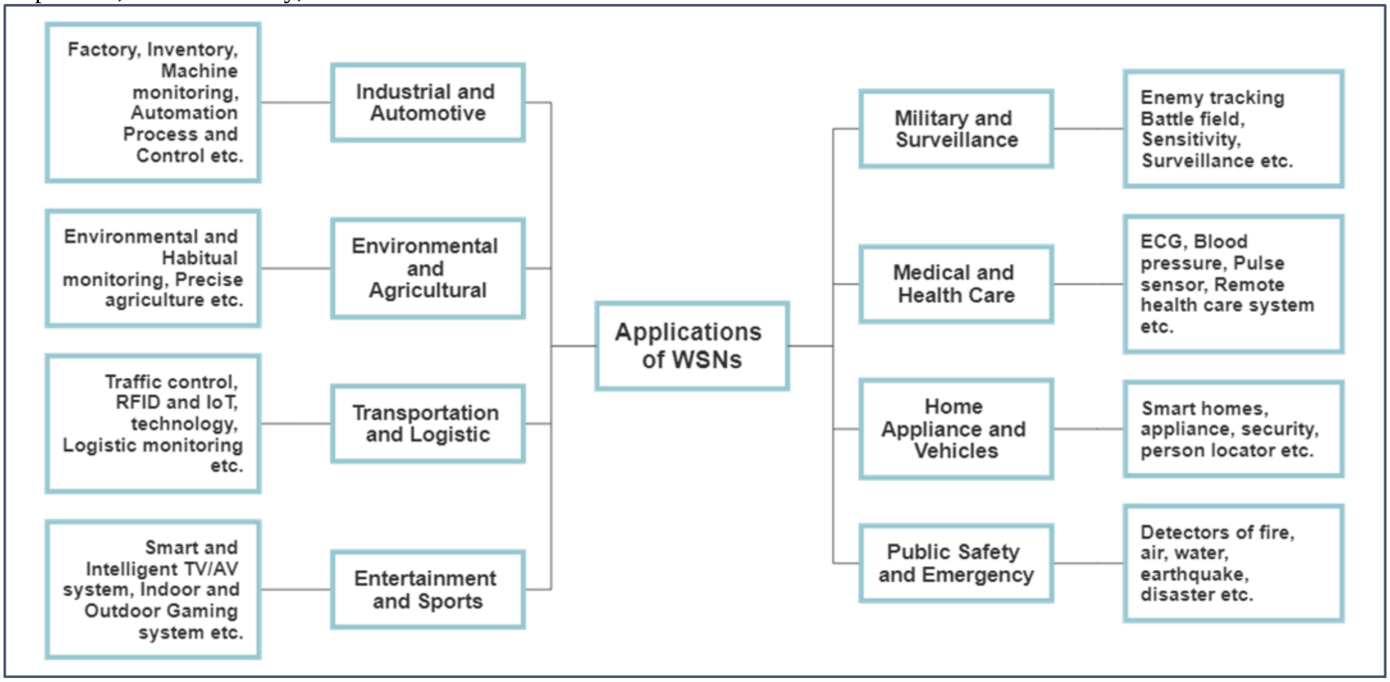

Figure 4 Applications of WSNs

Applications	Energy-Efficiency	Coverage-Quality	Fault-Tolerance	Extensibility	Mobility	Security	Robustness
Military and Surveillance [21, 22]	High	High	High	Low	Moderate	High	High
Medical and Health Care [23, 24]	High	Moderate	Low	Low	High	High	Moderate
Home Appliance and Vehicles [25, 26]	Moderate	High	High	Moderate	High	High	Low
Public Safety and Emergency [27, 28]	High	Moderate	Moderate	Low	Moderate	High	High
Industrial and Automotive [29, 30]	High	Moderate	Moderate	Moderate	Low	High	High
Environmental and Agricultural [31, 32, 33]	High	Moderate	Moderate	Low	Low	Moderate	High
Transportation and Logistic [34, 80]	Moderate	High	High	Low	High	High	Moderate
Entertainment and Sports [35, 36, 37]	High	Moderate	Low	Low	Low	Moderate	Low

Table 2 WSN Applications and Impacts of Various Parameters

2.5. Role of Sensors in Current Smart Cities

In this section, the goal of the discussion is to merge smart city innovation across many areas, including computing and sensing infrastructures, deployment costs, communication security, and adaptability to the environment, energy, and faults. A smart city is an improvement over current cities, both functionally and structurally. Smart factors such as Information and Communications Technology (ICT) are utilized strategically to improve sustainable growth while also enhancing city functions.

Finally, to benefit its citizens, the city seeks to enhance the quality of life and the general health of its citizens. Cities may be regarded as mini-societies made up of "things" that people come into contact with every day. Examples include furniture on the street, public buildings, transit, monuments, and street lighting. More importantly, real-world infrastructure is monitored constantly by sensors and computers. It provides an ongoing, continuous assessment of the city's condition.

The Internet of Things (IoT) idea envisions a linked world where every item is "smart," has access to the Internet, and can communicate with each other and with its surroundings. Information about mobility, energy usage, air pollution, and cultural information is collected and distributed by all IoT objects. Consequently, a smart city closely connects both the cyber and the natural worlds. For the city to be healthy and succeed, new services may be implemented when they are required, and assessment systems will be put up to measure the city's overall well-being.

Sensing in smart cities can be classified as follows [40]:

1. Smart Services
2. Smart Homes/Buildings
3. Smart Healthcare
4. Smart Transportation
5. Smart Infrastructures
6. Smart Surveillance
7. Smart Electricity, Water, and Air Quality Systems
8. Smart Vehicle Road Alert System
9. Smart Parking Systems
10. Smart Crowd-sourcing and Crowd-sensing systems
11. Smart Crowd Sensing Systems and many more.

New paradigms, such as the Internet of Things (IoT) and its ability to control and link thousands of sensors and actuators throughout the city, are anticipated to enhance residents' quality of life. Mobile devices greatly aid professional and personal tasks at the same time.

2.6. Role of Routing Protocols in Enhancing WSN Performance

In this section, several routing protocols are explained. How they are used is examined. Environment-specific, task-specific, and generic use of the routing protocol may be divided into three broad groups. To address the problems, researchers have devised routing algorithms. Most of these issues stem from inefficient code optimization and faulty problem model assumptions. When it comes to WSN, finding the optimal path is more complicated. The choice relies on many variables. Data transfer from the source node to the destination node results in routing issues. Most of the effort (approximately 44%) has been spent discussing the energy-efficient issue. Both trade-off and multi-objective routing optimization have been utilized in different investigations, as discussed in [41]. For the routing of data in wireless sensor networks, many routing techniques have been developed. These protocols take into account the features of the sensor nodes and the requirements for application and architecture. The performance measures are used to compare efficient WSN routing technologies.

Some critical performance indicators for routing protocols in WSNs are as follows: network delay, latency, network throughput, success rate, packet generation rate, network lifetime, and energy consumption [4, 42].

1. Network Delay: The average transmission delay of the data packet from one end to another is the average time between the initially sent packet and the time it is successfully received at the destination.
2. Latency: The average period from the beginning of the disclosure of data to the node of data receipt. The latency assesses the temporal performance of each communication.
3. Network Throughput: The average message latency should be defined as the average time from starting the data disclosure to the reception node. The latency evaluates the time performance of each transmission.
4. Success Rate: The ratio of packets received at destinations to packets transmitted from the source.
5. Packet Generation Rate: It refers to the number of packets transmitted by the sensor node in a certain period, typically one second.
6. Network Lifetime: Network lifespan is defined as the time interval between message loss rates exceeding a certain threshold.
7. Energy Consumption: energy consumption is the total energy consumed for all network nodes that comprise transmitting, receiving, and idling the energy used. To

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calculate overall energy usage, multiply total packets transmitted by the number of transmissions.

2.7. Mobility Enables Sensors and their Impacts in WSNs

The Mobile wireless sensor network takes its name from the nodes found inside the network—these nodes are referred to as "mobile sinks" or "sensors." The advantages of mobile WSN (which do not require constant monitoring and maintenance) include higher energy efficiency, more widespread coverage, better target tracking, and increased channel capacity. The creation of new applications and novel concepts mainly dependent on the utilization of Wireless Sensor Networks has come about because of the rising desire and necessity to link and manage our surroundings (WSN) [44].

The Mobile wireless sensor network takes its name from the nodes found inside the network—these nodes are referred to as "mobile sinks" or "sensors." The advantages of mobile WSN (which do not require constant monitoring and maintenance) include higher energy efficiency, more widespread coverage, better target tracking, and increased channel capacity. The creation of new applications and novel concepts mainly dependent on the utilization of Wireless Sensor Networks has come about because of the rising desire and necessity to link and manage our surroundings (WSN). Although many papers have been written on mobility in the network for traditional phone and internet protocols, they are not applicable in the IoT and WSN scenarios. When considering the traditionally two significant forms of node mobility, micro and macro mobility, it is necessary to include both. While the movement of sensors within the same sensor network domain is referred to as micro-mobility, this concept also applies to micro-mobility in other sensor network domains. These networks were not built to handle large-scale movement, which poses a significant difficulty in contending, especially since WSN nodes, such as low-powered and resource-constrained CPUs, must have constant connectivity.

Mobility in the network has been widely investigated for telephone and internet services. However, these standard telecommunication protocols are not suited for the current WSNs/IoT environment. For example, although rechargeable batteries are standard in mobile communications devices, Internet of Things sensors cannot often be recharged. Thus, low-power sensor protocols have been researched and created. There have been very few protocols developed for mobile sensors thus far [15, 38].

3. FUNDAMENTAL CHARACTERISTICS AND DESIGN LIMITATIONS OF WSNS

In this section, we will discuss various issues related to the characteristics and design limitations of WSNs. In Table 3, we discuss the characteristics and ECFI impacts on them. The characteristics of WSNs are shown as follows:

3.1. Fundamental Characteristics

Hardware and Software Resources:

The general sensor architecture has software implementation running on a fixed hardware design. It requires low complexity, low-maintenance protocol configurations with a remote operating system [5].

Finite Battery-Power:

Sensors usually use non-rechargeable batteries (in hostile or remote locations, energy harvesting is not possible), which is why they are an essential resource for a WSN. The relatively small size of a sensor and the limited power capacity of the battery are assembled with sensors. Once the battery power is over, the sensor dies. However, due to the slow advancement in battery technology, battery power continues to be a limited resource in WSNs [9].

Event Detection and Data Collection:

Event activity can be sensed and sent to other sensors or sink nodes, either in a centralized data collection or distributed manner. Creating an event detection method consisting of resource limitations is not an easy task [10].

Decentralized Monitoring:

There is no strict central control system in the WSNs. As a result, sensors can join or depart the network at any time. Therefore, it possesses high invulnerability [9].

Self-Organizing:

This feature explores many functions due to the network layout and expansion. It does not rely on any presupposed network facilities. Sensors can compose an independent network instantly once their initial set-up phase is done [39, 13].

Multi-hop Routing:

Sensors communicate with neighbors directly using their transmission and receiving range. Suppose the sensors wish to communicate with the other sensors outside. In that case, it is a radio frequency, and it should be routed by the intermediate hops that are called multi-hop routing [14]. Gateways and routers can realize the multi-hop routing of the fixed network. However, ordinary network sensor nodes complete the Wireless Sensor Network's multi-hop routing without special route equipment.

Mobility Support:

The sensor can never move outside the targeted zone because the sensor is disconnected from the network. If that sensor was a linking node/cut vertex, the network was partitioned. If sensors are in mobility, they are bound to move in limited ranges [15].

Dynamic Topology:

WSNs support a dynamic networking layout property. Sensors can move from one location to another, resulting in dynamic changes in the deployed topology. All of these would change the topology structure, so the network should have dynamic topology features. For example, a node may exit the network operation because of the exhaustion of battery energy or some other breakdown. On the other hand, it may also be added to the network because of job demand [38].

Deployment Strategy:

Sensors can be deployed at either a predetermined location (s) or randomly deployed into the monitored field. Predetermined deployment requires prior geographical information about the monitored field. In contrast, random does not need any geographical information to ensure strict environmental conditions for deployment. To enforce the monitoring task in the targeted zone, usually, thousands of sensor nodes are air-dropped. Sensor distributions with high density make use of the high connectivity between sensors and achieve many goals [20, 31].

Clustering Formation:

A group of sensors makes a cluster in terms of equal capabilities of sensing, communicating, processing, storage, etc., and is said to be a homogeneous WSN cluster. On the other hand, a network with different functional capabilities of sensors is said to be a heterogeneous WSN cluster [43].

Characteristics	Energy-Efficiency	Coverage-Quality	Fault-Tolerance
Hardware and Software Resources [5]	High	High	High
Finite Battery-Power [9]	High	Moderate	Low
Data Collection and Event Detection [10]	Moderate	High	High
Decentralized Monitoring [9]	High	High	Moderate
Self-Organizing [39, 13]	High	Moderate	Moderate
Multi-hop Routing [14]	High	Moderate	Moderate
Mobility Support [15]	Moderate	High	High
Dynamic Topology [38]	High	Moderate	Low
Deployment Strategy [20, 31]	High	Moderate	Moderate
Clustering Formation [43]	High	High	High

Table 3 WSN Characteristics and Impacts of ECFI

3.2. Designing Limitations in WSNs

Several limitations and design challenges, directly and indirectly, impact developing a QoS-based, sustainable, and self-configurable WSN. In the deployed network, sensors have non-rechargeable and non-replaceable batteries. Due to remote and hazardous scenarios, it is of principal significance to get free from sensor energy exhaustion as far as possible. Some designing limitations are shown in Figure 5.

Limitations on Hardware Resources:

The traditional architecture of the WSN is no longer compatible with the rapidly changing requirements of the new scope of applications. For several reasons, complex computations are added to this shared infrastructure. Due to the size of a sensor and the restriction on deploying area, it requires low complexity based networking software and a remote operating system [2, 3].

Limitations of Power Resources:

Because of these limitations, the size of a sensor only configures a relatively small scale of battery. Once the battery power is over, the network's work is interrupted [5, 14].

Limitations of the Deployment Strategy:

Sensor deployment can be done either randomly or predefined location-based. It Easy to implement and cost-effective is a random deployment, whereas predefined deployments require more calculations and additional resources with high-cost [20, 31].

Limitations of Scalability and Mobility:

A network whose exhibition improves in the wake of including equipment, relatively to the limit, is supposed to be a scalable network. The number of sensors sent to the monitored zone might be at the request of hundreds or, at least, thousands, with some having mobility as well. The mobility and heterogeneity nature of the sensors creates numerous confinements. For example, scalability to the enormous dispersion of sensors becomes astounding. Mobile sensor nodes are usually utilized with random deployment strategies, yet they devour more energy because of their mobility [15, 38].

Limitations in Computational capabilities and Transmission Media:

Some limitations exist in the sensor's cost, battery power consumption, size, and space complexity. Sensor networks pass through many challenges because of communication faults, computational constraints, and limited power supply. In a sensor network, communicating sensor nodes are connected by a wireless medium.

There are many common problems associated with wireless media, such as fading, signal loss, collisions, and signal errors. These issues may also affect the overall operation of the wireless sensor network [14, 15].

Limitations in Coverage and Connectivity:

Coverage and connectivity are the two main fundamental problems in WSNs, which reflect and influence the quality of service and overall performance that a particular sensor network can provide [8, 9, 56].

Limitations on Topology, MAC, and Routing Protocols:

The most common application of topology control is significant exhibitions. This visualizes how well sensing zones are verified and how frequently they are linked with sensors in WSNs. In the field, discretionally placed sensors. On a basic level, sensors in the sent system may be discretionarily positioned in the field. Henceforth, the basic topology chart that speaks of correspondence joins between nodes is usually unstructured.

Consequently, it is essential to design the series of systems administration boundaries suitably. The Medium Access Control protocols in WSNs have a significant impact on the energy depletion of sensor nodes. In general, MAC protocols coordinate access to a shared medium between several sensor nodes. The MAC layer has the control mechanisms for radio communications. Most of the energy depletion of sensors is done in communication only.

To a significant extent, MAC protocols influence how the general energy is spent, consequently deciding the hub's lifetime. *Geographic routing* is a routing rule that depends on geographic position data. For the most part, it is proposed for wireless systems. It is dependent on the possibility that the source makes an impression on the geographic area of the goal instead of utilizing the system address [16, 48, 49, 59].

Limitations on Controlling and Self-organizing Structure:

There is no precise control focus on the Wireless Sensor Network. The sensors can enter or leave the network at any point, and the fault originates from any sensor. It creates high in-susceptibility in the deployed network. The sensor network design and expansion do not depend on any predefined network structure. It requires more sophisticated protocols and structure-organizing algorithms. Therefore, a well-working network can be formed. Additionally, sensors can rapidly create an autonomous network and, consequently, when they start up and configure themselves [19, 39].

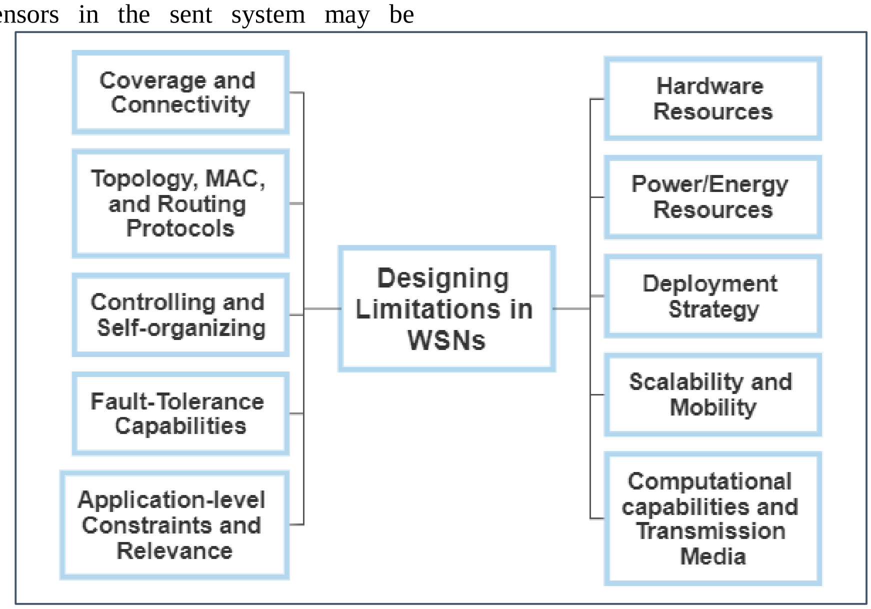

Figure 5 Designing Limitations in WSNs

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Limitations on Fault-Tolerant Capabilities:

Once sensors are deployed, they are easily handled because of remote locations or harsh environments. However, it is widespread for the sensors to become faulty and increase unreliability. So, the capacity to handle failed sensors is another limitation. WSN are prone to be affected by faults that may be caused due to hardware malfunction, software bugs, inadequate energy resources, and many others [10, 78].

Limitations on Dynamic Protocol:

Due to two behaviors of WSNs, viz., first an Ad-hoc structure in nature and second, wireless communication, designing of the protocol becomes a tedious task. Some sensor networks support mobility, which means sensors can move everywhere. Hence, it also becomes a sensitive part of the design because sensor movements result in network partitioning [2].

Limitations on application-level constraints and relevance:

Unlike regular networks, WSNs are primarily dependent on application-specific protocols. The overall objective of this research project is to get environmental data—various sensor networks use different physical signals to analyze data. It is impossible to apply a sensor network routing protocol to the other because it has no applicable criteria. Therefore, relevancy in the use of the WSN is a crucial consideration. [15, 17, 59]. Some other critical design limitations also exist and arise according to current scenarios. Such as data aggregation, data delivery, routing holes, security and threat issues, unwanted interference, communication issues such as well-known problems like hidden-terminal or exposed terminal challenges, and many more [50-52].

4. ENERGY DEPLETION AND ENERGY PROVISION IN WSNS

In this section, the authors further classify energy-related issues into two main aspects. First, we discuss various energy depletion or consumption causes of sensors, and another for energy provisioning and preservation of sensors in WSNs [53-55].

4.1. Energy Depletion Causes in WSN

One of the significant issues facing sensors is the energy constraint due to a small battery as their energy source. Energy depletion and prolonging network lifetime are two challenges in WSN [54, 55]. Prolonging the network lifetime with a limited energy storage capability of sensors has led us to find new horizons for reducing power depletion. The states of WSN are additionally significant as sensors devour various measures of energy in various states. To expand the lifetime of WSN, changing the states as indicated by the need is additionally essential. In wireless sensors, every sensor radio can be in any of the accompanying states [53]. Energy depletion is mainly classified into eight categories shown in Figure 6.

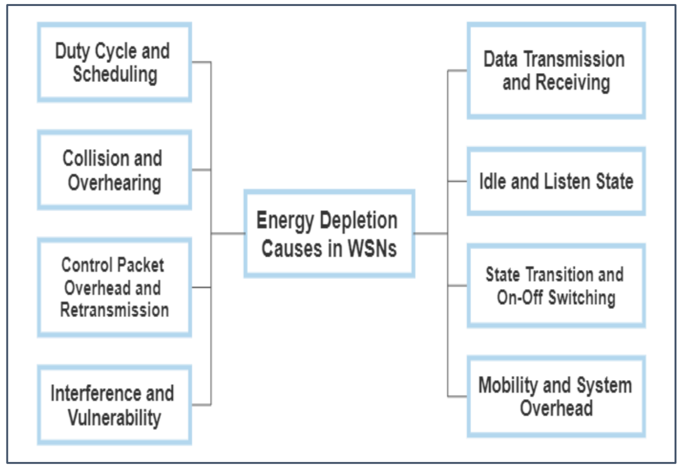

Figure 6 Energy Depletion Causes in WSNs

Some energy depletion issues are associated with deployment and setup with execution phases in wireless sensor networks, as follows:

Data Transmission:

When the transmitter is transmitting data.

Solution: Using an efficient routing and communication protocol reduces overall data transmissions at each sensor level [46].

Data Receiving:

When the receiver is receiving data.

Solution: If overall, less data transmission is there, data receiving complexity at each sensor level can also be reduced [46].

Idle and Listen States:

When a sensor listens to an idle channel to receive probable traffic or periodically waits to receive the expected data despite no communication over time.

Solution: Sensors are organized efficiently to spend less time in an idle state as much as possible. This cause can be minimized by enabling efficient duty cycle scheduling [53]. (Some sensors that are not scheduled to send or receive are placed in an energy-saving mode.)

State Transitions and On-Off switching:

When a sensor node transits from its current state to the next state. Moreover, when a sensor is eligible to be turned off, it consumes energy while turning off and requires more energy to be turned on.

Solution: Sensors are scheduled in such a systematic way that less switching is possible among the sensors throughout the network lifetime. Less turn-on and turn-off can be achieved only by deploying an efficient duty cycle scheduling approach [53].

Mobility and System Overhead:

Due to limited battery capacity, energy-efficient mobile WSN operation is critical for applications such as habitat and environmental monitoring, traffic monitoring, battlefield surveillance, smart homes, and smart cities.

In addition, overall system overheads are increased due to sensors' mobility during their updating of information and status. For these reasons, energy depletion is high with mobility [14, 38].

Duty Cycle and Scheduling:

Critical difficulties with WSNs, as the majority of sensors use non-rechargeable batteries. As a result, their lives may be prolonged by combining various duty cycles and scheduling techniques. However, it complicates the task of developing energy-efficient protocols for wireless sensor networks. Thus, lots of energy depletion is done during their changes in states and switching [71].

Collision:

At the point when a sensor gets more than one data bundle simultaneously, these data parcels collide. All data parcels that met the collision must be disposed of, and the retransmission of these bundles is required.

Solution: The wastage of energy due to retransmission in collision situations can be avoided by employing the request-to-send/clear-to-send (RTS/CTS), the back-off random-based approach proposed by various researchers [57].

Overhearing:

Energy-wastage when a transmitted data packet is unnecessary received by sensors even if they are not destined for that communication [58].

Solution: This issue can be resolved by using network allocation vector information where the sensor (s) periodically enters into a sleep mode to avoid overhearing communications.

Control packet overhead:

A base number of control packets should be utilized to empower data transmissions beneath the edge; else it can be rethought energy as wastage.

Solution: Message forwarding can be used to reduce application-perceived latency and control packet overhead. [58].

Retransmission:

There may be numerous explanations behind retransmission. When a sensor sends a packet to another sensor, the recipient sensor is not prepared to receive it, and the bundle must be re-transmitted and more.

Solution: Transmissions must take place at a fixed duration for each deployed sensor. Also, there must be adjustable transmission ranges that reduce retransmissions and overall energy consumption [58].

Interference:

There are always possibilities of radio interference errors. Each sensor is located between a transmission, and the interference range receives a packet, but the received data is vulnerable [57].

Solution: This interference problem is solved by the MAC protocol strategy discussed in [60].

Vulnerability:

The degree of security and the vulnerability of wireless sensor networks depend upon the application that we need to convey. Due to the vulnerability of the deployed zone, in which sensor networks predominantly suffer from imbalanced energy depletion. Consequences in the mid-operation hot spot or uncovered area can be seen in the monitored RoI.

Solution: If early detection is possible, then do it. Also, try to add more RFID sensors, re-positioning sensors, and introducing secondary data-backup sensors to validate recorded data and recover it if the sensor is affected by vulnerability [61].

4.1.1. Power Consumption by Sensors

Category	Telos or Tmote	Mica2 or Micaz	Shimmer	IRIS	Sunspot	Waspmotes
Power consumption in transmission(mW)	52.2	52.2	52.2	51	52.2	165
Power consumption in receiving(mW)	56.4	56.4	56.4	48	56.4	148

Power consumption in idle(mW)	3	33	5.94	21.6	92.5	21.6
Power consumption in sleep(µW)	2	30	16.8	21.6	1850	21.6

Table 4 Power Consumption in WSNs [62]

In Table 4, a correlation of different nodes is shown dependent on the power devoured by nodes in different phases of the sensor. Table 4. Develop with the help of this article [62]. Battery-powered WSN nodes' long-term lifetimes are therefore greatly affected by their energy usage. Because each node is so inexpensive, replacing the whole node is much more cost-effective than locating the node and replacing or recharging its battery supply.

4.1.2. Energy Consumption and Conservation of Sensors

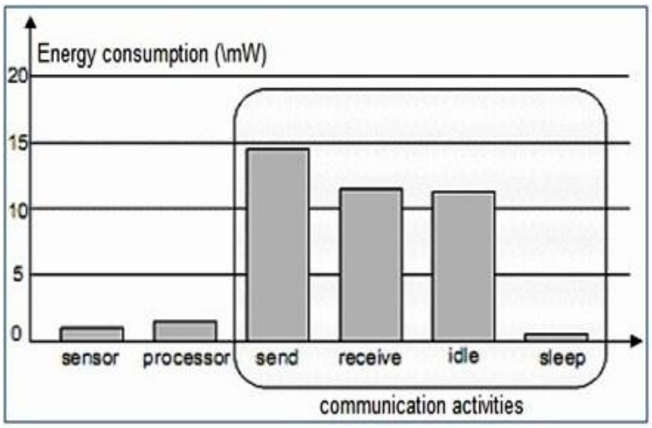

Figure 7 Energy Consumption Rate

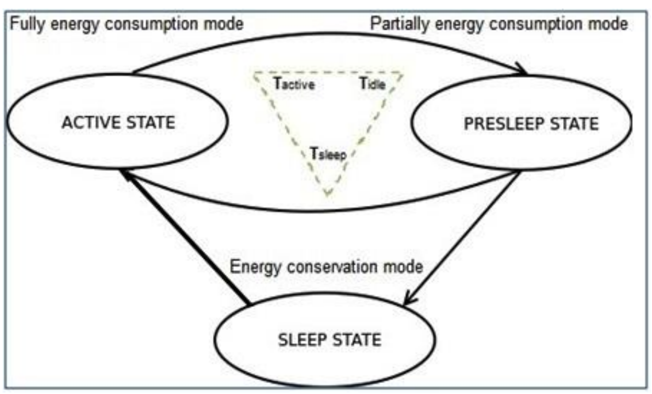

Figure 8 Energy Consumption and Conservation in Different States

Figure 7 represents an analysis of the energy consumption rate in various sensor modes [53]. There is mainly depletion found in sending, receiving, and idle states. Simultaneously, energy depletion is less or negligible in the sleep state, processing, and initial sensor phase. Figure 8 shows the various energy consumption and conservation in different switching states as active or presleep or sleep sensors in execution mode in WSN [63, 71]. The authors also discussed the distribution of energy consumption in data transmission, data aggregation, data memorization, routing, and data security.

4.2. Energy Provision and Preservation in WSNs

The secret of energy management in WSN is based on two design considerations; energy-provisioning and energy-preservation [53]. For a wireless sensor, power sparing procedures can by and large be grouped into the accompanying classifications. The energy provisioning in WSNs, as shown in Figure 9, can be broadly classified into four categories, viz.:

1. One time Battery driven (Fixed/Static Battery based) [4].
2. Rechargeable Battery driven (Rechargeable/Replaceable Battery based) [4, 5].
3. Energy harvesting (Environmental energy harvesting based on solar and wind energy) [66, 67].
4. Energy Transference (Energy Transferring based sources such as magnetic resonance, MW/RF Energy [68].

Authors [53] featured a sequential request for energy provisioning innovation beginning from battery-driven sources to energy provisioning and remote exchange of energy to a sensor gadget in the objective field of a sensor network [69].

Energy preservation can be done or can be classified under two sections as indicated in Figure 10 [4, 70]:

- Sensor Level-Optimized sensor hardware components selection and optimal configuration achieve the low energy-depletion rate of total deployed sensors.
- Network Level-Selection of communication protocols and routing/scheduling protocols to minimize total deployed sensors' energy-depletion rate.

As a battery is the main wellspring of energy in WSN and it cannot be revived. So control sparing procedures are utilized to ration the energy in WSN. Some other energy preservation can be done as follows [72-75]:

- Efficient duty cycling or scheduling where the sensors alternate between active, idle, and sleep modes to conserve energy as much as possible [71].
- Power control mechanism by adjusting and optimizing the sensing and communication ranges of the sensors [46, 72].

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- Energy-efficient multi-hop routing and data-gathering reduce the amount of data transmitted and unnecessary re-transmissions [72, 73].
- Power conserving techniques can be used in hierarchical clustering, efficient routing, or energy-efficient sensor scheduling techniques to increase the overall lifetime of WSN [4, 72].
- Adopted methods must be distributed because all decisions are made using local information rather than global or central systems [5].
- Residual energy conservation management in which the sensor is considered alive if it has enough remaining energy for sensing and communication to its neighbors [4].
- Sensing and Communications Ranges and distances between sensors and base stations also manage to preserve each sensor level's energy [46].

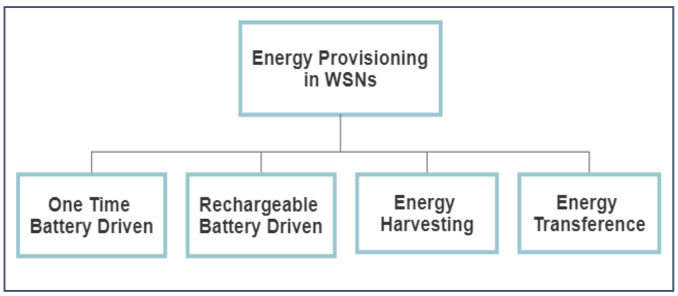

Figure 9 Energy Provisioning in WSN

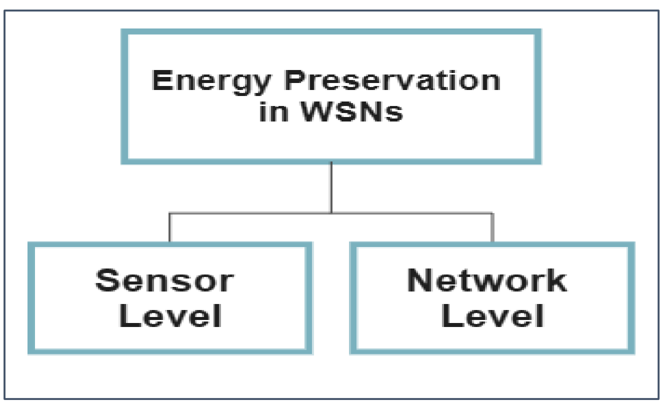

Figure 10 Energy Preservation in WSN

5. COVERAGE-QUALITY AND FAULT-TOLERANCE ISSUES AND AVAILABILITY OF SIMULATION TOOLS IN WSNS

This section describes the coverage and fault-related issues in WSNs. Coverage quality and fault-tolerance are two significant concerns in wireless sensor networks (WSNs) for sustainable systems [64]. First, we present a simple yet essential relationship between coverage quality and coverage quality in WSNs. Similarly, various fault types and their classifications are discussed. We then discuss and analyze a few critical performance factors in these areas.

5.1. Coverage-Quality Issues in WSNs: A Concise Survey

In WSN, each sensor node has its own sensing range for neighboring sensors. It sends data or gathers information to the base station. Each sensor has a sensing and the communication range, as shown in Figure 11, a relationship between the sensing range and communication range. Figure 11 shows two ranges, where Rs is the sensing range and Rc is the communication or transmission range. The relationship between Rs and Rc is given as $Rc \geq 2*Rs$ [76].

Authors [8] talked about detecting models, arrangement of inclusion, research issues in WSNs, and commonsense difficulties in deploying WSNs. They also survey a brief, complete outline of the different arrangements for inclusion issues in associated WSNs and depict experiences with issues and difficulties in research around here.

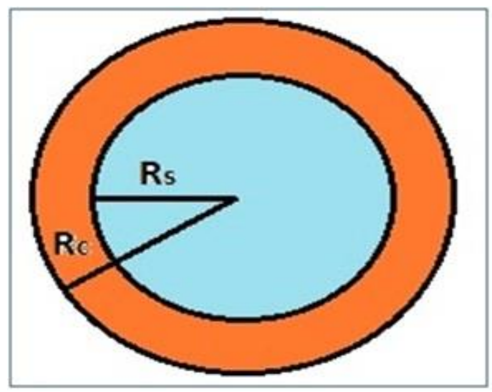

Figure 11 Sensing and Communication Range

Coverage issues can be classified as either continuous coverage or sweep coverage. In addition, there are three coverage qualities: area or region coverage, target or point coverage, and barrier or boundary coverage. Furthermore, according to the need for coverage degree, coverage requirements can be classified into either 1-coverage or a K-coverage problem (discussed below).

It is always primarily concerned with coverage issues: the degree to which an area, a target point, a barrier, or a border is covered by a WSN [6]. Three categories of coverage quality exist: area or region coverage, target or point coverage, and barrier or boundary coverage. In general, coverage issues become apparent when homogeneous and stationary sensors are randomly deployed in hostile or isolated places. Occasionally, topological and routing changes, as well as network vulnerabilities, occur. According to the authors [6, 9], coverage issues in WSNs can be roughly classified as follows:

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1. **Coverage for Area or Region**: In some instances, the primary objective is to constantly cover or monitor a specific area/region or the entire sensing area.
2. **Coverage for a Specific Participating Point or Target Field**: It is designed to monitor or cover a single participating point. The target might be defined as the region of interest.
3. **Coverage for Barrier or Boundary Field**: This is referred to as being observed or covered by a fence regarding national border monitoring, security surveillance, or intruder detection, for example.

5.1.1. Coverage Degree or level

Since coverage issue in WSNs is one of the essential critical metrics in a performance evaluation that ensures how well an RoI is covered. Here, we briefly discuss various types of coverage levels. Such a key metric has always been addressed by many researchers worldwide over the last two decades. Some important aspects are to be covered and related to our review works as under coverage classification.

1-Coverage:

In a given RoI, the entire region is 1-covered while each point inside the RoI is covered by at least one sensor of the set of active sensors. In [76], OGDC provides complete 1-coverage and connectivity for WSNs. Due to deployment fields and sensors' unreliability and vulnerability properties, 1-coverage is not enough for some crucial applications. Some applications may request a higher or different degree or level of coverage into their different portions of the RoI. Such applications require that their entire RoI be covered by multiple sensors while maintaining the QoS and coverage requirements. The concept of k-coverage comes in the picture where a RoI requires a different coverage degree.

k-Coverage:

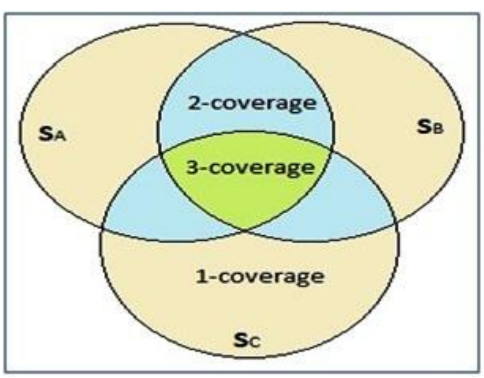

Figure 12 k-Coverage Scenario (k=1-2-3) in WSNs

A region of interest is said to be k-covered if at least k-sensors cover each point inside the region (k can be any integer value). An overview of a network's coverage plan is shown in Figure 12, where S_A, S_B, and S_C are the three sensors and they all are intersecting and covering each other by their sensing ranges (R_s). Moreover, their intersected sector is covered by light-green shade, sky-blue shade, and light-yellow shade of 1, 2, and 3-coverage respectively, shown in Figure 12.

5.1.2. Classification of Coverage Techniques in WSNs

Coverage techniques are broadly based on three main approaches: based on deployment, based on scheduling approach, and based on heuristic approaches, as shown in Figure 13 [6-8].

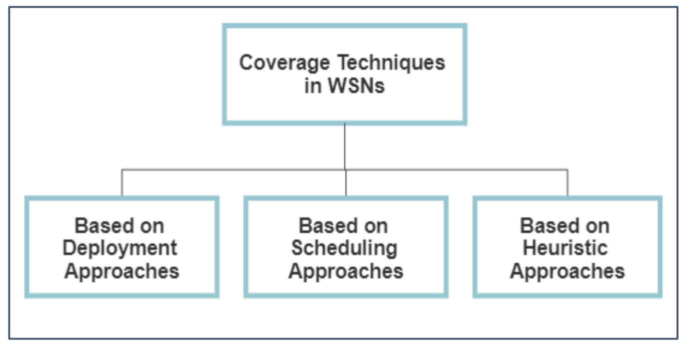

Figure 13 Coverage Techniques in WSNs

Deployment Based Approaches:

Contingent upon different utilization of WSNs, the situating of sensors is essential because the achievement of WSN's activity relies upon the situation of these sensors. Because the arbitrary deployment of sensors brings about an unpredictable density, a few regions are inadequately sent while different regions are densely deployed. In this way, full coverage cannot be accomplished because of coverage openings, and the outcome network will not be figured out.

Scheduling Based Approaches:

A practical approach to WSN is scheduling to conserve the energy of sensors and maximize the overall network lifetime. More concisely, schedule in sleep state all redundant sensors in such a way while keeping the remaining sensors active to maintain coverage and connectivity. For example, in scheduling algorithms, the sensors are arranged to sleep when they are not in use and are active to provide services.

Heuristic Based Approaches:

Numerous research works provide optimal trade-offs between energy consumption, coverage quality, and overall network lifetime based on heuristic approaches. For example, two popular methods, ABC (artificial bee colony) and PSO (particle swarm optimization) approach are heuristic search methods [83]. These techniques are enlivened by the clever rummaging conduct of bumblebees in nature. It targets finding the ideal answer for a consistent smoothing out of the issue in an iterative manner.

5.2. Fault-Tolerance Issues in WSNs: A Concise Survey

As the day-by-day needs, requests, and prominence increment, the obligation is to make the sensor network more hearty and solid. These destinations lead to the improvement of a fault-tolerant WSN. Furthermore, WSNs are conveyed to distant check-in areas or segregated or perilous regions, requiring a profoundly solid fault-tolerant component [10, 13].

Fault tolerance is perhaps the essential affect boundary in WSNs. It ensures that the general framework stays to work effectively in any event when a few sections or segments come up short. There is a requirement for fault tolerance in light of sensors' eccentric attributes, radio correspondence, and distant/threatening conditions in which these organizations are conveyed.

As the need and prominence increment, the obligation to make the organization more dependable likewise increments. It led to the advancement of fault-tolerant WSN. For the most part, WSNs are utilized for observing or controlling a secluded or dangerous region, which needs a profoundly solid fault-tolerant framework. Weakness is a Latin word used to portray the framework's qualities, and segments could be handily influenced and destructed.

The essential central question of WSNs is that the primary outcomes of batteries depleting and deficiencies in energy are failure and trade inaccurate information among the sensors. Consequently, expanded fault-tolerance abilities in WSNs bring about broadened sensors' leftover lifetime. The sensor should endure failures and send the correct information to the base station because of necessity.

There are unique fault-tolerance central ideas. We present the various phrasings utilized and the various levels at which faults may occur in the WSN.

- A **fault** is any deserted or rowdy quality of a framework part that prompts a blunder.
- An **error** can be characterized as an inaccurate reaction state that may prompt a failure.
- A **failure** is an efficient deviation from legal help, which influences its expected usefulness.
- **Fault tolerance** is the capacity of a functional unit or framework to keep on playing out a necessary capacity within sight of faults or blunders.
- **Fault detection** comprises recognizing faulty usefulness in a framework without anyone else's determination or helpful analysis.
- **Fault recovery** is the recovery of actual usefulness after fault detection by fixing or supplanting the bombed part. In WSNs, some fault tolerance systems misuse repetition or replication to recuperate from faults.

A fault-tolerant framework will proceed with its administration even within sight of a fault. It is likewise ready to distinguish mistakes and recuperate the framework from failure. Consequently, a fault-tolerant framework has numerous prerequisites. Fault-tolerance mechanisms have been studied and discussed on a large scale in the field of wireless sensor networks [11]. Many researchers made their contributions to fault-related challenges associated with sensor failures, connectivity problems, network partitioning, and inaccuracy in data delivery, dynamic routing, and many others [59]. In another paper, [77] authors observed that a sensor network is prone to failure for two main reasons. First, a sensor may fail due to battery drain or other hazards. Second, it may also fail due to the breaking of the communication link between the sensors.

A failing sensor never knows in advance that it will fail, so the network itself is not capable enough to activate another optional sensor or replace it immediately. When an existing active sensor fails, an ideal fault-tolerance mechanism promises to immediately activate the available sensors to avoid coverage holes or hot spot problems in WSNs. Furthermore, such identified problems can be resolved with the dense deployment of sensors to generate the RoI's maximum number of redundant sensors.

The fault-tolerance mechanism ensures the delivery of essential services. It leads to high accuracy in sensing and aggregating sensed data by deployed sensors. Once sensors are deployed in the target region of interest (maybe hostile/harsh/remote location) and run out of power or damage, they are not easily replaceable and rechargeable. Therefore, the consistently fault-tolerant property of WSNs has become a discussion point for researchers over the decades. Fault (s) correspondingly belong to many reasons, such as energy depletion, hardware failures, communication link errors or network partitioning, software bugs, environmental hazards, etc., as discussed in the next section.

5.2.1. Classification of Failures and Fault Levels

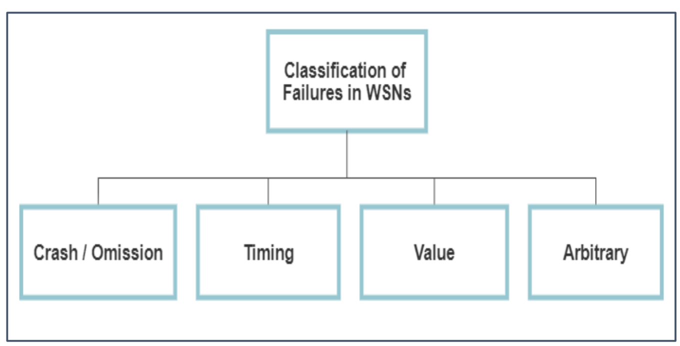

Figure 14 Classification of Levels of Failures in WSNs

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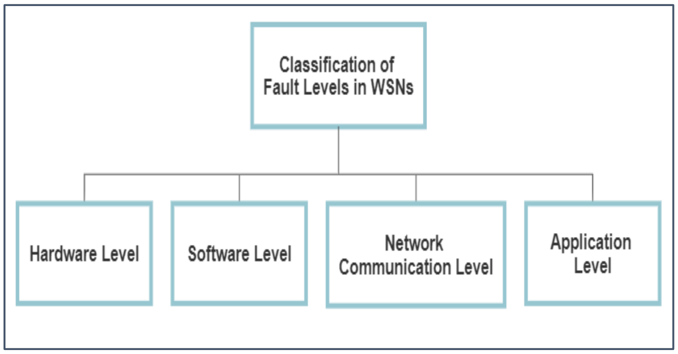

Figure 15 Classification of Levels of Faults in WSNs

1. **Crash/Omission:** In any event, if the service is not responding because of any actual harm or obstruction, at that point, a crash failure has happened.

2. **Timing:** This sort of failure is going on in a framework that is time-severe.

3. **Value:** An error in the created esteem is the justification for this sort of failure.

4. **Arbitrary:** All failures excluded from the over three classes are sorted as arbitrary failures (ex. Byzantine failure).

The level of faults was discussed in [12, 78]. Fault levels can fall mainly into five layers, viz., physical layer, hardware layer, system software layer, middleware layer, and application layer. More specifically, authors in [12, 78] classify faults into four levels in a WSN, such as hardware, software, network communication, and application-level faults, as shown in Figure 15.

1. **Hardware Level:** The component or chip-level failure of sensor nodes

2. **Software Level:** The system operating system and middleware.

3. **Network Communication Level:** Wireless network layer protocols and topology.

4. **Application Level:** The application-oriented protocols, mechanisms, techniques, firmware, etc.

The other two-level faults considered in [13] are as follows:

1. **Sensor Level:** Faults can appear in node components at either or both hardware or software levels.

2. **Sink level:** A fault in the sink node level will cause a disaster in the system.

The primary source of energy for the active sensor is only its limited battery capacity. After the RoI deployment, the sensor's battery is not easily rechargeable or replaceable, or, as we can say, almost impossible.

Some applications request a high degree of coverage quality and demand a long-lasting network lifetime. The sensor network's inevitable failure to deliver the promised degree of coverage results in minimizing or reducing the operational lifetime of the network.

These faults may be classified as per our considerations as follows: **One sensor failure** and **Multiple sensor failures**.

1. **One sensor failure** stated that only a single sensor failed from a set of active sensors that actively participated in providing full coverage for the RoI.

2. **Multiple sensor failures are** said to be more than one sensor may fail simultaneously for any reason in the RoI.

5.2.2. Classification of Fault-Tolerance Techniques

Fault tolerance is one of the critical and crucial issues in WSN's applications. Many researchers have proposed fault-tolerant mechanisms to extend overall network lifetime, reduce failure of components, and achieve higher data reliability, accuracy, and energy-saving.

The fault-tolerance capabilities of the network typically include redundancy and diversity mechanisms. The authors [82] describe the redundancy mechanisms that can be categorized into three main classes: temporal redundancy, information redundancy, and spatial redundancy. Primarily, redundancy is based on replication, which provides resilience against faults arising in the network [82]. A fault-tolerant method may not satisfy all of the criteria for a wireless sensor network (WSN). Different sorts of fault-tolerant techniques have been discovered in WSNs for various purposes. Some other essential criteria for designing fault-tolerance techniques are as follows (also shown in Figure 16) [10, 74, 78].

1. **Time criteria based**: This rule sorts the fault tolerance strategies according to the time at which they are applied. They are both preventative and curative**. Preventive**-As the name implies, this category encompasses all operations used to avert a failure by implementing a workaround for the bombed administration. It may be true both at the node and network level. **Remedial**-This category includes procedures that take effect only after an error is discovered in an organization's operation. They typically employ repeated tactics to attempt to re-establish the framework.

2. **Power/Energy management based**: The primary goal of this class is to increase a framework's energy efficiency, reduce energy fatigue, and minimize node failure to extend the network's lifetime. This can be done at the MAC or organizational level.

3. **Structure and Network costing based**: This criterion classifies networks according to their size and density. Due to the differences in their network structures, the strategies can be employed on a small or large scale. The

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cost of the mechanism may vary as a result of these criteria.

4. **Implementation methods based**: This standard is determined by the execution approach used for a fault tolerance mechanism, which may be redundancy-based, clustering-based, or deployment-based. Node disengagement or availability changes affect the organization's geography. A geography control component is critical for extending the organization's life.

5. **Fault and vulnerability of deployment fields based**: This classification is dependent on the location of the defect, such as link-based, node-based, or malfunction-nodes.

6. **Environmental and Location-based**: This rating is mainly utilized for RoI applications in distant locations or hazardous situations. Occasionally, these techniques are associated with security or reliability concerns.

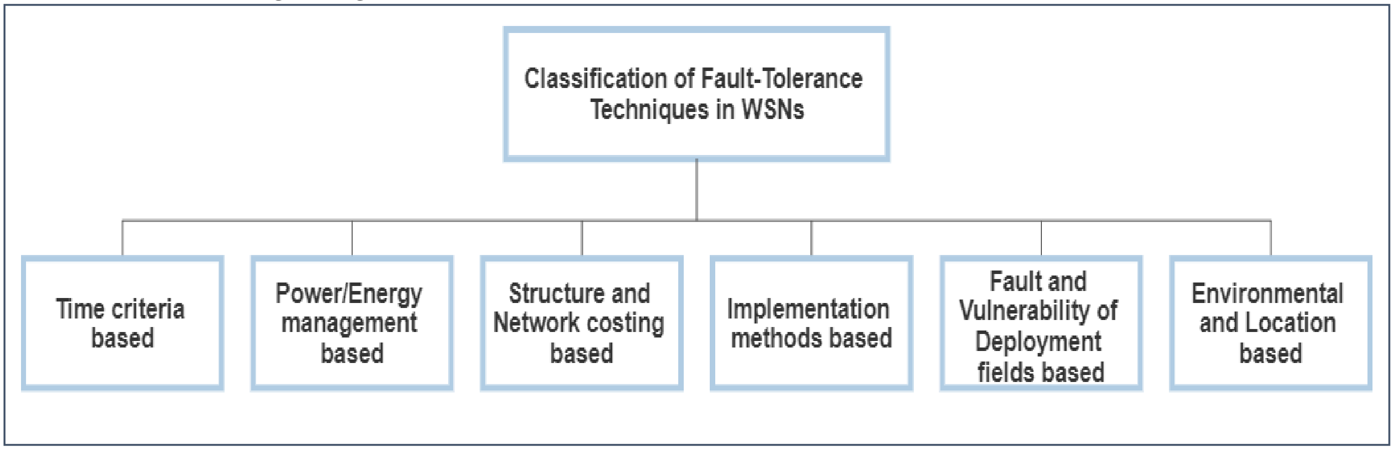

Figure 16 Classifications of Fault-Tolerance Techniques in WSNs

5.3. Availability of Simulation Tools for WSNs

A notable feature of WSNs is that simulation-based testing and approval are more manageable and less expensive. To research and answer this problem, we are going to employ a survey [81]. This survey is one of the most widely utilized and best-in-class simulation tools for WSNs. The point is to aid in analysts' selection of an appropriate simulation instrument suited for assessing work and achieving large-scale goals in the WSNs shown in Table 5.

Simulation Tools	Interface	Accessibility	Compatibility	Availability
NS-2/NS-3	C++/OTcl with limited visual support	Open source with Good user support	Excellent	Limited
OMNeT++	C++/NED with good GUI and debugging support	Free for academic use, license for commercial use with Good user support	Excellent	Large-scale
GloMoSim	Parsec (C-Based) with limited visual support	Open source with Poor user support	Good	Large-scale
OPNET	C or C++/Java with Excellent GUI and debugging support	Free for academic use, license for commercial use with Excellent user support	Excellent	Moderate
SENSE	C++ with good GUI support	Open source with Poor user support	Excellent	Large-scale
TOSSIM	C++/Python with good GUI support	Open source (BSD) with Excellent user support	Good	Large-scale
GTSNetS	C++ with good user interface	Open source with good user support	Excellent	Very Large scale

MATLAB	Java, C with good GUI support	Commercial license required	Excellent	Very Large scale
NetSim	Java, C with good GUI support	Commercial license required	Excellent	Very Large scale

Table 5 WSN Simulation Tools: A Comparison [81]

6. DISCUSSIONS AND ANALYSIS

The authors focus on the three most important concerns facing by WSNs. The added guarantee of Network Lifetime Coverage Quality (NLCQ) and better tracking and monitoring is combined with Energy Efficiency, Coverage Quality, and Fault-Tolerance Issues (ECFI) to guarantee and ensure the prolonging of the network lifetime coverage quality for better tracking and monitoring and uninterrupted services of self-configurable WSN. This analysis and survey essay addresses the multiple promising issues of numerous fundamental characteristics, design limits, and applications of WSNs with their impacts. The authors emphasize challenges with WSN energy depletion and provision as well as WSN coverage quality and fault-related issues. Many characteristics of WSN and a wide range of applications have been mentioned. When this point is reached, each part contains a tabular comparison of several possibilities.

At the top of the list for energy conservation and lengthening the lifetime of the network are duty-cycle, clustering, and sensor scheduling. However, the overwhelming bulk of recent activities are focused on preservation-centered, rigorous energy use. Energy-proficient plans for sensor equipment, programming, calculations, and protocols have served effectively. On the other hand, they decide to give up once they have used up all the batteries linked together. This study report may have found that WSN has affected nearly every sector of cutting-edge technology. It is not an enormous realm of focus when it comes to human existence. Additional concerns about WSNs are also featured concerning the WSNs' planning constraints. Environmental conditions such as equipment needs, climatic molding, restricted practical limits, power costs, network difficulties, and microscopic working framework programming are only a few variables considered when implementing project requirements. The requirements applied to WSNs in the various application proposals include scalability, coverage, robustness, security, mobility, and latency.

The authors finally summarize a brief analysis and survey article by discussing the main findings and observations, including various characteristics and influencing parameters, as the article's title Energy, Coverage, and Fault Issues and their Impacts on Applications of Wireless Sensor Networks through tables as follows:

- ✓ In Table 1, we discuss the sensor categories and ECFI impacts on them in WSNs.
- ✓ In Table 2, we summarize the concise classification of applications and the impacts of various parameters of WSNs.
- ✓ In Table 3, we discuss the various characteristics and ECFI impacts on them in WSNs.
- ✓ In Table 4, we review the different power consumption rates of various types of available sensors in WSNs.
- ✓ In Table 5, we review the availability of different simulator tools and make a concise comparison between them.

"Finally, as wireless sensor networks are still a youthful exploration field, the significant movement continues to understand many outstanding problems and forthcoming challenges".

7. CONCLUSION AND FUTURE RESEARCH DIRECTION

7.1. Conclusion

This article discussed many features of WSNs with simplicity and clarity. The introduction briefly explains the WSN architecture and the various difficulties connected to power, coverage, and faults. In living and non-living objects, such as human life, everyday requirements, and other fields, WSNs have been proven to be quite prevalent. The WSN survey article describes the architecture, characteristics, design limits, and energy depletion/consumption difficulties, followed by coverage and fault issues. This article discusses the wireless sensor network influencing parameters and applications that focus primarily on changing the overall operation of WSNs.

7.2. Future Research Direction

Energy, Coverage, and Fault are three critical issues in wireless sensor networks. They are responsible for providing an uninterruptible and long-lasting service. This proposed survey article is based on the primarily two-dimensional based architecture and scenarios of WSNs (2D-WSNs). Various researchers have proposed many algorithms and mechanisms for 2D-based WSNs to be energy-efficient, coverage-quality, and fault-tolerant.

As for future research remarks, the authors suggest that the survey should be extended to include 3D and future-technology-based WSNs. Future research will also cover three crucial issues: energy, coverage, and fault issues in 3D-WSNs. This work may help in a new way to research

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sustainable WSNs by maximizing total network lifetime. The best utilization of methodologies and tools will assist both the enhancement of existing applications and the development of new dimensions of future technology, such as 3D-based applications of WSNs.

Some future remarks are discussed below: energy-efficient protocols, network lifetime maximization methods, localization issues, data aggregation, coverage, QoS optimizations, and routing issues with modern WSNs. This research, the main aim is to raise researchers' awareness of all the new trends and types of algorithms used in the methodology to maintain their efficiency. Nonetheless, most concerns remain unfixed and require significant additional study to create resource-constraint and lightweight models that will improve the WSN and IoT's intelligence and reliability.

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