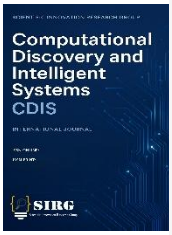

Computational Discovery and Intelligent Systems
CDIS
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Journal Homepage
https://pub.scientificirg.com/index.php/CDIS/index

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Evolution of Routing Protocols in Wireless Sensor Networks Considering Challenges Advances and Drone-Assisted Innovations

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ABSTRACT - Wireless Sensor Networks have been utilized in a variety of fields, including environmental monitoring, agriculture, and disaster management. In view of the limited energy resources of WSNs, energy-efficient routing can significantly help in enhancing the WSN performance regarding energy conservation, reliability, and scalability. This survey explains appealing features of WSNs, addressing routing protocols along their usage constraints and performance expectations, considering first the traditional ones, and then the drone-based methods that are seen as a novel solution for many of the weaknesses of current practices, especially in wide and remote areas. Drones, or Unmanned Aerial Vehicles (UAVs), overcome challenges such as gaps in coverage, energy restrictions, and network growth by offering mobility and adjustability. Drones function as effective mobile data gathering and transmission devices, improving the network performance in a dynamic and massive environment. This survey investigates recent advances in WSN routing protocols, presents emergent problems including energy preservation, delay, and safety issues, and explains how the integration of drones solved most of these problems. Finally, the study presents future trends and the residual challenges for drone-based routing, from different routing features, connectivity, energy efficiency, control of the topology, and security.

PAPER INFORMATION

HISTORY
Received: 25 August 2025
Revised: 18 November 2025
Accepted: 30 January 2026
Online: 4 February 2026

MSC
62K05
62K15

KEYWORDS
Wireless Sensor Networks,
Routing Protocol,
Drone based routing,
Unmanned Aerial Vehicles (UAVs).

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1. Introduction

Wireless Sensor Networks comprise small, low-cost, lightweight, and low-power sensor nodes that are usually deployed in an isolated area where laying wires is difficult. The sensor nodes are deployed with the aim of monitoring different environments or activities through the discovery of various changes in a particular environment or activity, such as temperature, humidity, pressure, and movement. The sensor nodes collect this data and then forward it to a Base Station (BS) for further analysis and processing [1]. WSNs are very useful in data collection in areas that are difficult to access or monitor. The small size, low cost, and ability to cover a wide area make sensor nodes useful in slow and accurate monitoring [2]. However, sensor nodes are also characterized by a lack of power, making them very important in WSN design. WSNs are used in various activities. In environmental monitoring, WSNs are used to monitor climate change, air and water quality, or to monitor various natural resources such as forests and rivers [3].

In the agricultural sector, WSNs help farmers to monitor soil moisture, crop status, and weather. In the military field, WSNs are used in the detection or tracking of movement, area coverage, or threat detection, which includes chemical and biological threats. In the smart cities field, WSNs are used in monitoring the safety of infrastructure, which includes roads, bridges, or pipelines. In the industrial field, WSNs are used in the monitoring of equipment to prevent failures, which may cause delays in production. However, there are several challenges associated with WSNs, which include energy constraints, network reliability, and management of large-scale WSNs. The use of routing protocols assists in addressing the challenges associated with WSNs. Routing protocols assist in developing a strategy for routing the information from the sensor nodes to the base station. The use of a suitable routing protocol assists in saving energy, utilizing resources of the network, and increasing the lifetime of the network, which is the main aim of this work [4].

However, the existing routing protocols are not that efficient in meeting the demands of the current network environments for several reasons. The first reason is the problem of scalability: there may be hundreds, thousands, or even more sensor nodes in the sensing area; the conventional routing protocols cannot support such a huge number of sensor nodes. Deficiency in Real-Time Adaptability: Most of the existing protocols use static or periodically updated information and do not support real-time adaptability. Security issues: Most of the conventional routing protocols have been developed without proper security considerations, making the protocols susceptible to security threats such as route spoofing, blackhole attack, denial of service (DoS), etc.

High Energy Consumption: The nodes are kept in a state where they operate using a small amount of battery; they can exhaust their battery life by transmitting data in a wireless environment. Coverage Area: Each sensor node in a WSN has its own viewpoint of the surrounding area. Only a specific physical region of the environment can be covered by a given sensor, which limits its precision and range of view. To enhance the coverage area, we will add more nodes, which will increase the total cost. Limited Support for QoS: Traditional protocols like RIP, OSPF, and BGP lack sufficient mechanisms to prioritize traffic based on service quality, latency, or bandwidth requirements.

Another possible solution is the integration of drones and WSNs. Drones, or Unmanned Aerial Vehicles (UAVs), can be integrated with WSNs to provide mobility and flexibility to static WSNs, in which nodes are static and do not move. One major advantage that can be obtained through the integration of drones and WSNs is that drones can be used as mobile data collectors. Instead of nodes using their energy to transmit their data over long distances, drones can be used to move over the nodes and collect their data, thus increasing the lifetime of the network and reducing the amount of energy used. The drones can then transmit the collected data to a central station, reducing the load on the network. Drones can be used to improve the coverage of WSNs [4].

In areas where static nodes cannot be used to cover the whole area due to their size, drones can be used to move to specific locations and collect data. In addition, drones can work in flexible environments. For instance, if there are changes in the network topology, such as after a natural disaster, drones can modify their routing paths to obtain information from new sensor positions or to substitute damaged communication channels. This flexibility makes drones essential for improving the flexibility of WSNs [5].

Drones can also be used to obtain real-time information, which is essential for real-time applications such as disaster response, military operations, and agricultural monitoring. This is achieved through a fast response to changing events. In addition, drones can minimize data collection time by transmitting information directly to sensor nodes, eliminating multi-hop communication. This is essential for applications that require fast access to information, such as industrial monitoring, agricultural monitoring, and disaster response. The main objective of this research is to survey different routing protocols designed for WSNs, with a focus on their strengths, weaknesses, and optimization techniques. The survey also discusses drone routing protocols and their major improvements to WSN performance.

2. LITERATURE REVIEW

It is widely acknowledged that a considerable amount of research has been done in routing strategies within WSNs, and many protocols have been put forward to solve energy usage, scalability, and reliability concerns. This part of the analysis discusses particularly interesting works and focuses on routing techniques such as single-hop, multi-hop, and finally, using drones as mobile sinks. In small networks where energy requirements are not too great, single-hop routing is the most suitable because direct communication between the nodes and the base station is possible. For example, Direct Transmission Protocol (DTP) [5] is a routing strategy that tends to be efficient but may not scale up well for larger network communications.

Multihop routing techniques such as Low Energy Adaptive Clustering Hierarchy (LEACH) [6] and Ad Hoc On-Demand Distance Vector (AODV) [7], on the other hand, use extra nodes to expand the communication limit. Moreover, although such multi-hop routing mechanisms are effective for large networks, they introduce other problems, such as increased energy consumption and higher latency and delays of information feedback. By harvesting small area networks with a large amount of generated traffic, clustering protocols such as LEACH and Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN) [8] help conserve energy further since the node batteries last longer. These kinds of approaches do help to optimize the energy spent throughout the entire system, but may have some limitations, especially in cases where the space is mobile or there is uneven data generation.

To overcome the limitations caused by static base stations, mobile sinks have been proposed to traverse across the area of interest while collecting data from various sensor nodes. Some techniques, for instance Mobile Sink-Based Energy Efficient Clustering Algorithm (MSBECA) [9] shows great improvements in energy consumption and data reliability. However, mobility introduces new challenges, such as determining optimal sink paths and ensuring timely data collection. Drone-based routing can solve most of the problems; for instance, drones can economize on flying over sensor nodes to save energy and lengthen the lifespan of a network. Research like Energy-Efficient Data Collection with Drones (EEDCD) [10] makes it clear that drones are very helpful to beat barriers in routing that include limited geometrical coverage or congestion on the network.

Although the development in routing protocols, challenges remain in optimizing the integration between static and mobile routing techniques. Existing routing protocols usually fail to completely exploit the advantages of drones, such as their capability to adapt to environmental changes or dynamically collect data from critical nodes. Additionally, issues such as real-time processing, energy conservation for drones, and multi-drone coordination in large-scale networks are underexplored areas that require further attention.

This survey's primary objective is to rely on the existing work by introducing an analysis of routing protocols, emphasizing the role of drone-based routing in addressing the weakness of traditional methods, and proposing future directions for more efficient and scalable WSN deployments.

2.1 The Pros and Cons of WSNs

- **Flexibility:** Wireless sensor networks possess greater flexibility when compared with their wired counterparts, as the requirement for connecting individual sensors and the central controlling system is eliminated. Such a feature makes the installation and deployment processes easier and more flexible in terms of the placement of the sensors.
- **Cost-effectiveness:** Wireless sensor networks prove to be more cost-effective when compared with their wired counterparts, mainly because the infrastructure and the cables required may lead to increased costs.
- **Scalability:** Wireless sensor networks possess greater scalability when compared with their wired counterparts, as the size of the network can be easily extended according to the requirements. Such a feature makes the sensor networks more suitable for applications that require a larger number of sensors.
- **Reliability:** Wireless sensor networks can be made more reliable by providing redundant paths for communication and using error correction methods. Such features increase the precision and reliability of the data being sent.

2.2 The challenges of WSNs are

- **Energy Efficiency:** Due to the restrictions placed on the battery that powers the nodes, energy efficiency is one of the most challenges in WSNs. In this regard, energy management techniques include duty cycling (turning nodes on and off), energy harvesting (using, for example, solar energy), and energy-efficient routing strategies such as cluster-based routing in which sensor nodes are organized into clusters, only some nodes, typically called cluster head relay messages to the base station to reduce the energy used in direct transmission. Another important aspect is optimizing hardware components to have low active power.
- **Scalability:** It is evident that with the addition of many nodes in a WSN, the network must accommodate this increase without degradation of performance. Scalability problems can, however, lead to more communication overhead and latency. To mitigate so much difficulty in a very large network, the nodes can be arranged into clusters, and the communication is organized in such a way as to reduce overhead and ensure efficient communication. It is also important to prevent deterioration of performance as the network grows by implementing adaptive routing that changes as per the size and conditions of the network.
- **Dynamic Network Topology:** In WSNs, the network topology is prone to frequent changes caused by the movement of nodes or depletion of energy resources. This requires the network to adapt quickly to these

changes. The routing protocol used in these scenarios must adapt to changes without significant performance losses.

- **Heterogeneity of WSN Nodes:** It is observable that nodes of different WSNs have varied levels of performance attributed to the differences in battery life, processing capacity, or even communication range. Such differences may in some cases create a misbalance in the whole network's performance. The routing protocol must consider the capabilities of each node. For instance, when more data needs to be processed, more capable nodes may be given the tasks, or they may be appointed as the cluster head so that the load of the network is maintained.
- **Quality of Services (QoS):** Different applications of WSN have their own criteria about their goals, such as speeding up the data, increasing throughput, or enhancing the transmission accuracy. It is rather difficult to satisfy these QoS specifications because of various limitations imposed by environmental factors. The routing protocols designed for this purpose improve QoS by shifting the emphasis to the critical data and ensuring its speedy delivery and reliable destination. Multi-path routing is also mentioned as a method that can enhance the delivery of data by making multiple paths for data to reach its destination.
- **Fault Tolerance:** In WSNs, nodes or links may fail due to energy depletion or other environmental effects. Fault tolerance is necessary to ensure that the WSN continues to operate. Redundancy of paths or self-healing of networks can be used to route the data in case of failure.
- **Security and Privacy:** WSNs are vulnerable to various security attacks, including interference attacks and data interception. The wireless nature of WSNs makes them vulnerable to security attacks. Lightweight security protocols or secure routing protocols can be used to improve the security of WSNs.
- **Geographic Awareness:** Geographic information can be used to improve the performance of WSNs. Geographic routing protocols can be used to improve the performance of WSNs. Obtaining accurate location information is difficult for WSNs due to the lack of GPS.
- **Interference and Collisions:** Interference and collisions are major issues in wireless communication. Interference occurs when two or more devices use the same channel for communication. Interference should be managed to improve the performance of WSNs. Interference management techniques include using dynamic channel allocation, frequency hopping, or power control. In WSNs, scheduling algorithms or collision avoidance protocols can be used to manage the transmission of data.
- **Data Delivery Models:** Various WSN applications demand different data delivery models like continuous, event-driven, and query-driven. To optimize data delivery, adaptive data management techniques that dynamically change the data collection and transmission approach according to the application needs can be used. In-network processing and decision-making can also minimize the need for continuous data transmission, thus conserving energy and bandwidth.
- **Limited Bandwidth:** WSNs usually function in environments where bandwidth is limited, causing congestion and packet loss. Bandwidth management methods like data compression, data aggregation, and prioritization of important data can be used to optimize bandwidth utilization. Execution of congestion control algorithms and scheduling mechanisms can also manage data transmission effectively.
- **Latency Management:** Data transmission with minimal latency is required for real-time applications. To manage latency, data prioritization based on time-criticality, effective scheduling, and in-network processing can minimize latency. Predictive models that forecast network congestion and dynamically change transmission rates can also minimize latency.

As mentioned above, Routing can be used in WSNs to overcome various challenges and improve their overall efficiency, reliability, and performance.

3. CLASSIFICATION OF ROUTING PROTOCOLS IN WSNS

Routing involves identifying an appropriate pathway from a source node to a base station, and it encompasses the communication and data transmission processes among various nodes. There are two primary types of routing (single hop & multi-hop). [11]

Single-hop routing represents a direct communication framework in which data is sent straight from the source node to the base station. This method relies on a simple point-to-point communication model, necessitating that every node keep a direct connection with the destination node. Single-hop routing is typically employed in situations where the distance between nodes is minimal.

3.1 Single-hop advantages

- **Low Latency:** Single-hop networks demonstrate minimal latency due to the direct transmission of data between the source and the destination. The absence of intermediary relays or additional hops eliminates potential delays.

- **Simplicity:** The straightforward nature of single-hop networks facilitates their design, deployment, and management. Due to a clear point-to-point communication framework, the processes of network configuration and troubleshooting are rendered considerably simpler.
- **Energy Efficiency:** For Short Distances: Single-hop networks typically exhibit lower energy consumption than multi-hop networks due to the direct transmission of data without the involvement of intermediate nodes. This characteristic is especially beneficial for devices reliant on battery power, as it extends their operational lifespan.
- **Lower Complexity:** The network topology is simpler with single-hop communication, as there are no intermediate nodes or complex routing paths.

3.2 Single-hop limitations

- **Scalability:** As the quantity of nodes expands, the intricacy of sustaining direct communication pathways escalates significantly. The process of scaling single-hop networks to support a substantial number of nodes presents considerable challenges and often necessitates substantial investments in infrastructure.
- **Limited range:** In a single-hop network, each sensor node is restricted to direct communication with the sink only if it falls within its transmission range. This constraint restricts the overall coverage area of the network and may require an increased density of nodes to adequately cover a larger geographical region.
- **Single Point of Failure:** In a single-hop network configuration, the failure or inaccessibility of the sink node results in a complete loss of the network's data collection functionality. This architecture lacks redundancy or alternative pathways for the transmission of data.

3.3 Scenarios Best Suited for Single Hop

- Small Networks: Single-hop communication is particularly effective in small networks that have a limited number of nodes or devices. In these configurations, each node is capable of directly interacting with a central hub or base station, eliminating the necessity for intermediary devices to transmit messages. This approach simplifies the network architecture by obviating the need for complex routing protocols, thereby enhancing communication speed and efficiency with minimal latency. Additionally, maintenance becomes more straightforward due to the reduced number of devices requiring oversight, resulting in lower overhead associated with managing routing pathways. A pertinent illustration of this concept can be found in a smart home network, where devices such as temperature and motion sensors relay information directly to a central controller.
- **Short-Range Communication:** Single-hop communication is particularly suited for scenarios involving short-range interactions between nearby devices. Given the minimal distance, these devices can operate at lower power levels for direct exchanges, thereby conserving energy and prolonging battery longevity. This proximity facilitates rapid and dependable data transmission, minimizing the likelihood of loss or degradation. Furthermore, the limited range enables higher data transfer rates and the implementation of more straightforward protocols, as the potential for interference or data loss is significantly reduced. A pertinent illustration of this is the Bluetooth connection established between a smartphone and wireless headphones situated within the same room.
- **Low Power Devices:** For low-power devices that have limited battery life, single-hop communication is highly suitable. It reduces energy consumption because devices only need to send data over a short distance directly to the receiver without relaying through multiple nodes. This simplicity also reduces the need for complex processing and extends the overall battery life of the devices. Low-power devices, like fitness trackers or health monitors, benefit from this setup as they can send data directly to a paired smartphone or central hub, preserving battery life.
- **Static Networks:** Static networks, characterized by immobile devices or nodes, are particularly advantageous for single-hop communication. The fixed locations of all nodes eliminate the necessity for dynamic routing or regular updates to network pathways, thereby streamlining network management. The stability and reliability of communication are enhanced due to the unchanging connections, and the setup process is uncomplicated, avoiding the need for intricate configurations. A pertinent example of this is a greenhouse monitoring system, where sensors that track temperature, humidity, and other environmental factors are stationed in fixed locations and communicate directly with a central controller.
- **Simple Sensor Networks:** Single-hop communication is ideally suited for straightforward sensor networks, where the main objective is to collect data from various sensors and relay it to a central hub. In these configurations, intricate routing mechanisms are unnecessary, as each sensor can directly communicate with the central base station. This simplicity not only lowers costs by eliminating the need for sophisticated hardware but also enhances the network's reliability and ease of maintenance. A pertinent example of this is a

fundamental weather station arrangement, in which sensors measuring temperature, humidity, and precipitation transmit their data directly to a central base station.

- **Emergency or Critical Communication:** In emergency or critical communication scenarios, Single-hop communication plays a pivotal role in facilitating rapid and dependable data transmission. This direct mode of communication guarantees that messages are conveyed without latency, an essential factor during emergencies. The likelihood of failure is significantly reduced, as data transmission does not traverse numerous intermediary points. The straightforward nature of this method enables swifter responses and enhanced oversight of the communication process. For instance, in a search and rescue scenario, a distress signal transmitter can establish direct contact with a rescue team, ensuring an immediate reaction without the delays associated with multiple relays.

3.4 Scenarios Best Suited for Multi-Hop

- **Large Networks:** Multi-hop communication is particularly advantageous in extensive networks characterized by a wide spatial distribution of nodes. In such configurations, the direct transmission of data from all nodes to a central hub is often impeded by both distance and energy constraints. Consequently, nodes transmit their data to adjacent nodes, which subsequently relay the information until it arrives at the intended destination. This method not only conserves energy but also facilitates communication across greater distances without the necessity for robust signal strength. A pertinent illustration of this concept can be observed in a large agricultural setting, where soil sensors relay data through proximate sensors to a distant base station.
- **Energy Efficiency in Sparse Networks:** In networks characterized by a limited number of nodes that are widely dispersed, multi-hop communication serves as an effective means of conserving energy. Direct transmission of data over extensive distances by each node would result in significant power consumption, leading to rapid battery depletion. Conversely, by relaying data through adjacent nodes, energy expenditure is minimized. This approach is particularly crucial for devices reliant on battery power. A pertinent illustration of this concept can be found in a network designed to monitor wildlife within a vast forest, where each sensor transmits data to its neighboring sensor until the information reaches a central aggregation point.
- **Dynamic or Mobile Networks:** Multi-hop communication works well in networks where nodes are moving or the network changes often. In these networks, routes need to change frequently to keep connections. Multi-hop systems can quickly find new routes by sending data through other nodes, keeping communication stable even when nodes move or drop out. An example is a network of cars sharing traffic information, where vehicles continuously move and need to relay data to each other.
- **Dense Networks with High Data Traffic:** In networks with many close nodes and a lot of data traffic, multi-hop communication helps manage congestion and balance the load. It spreads data across different paths, preventing any single path from getting overloaded. This keeps the network reliable and reduces data loss. An example is a smart city with many devices like smart meters and sensors, where data needs to reach a central server without overwhelming the network.
- **Networks with Obstacles or Difficult Terrain:** Multi-hop communication proves advantageous in environments characterized by obstacles or challenging terrains that impede direct communication between nodes. By employing multi-hop pathways, data can circumvent these barriers, thereby facilitating dependable connections. This approach is particularly beneficial in rugged landscapes, densely populated urban settings with high-rise structures, or within buildings that contain numerous walls. A pertinent illustration of this is found in building automation systems, where sensors distributed across various rooms or levels relay information through intermediary sensors to connect with a central controller.
- **Reliable and Fault-Tolerant Communication:** Multi-hop networks provide a robust framework for reliable and fault-tolerant communication by facilitating multiple pathways for data transmission. If one pathway becomes inoperative, the network can swiftly reroute the data through an alternative path. This capability ensures the continued operation of the network, even in scenarios where certain nodes may fail. A pertinent illustration of this is found in industrial monitoring systems, where sensors need to maintain data transmission despite the potential failure or disconnection of some sensors.

3.5 Multi-Hop Advantages:

- **Extended Range:** Multi-hop networks address the range constraints inherent in single-hop networks by facilitating the transmission of data through several intermediary nodes. This capability permits communication over extended distances, rendering it appropriate for extensive networks and regions characterized by physical barriers.
- **Increased Reliability:** Multi-hop networks improve reliability through the creation of redundant pathways for data transmission. In the event of a relay node failure or disruption of a communication link, alternative routes can be employed to sustain connectivity, thereby enhancing the overall resilience of the network.

- **Scalability:** Multi-hop networks demonstrate enhanced scalability in comparison to single-hop networks. The incorporation of relay nodes allows for an increase in network capacity while maintaining minimal effects on the complexity of individual nodes and the requirements for direct communication range.

3.6 Multi-hop challenges

- **Higher Latency:** Compared to single-hop networks, multi-hop networks have higher latency because of the hop-by-hop data transmission procedure. Each intermediate relay node contributes to a delay, which may adversely affect real-time applications that are particularly sensitive to latency, including video streaming and online gaming.
- **Increased Energy Consumption:** The presence of numerous relay nodes in multi-hop networks results in higher energy consumption when compared with single-hop networks. This increased energy demand arises from the necessity for relays to utilize additional power for functions such as signal amplification, routing, and data processing, posing potential challenges for devices reliant on battery power.
- **Increase the network overhead**: Multi-hop communication requires the implementation of complex routing protocols to identify the most efficient pathways for data transfer. This complexity contributes to increasing overhead related to both processing and communication.
- Complexity in network management: The management and maintenance of multi-hop networks present increased complexity, primarily due to the requirements for dynamic routing, path selection, and inter-node coordination.

4. ROUTING PROTOCOLS IN WSNS

Routing protocols are classified into three categories, as shown in **Figure 1**: network structure-based routing, function-based routing, and transmission mode routing. [12]

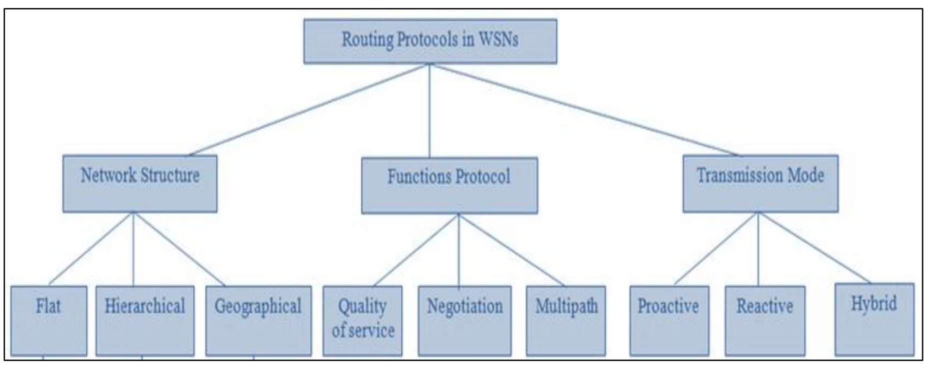

Figure 1: classification of routing protocols

4.1 Network structure-based routing

4.1.1 Flat routing

It is also called a peer-based routing protocol. It regards all sensor nodes uniformly and facilitates direct communication among the nodes or with the base station [13]. Each node possesses identical characteristics and functionalities, typically assuming the same role, while the sensor nodes work collaboratively to execute the sensing operations.

Flooding: The flooding mechanism operates independently of the network topology or any routing algorithms. In this process, each sensor receives a packet of data and subsequently transmits it to all adjacent (neighbor) nodes. The broadcasting continues until the packet reaches its intended destination or the maximum number of hops is achieved, at which point the broadcasting ceases [14].

There are four operations:

1. **Packet Reception:** After a packet is received, the node initially verifies if it is the designated recipient. If so, the packet will be processed by the node; if not, it will move on to the subsequent step.
2. **Duplicate Check:** To avoid looping and redundant transmissions, nodes keep a record of recently received packets (or their identifiers) and verify whether the current packet has already been processed. If it has been processed, the packet is discarded.
3. **Forwarding:** If the packet has not been previously received, the node transmits it to all its neighboring nodes, excluding its source.

4. **Termination:** The procedure persists until the packet arrives at its intended destination or is discarded according to a predetermined criterion (e.g., maximum hop count or TTL - Time to Live).

- **Advantages of Flooding Routing Protocol:**

a. **Simplicity and Ease of Implementation** [15]**:** The straightforward nature of the protocol facilitates its implementation and integration across diverse network environments, eliminating the need for complicated routing algorithms.

b. **Guaranteed Delivery:** Flooding provides a high level of reliability for packet delivery.

c. **No Need for Route Discovery:** Every node transmits the packet, eliminating the necessity for route discovery or the upkeep of routing tables.

- **Disadvantages of Flooding Routing Protocol:**

High redundancy, excessive overhead, and inefficiency characterize sparse networks, and in networks characterized by low node density or high mobility, flooding may prove to be inefficient because the probability of nodes being within communication range is diminished.

4.1.2 Sensor Protocols for Information via Negotiation (SPIN)

The system distributes all information from each node to every other node within the network, operating under the assumption that all nodes may serve as potential base stations. Before transmission, metadata, which consists of the collected data, is exchanged among sensors through a data advertisement mechanism, a fundamental characteristic of SPIN.

Each node, upon acquiring new data, disseminates it to its neighboring nodes. Neighbors that do not possess the data, referred to as interested neighbors, can obtain the information by sending a request message. This process ensures that redundant data is not transmitted across the network. A sensor node engages in negotiations through the utilization of its metadata.

This process involves the exchange of a new data advertisement message (ADV) and a data request message (REQ) between the sender and the receiver. Following the negotiation, the sender proceeds to transmit its data to the receiver (DATA) [16]. **Figure 2** displays the SPIN architecture.

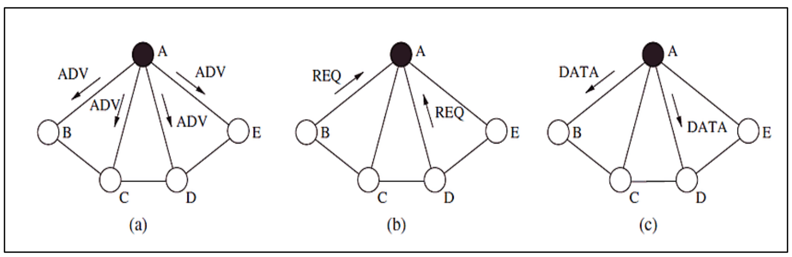

Figure 2. SPIN protocol

- **Advantages of SPIN protocol: Reduced Redundancy:** Through the implementation of negotiation and advertising techniques, SPIN minimizes unnecessary data transmissions.
- **Efficient Energy Usage:** SPIN contributes to energy conservation by eliminating unnecessary communication [17].
- **Improved Data Delivery:** The negotiation-based method guarantees that data is provided solely to those nodes that have made a request, thereby enhancing the relevance of the data received.
- **Scalability:** SPIN demonstrates superior scalability compared to basic flooding by minimizing network traffic and preventing the network from being inundated with duplicate messages.
- **Disadvantages of SPIN:** Overhead of Control Messages; The advertisement and request messages introduce supplementary control overhead.
- **Increased Latency:** The negotiation process may result in slower data transmission when compared to simpler protocols.
- **Complexity:** The negotiation-based approach introduces a greater level of complexity to the protocol when contrasted with more straightforward methods such as flooding.

4.1.3 Directed Diffusion (DD)

The framework presupposes that all data produced by sensor nodes is identified through attribute-value pairs, enabling queries to be directed at the sensors based on demand, utilizing these pairs. It employs an attribute-value pair schema for conducting data queries. A list of attribute-value pairs, such as objects, intervals, durations, geographical areas, etc., is used to specify an interest in creating a query. The interest is broadcast by a sink through its neighbors. After acknowledging the interest, each sensor creates a gradient that points in the direction of the sensor nodes that sent it [18]. The primary objective of the data distribution (DD) system is to integrate information from various sources during transmission (in-network aggregation) by reducing redundancy and decreasing the frequency of data transmissions. This approach not only conserves network energy but also extends the overall lifetime of the network.

Direct Diffusion operation as shown in **Figure 3**, (a) Interest propagation, (b) Initial gradients set up, (c) Data delivery.

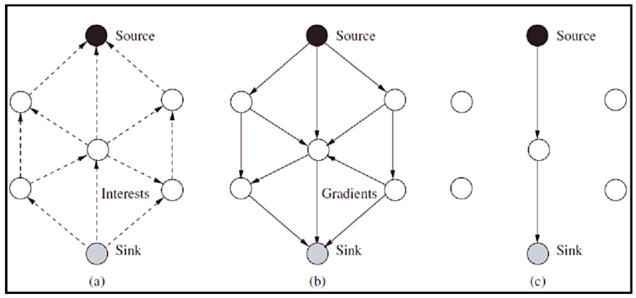

Figure 3: direct diffusion operations

- **Advantages of direct diffusion: Data-Centric Routing:**
  Emphasizes the substance of the data instead of nodes, thereby enhancing adaptability and significance in the distribution of information [19].
- **Scalability:**
  This technology is well-suited for extensive networks because it can handle data and queries by focusing on content rather than relying on node addresses.
- **Dynamic Adaptation:**
  Adjusts to variations in data needs and network circumstances by dynamically modifying interest and data pathways. Energy Efficiency: Energy efficiency can be achieved by minimizing the volume of the transmitted data and emphasizing the aggregation of the data, thereby aiding in the conservation of node energy.
- **Disadvantages of direct diffusion: Overhead in Path Establishment**
  The establishment and maintenance of interest paths may incur additional overhead, especially in extensive or rapidly changing networks.
- **Complexity in Aggregation**
  The incorporation of data aggregation at intermediate nodes introduces additional complexity to the protocol. It is essential to implement efficient aggregation mechanisms to guarantee that data is merged effectively while minimizing any potential delays [20].

4.1.4 Rumor Routing (RR)

The Rumor Routing goal is to establish pathways that connect to each event, allowing any generated query to traverse these paths through a random walk until it identifies the corresponding event path, instead of disseminating the query across the entire network. The rumor routing algorithm employs a collection of persistent agents that construct directed paths toward the events they face.

When an agent encounters a route that leads to an unfamiliar event, it modifies its behavior, resulting in a path state that connects to both events. Additionally, when agents discover shorter routes, they enhance the network's efficiency by revising the routing tables to incorporate the more optimal paths [21] as shown in **Figure 4**. Each node is responsible for keeping a record of its neighboring nodes as well as an events table. Upon encountering an event, it incorporates this event into its events table. The agent possesses a finite lifespan, measured in a specific number of hops, after which it ceases to function. The Rumor Routing (RR) approach may prove effective for disseminating queries related to events within extensive networks.

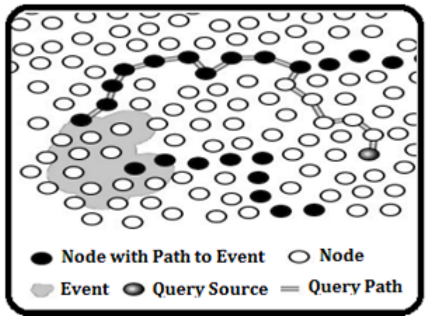

Figure 4. query path

- **Advantages of Rumor Routing: Energy Efficiency**
  Minimized energy usage by preventing widespread network flooding. Scalability: The protocol works well in large-scale networks due to its localized query and event propagation.
- **Low Communication Overhead:**
  Nodes that are engaged in the generation of events or the submission of query requests are the sole participants in the routing process, causing the number of transmissions to be reduced.
- **Disadvantages of Rumor Routing: Latency**:
  The duration required for a query to reach an event trail may exceed that of flooding-based protocols.
- **Reliability:**
  If the network is too sparse or the number of events is high, the protocol's performance can degrade, as queries may miss the event trails [22].

4.1.5 Location-Based Routing

Also known as geographical routing**,** it depends on the physical positions of nodes within a network. Nodes employ GPS or alternative localization methods to ascertain their locations and make routing decisions [23]. **GPS (Global Positioning System)** is a commonly used technology for obtaining these coordinates. However, its usage in WSNs has significant limitations due to various constraints associated with technology.

- **Limitations of GPS Usage in Location-Based Routing:**

1- **High energy consumption**
  a. GPS receivers use a lot of energy to continuously find the location of a node.
  b. Wireless sensor nodes are typically battery-powered with limited energy resources, and frequent GPS use can rapidly drain their power.

2- **High cost**
  a. Each node in the WSN would require a GPS module, which increases the network deployment cost.
  b. Cost concerns are especially critical in low-cost applications such as environmental monitoring or agriculture.

3- **Scalability Concerns**

In large-scale WSN deployments, using GPS for every node increases Network complexity**.**

4.1.6 Geographic Adaptive Fidelity (GAF)

The adaptive fidelity algorithm involves the deployment of numerous sensor nodes within a designated observation area, where only a select few nodes are activated to transmit data, while the remaining nodes enter a low-power sleep mode. This process is structured into three distinct phases. Initially, the algorithm determines the direction of communication, which can be visualized as a grid layout. Subsequently, any active node asserts its role in the routing process, requiring no extra energy for path identification. In the final phase, the packets are forwarded to the intended destination [24].

- **Advantages of GAF:** Energy Efficiency: By turning off redundant nodes, GAF significantly reduces energy consumption, thereby increasing the lifetime of the network [25]. Scalability: The grid-based architecture of GAF enables effective scaling within extensive, densely populated networks, facilitating a reduction in the number of active nodes. Robustness: GAF demonstrates resilience to node failures and mobility challenges by reactivating sleeping nodes as necessary.
- Disadvantages of GAF: Assumption of Location Information: GAF mandates that all nodes possess awareness of their geographic positioning, which may require supplementary hardware, such as GPS devices, thereby increasing both the cost and complexity of the system.

4.1.7 Minimum Energy Communication Network (MECN)

A position-dependent protocol is designed to achieve minimal random network electricity consumption and energy usage. This protocol is predicated on the existence of a mobile network. The routing approach establishes a distinct sub-network, wherein a master node manages the current inactive nodes through a topology that operates at significantly reduced power levels [26]. This sub-network comprises a limited number of nodes, which necessitate fewer resources for connectivity with the network nodes.

- **Steps in MECN protocol:**
  1. **Initial Network Setup:** Each node within the network establishes its relay area, recognizing other nodes that exist within its transmission range and are capable of effectively relaying messages.
  2. **Development of Enclosure Graphs:**
     Nodes utilize localized data to construct an enclosure graph, which illustrates the least energy-consuming routes from the node to every other node within the network [27].
  3. **Route Discovery:** When a node is required to transmit data to a specific destination, it identifies the path that utilizes the least amount of energy, as determined by the enclosure graph. This routing choice is made in real time, considering the present condition of the network.
  4. **Data Transmission:** Data packets are transmitted via the most energy-efficient routes determined during the route discovery phase, thereby optimizing energy usage throughout the transmission process.
- **Advantages of MECN:**
  By reducing energy consumption and equalizing energy use in the network, MECN greatly extends the lifetime of wireless sensor networks (WSNs). Energy-efficient routing algorithms and adaptive transmission power control in MECN help to achieve great energy conservation, allowing sensor nodes to run for a longer time even with low battery capacity. Moreover, MECN decreases communication overhead by optimizing routing paths and preventing unnecessary data transmission.
- **Disadvantages of MECN:**
  1. **Complexity:** The execution of energy-efficient and adaptive routing necessitates advanced algorithms and supplementary computational resources.
  2. **Latency:** The dynamic selection and updating of routes can lead to increased latency, which may adversely affect applications that necessitate real-time data transmission.

4.1.8 Geographic and Energy Aware Routing (GEAR)

known as a Geographic Information System, which operates exclusively within certain segments of the system, has been employed in GEAR to determine the locations of both sensor nodes. GEAR implements energy-efficient and geographically informed heuristics for neighbor selection to facilitate the routing of packets toward the designated target area [28]. GEAR helps in enhancing the energy usage and increasing the lifetime of the network.

- **Advantages of GEAR:**
  a. **Energy Efficiency:** Considering both energy efficiency and geographical factors, GEAR ensures an equitable distribution of the routing load, thereby preventing the excessive utilization of specific nodes. Increase network lifetime.
  b. **Geographic Efficiency:** GEAR leverages locational data to enhance the efficiency of packet forwarding, thereby minimizing both the number of transmissions and the hops required to arrive at the intended destination.
- **Disadvantages of GEAR:**
  a. **Localization Requirement**: GEAR operates under the assumption that nodes possess knowledge of their geographical position, a requirement that could necessitate supplementary hardware, such as GPS modules, thereby elevating both the cost and complexity of the network.
  b. **Scalability:** GEAR may encounter challenges in scaling effectively within extensive networks, where both the quantity of neighboring nodes and the intricacy of recursive forwarding may rise significantly [29].

4.1.9 Hierarchical-based routing

Certain nodes exhibit greater advancement and capability compared to their counterparts. These nodes are organized into clusters, wherein designated cluster heads take on the role of aggregating and sending data to the base station [30]. The benefits of employing hierarchical routing protocols encompass diminished communication overhead, enhanced scalability, extended lifetime of WSN, and improved energy efficiency. [31].

a. **Cluster-Based Routing:** In the clustering schemes, each node has a different role, such as CH, cluster gateway (CGW), and cluster member (CM). The CH serves as a local coordinator within its cluster, facilitating communication between clusters and managing data forwarding. CMs are the regular sensor nodes within a cluster that gather data from their environment and send it to the cluster head. The CGW is employed to connect with adjacent clusters, enabling the exchange of information across these clusters [32]. For WSNs, cluster-based routing is very helpful because it reduces data transmission frequency, saves energy, lengthens the network's lifespan, and improves the quality of services (QoS) parameters such as throughput [33]. It also provides Scalability and reliability. See **Figure 5**.

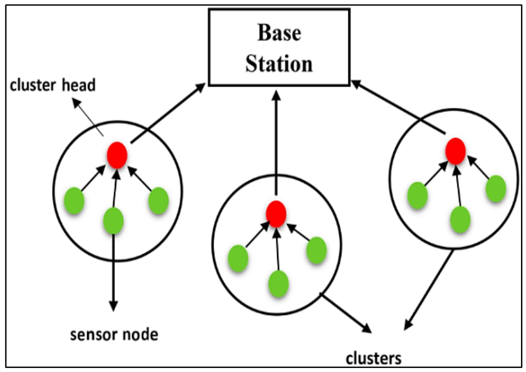

Figure 5. cluster-based routing

b. Low energy adaptive clustering hierarchy (LEACH): The hierarchical routing protocol is essential for energy conservation within the network. This protocol operates by segmenting the entire network into multiple clusters, with each cluster probabilistically designating a node as the Cluster Head (CH). The CH role is receiving, aggregating, compressing, and transmitting the data gathered from the non-CH nodes to the Base Station [34] as in **Figure 6**.

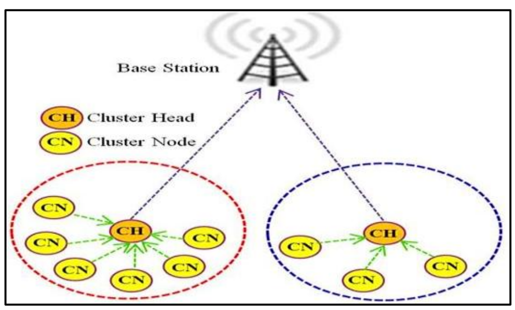

Figure 6. LEACH protocol

- **The operations of LEACH:**

$$T(n) = \frac{P}{1 - P \times (r \mod \frac{1}{P})} \text{ if } n \in G$$

Cluster Head Selection: In every round, nodes determine their eligibility to serve as cluster heads by evaluating a specific threshold T(n). T(n) is given by [35].

Where:

T (n): threshold for node n.

P: desired percentage of CHs (e.g., 5%).

r: current round.

- **Data Transmission:** In the steady-state phase, the member nodes collect and send data to the cluster head. The cluster head then consolidates this data and forwards it to the base station, thereby minimizing the volume of data that must be transmitted over extended distances.

- **Advantages of LEACH: Energy Efficiency:** LEACH markedly decreases energy usage by organizing and rotating cluster heads, thereby facilitating an equitable distribution of energy throughout the network. Scalability: LEACH demonstrates scalability and is applicable in extensive networks, owing to its localized operational framework and hierarchical organization. Data Aggregation: Through the data aggregation at the cluster heads, LEACH minimizes the volume of data sent to the base station, thereby conserving energy.
- **Disadvantages of LEACH: Not Suitable for large Mobile networks [36]:** LEACH is specifically tailored for static networks, and its efficiency may diminish in scenarios where nodes exhibit mobility. Single-Hop Communication: LEACH posits that cluster heads can establish direct communication with the base station in a single hop. However, this assumption may not hold true in extensive networks where nodes are situated at considerable distances from the base station.

c. **Hybrid Energy-Efficient Distributed Clustering (HEED):** The approach is grounded in the residual energy of sensor nodes and the associated communication costs. The primary goals of HEED are to extend the lifespan of the network, to produce evenly distributed cluster heads (CHs), to reduce control overhead, and to complete the clustering phase of wireless sensor networks (WSNs) within a predetermined number of iterations [37].

- **Advantages of HEED:**
  Deterministic Cluster Head Selection: The selection process employed by HEED is characterized by a more deterministic and regulated approach compared to the random cluster head selection utilized in LEACH, resulting in an improved distribution of cluster heads. Scalability and Multi-Hop Communication: HEED supports multi-hop communication; this is advantageous for large-scale networks in which nodes are situated at considerable distances from the base station. Energy Efficiency: The HEED protocol promotes balanced energy utilization throughout the network and extends its operational lifespan by periodically re-clustering and selecting cluster heads according to their remaining energy levels.
- **Disadvantages of HEED:**
  Overhead in Cluster Head Selection: The process of selecting cluster heads iteratively may result in additional overhead when compared to more straightforward protocols, as it necessitates multiple rounds of communication prior to the election of the final cluster heads.

d. **Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN):**

TEEN routing protocol is the improvement of LEACH [38]; the system incorporates both hard threshold (HT) and soft threshold (ST) mechanisms to regulate the volume of data transmission. It organizes sensors into clusters, each managed by CH. Within each cluster, sensors relay their collected data to the designated CH. The nodes continuously monitor their surroundings. Upon the initial occurrence of a parameter from the attribute set reaching its hard threshold, the node activates its transmitter and transmits the collected data. This sensed data is then recorded in an internal variable referred to as the Sensed Value. See **Figure 7**.

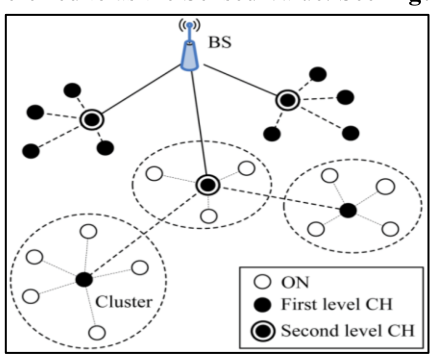

Figure 7: Structure of the TEEN protocol

- **The operations of TEEN:**

a. **Cluster Formation:**

Cluster heads are chosen through an assessment of both energy levels and their distance to neighboring nodes. Once the cluster heads are appointed, they disseminate their status to adjacent nodes, which subsequently affiliate with the closest cluster head determined by signal strength.

b. **Setting Thresholds:**

The cluster head disseminates the HT and ST values to all nodes within its cluster [39]. These threshold values are determined based on the specific application requirements, and each node retains these values in its local storage.

c. **Sensing and Data Transmission:** Data will be transmitted only if the sensed value is greater than or equal to the HT.

- **Advantages of TEEN:** Energy Efficiency: TEEN is highly energy efficient. Reduced Communication Overhead: The implementation of hard and soft thresholds effectively decreases superfluous data transmissions, thereby reducing communication overhead.
- **Disadvantages of TEEN:** Threshold Setting Complexity: The effectiveness of TEEN is significantly influenced by the proper calibration of both hard and soft thresholds.

4.1.10 Protocol operations-based routing protocols

a. **Multipath routing protocol:** Instead of depending on a single route, the method uses multiple pathways to increase network efficiency. A protocol's resilience, or fault tolerance, is determined by how likely it is that a backup path will still connect a source and a destination in the case of a primary path failure. This strategy may result in heightened energy usage and increased traffic generation [40].

b. **Negotiation-based routing protocol:** These protocols employ advanced data descriptors to reduce unnecessary data transmissions through a negotiation process. The fundamental principle of negotiation-based routing in wireless sensor networks (WSNs) is to initiate a sequence of negotiation messages prior to transmitting any actual data to avoid transmitting duplicate data and to avoid sending redundant data to the base station [41].

c. **Quality-of-Service-based routing protocol:** Quality-of-Service is a set of service requirements that must be achieved by the network while sending a packet. The network must achieve a balance between energy consumption and the quality of transferred data. In particular, the network needs to guarantee the successful transfer of data to the Base Station while satisfying several Quality of Service (QoS) requirements, like latency, energy efficiency, and bandwidth.

4.1.11 Transmission modes-based routing protocols

a. **Reactive routing:** protocols do not preserve the whole network topology; they are activated on demand when any node wants to transmit data to any other node. So, the routes are created only when queries are initiated.

b. **Proactive protocols or table-driven routing protocols:** they maintain the routing tables for the complete network by passing the network information from node to another, and the routes are pre-defined before their use, and even when there is no traffic flow [42].

c. **Hybrid routing protocols:** Hybrid Routing Protocols have the features of proactive and reactive routing protocols by ignoring their weakness.

Table 1 gives a Comparison of different routing protocols

Table 1. Comparison of different routing protocols

protocol	overhead	Data aggregation	scalability	Delay	QoS	Power usage	Multipath
SPIN	Low	Yes	Limited	High	No	Limited	Yes
DD	Low	Yes	Limited	Moderate	No	Limited	Yes
RR	Low	Yes	Good	High	No	Low	No
GAF	Mod	No	Good	High	No	Limited	No
MECN	Low	No	Limited	High	No	Low	No

GEAR	Mod	No	Limited	High	No	Limited	No
LEACH	High	Yes	Good	Very small	No	High	No
HEED	High	Yes	Good	Moderate	No	Low	No
TEEN	High	Yes	Good	Small	No	High	No

5. MOBILITY IN WSNS:

In WSNs, "mobility" refers to nodes that can change their location after being first deployed [43]. This concept can be categorized into two types: physical mobility and software mobility. Physical mobility involves the relocation of tangible devices, such as laptops or smartphones. In contrast, software mobility refers to the transfer of a software application across multiple physical devices, with the mobile software entity being designated as a component, agent, or mobile application.

5.1 Network Architecture of Mobile Sink-Based Wireless Sensor Network (mWSN):

The architecture of mWSN contrasts with that of a static WSN in that, within the mWSN framework, the sink continuously traverses the sensor field to optimize data collection. mWSN network architecture is shown in **Figure 8**:

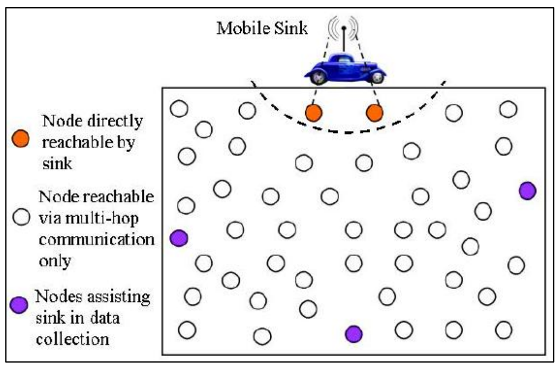

Figure 8. Network architecture of mWSN

5.1.1 Types of Mobility in WSNs

a. **Controlled Mobility:** A mobile sink traverses a specified route to guarantee uniform data collection across all areas of the network. This approach can be advantageous for enhancing and increasing the lifetime of the network.

b. **Uncontrolled or Random Mobility:** The mobile data collectors move randomly and [44], the opportunistic buffered samples are collected. The motion is unpredictable or determined by arbitrary patterns.

- **Advantages of Mobility in WSNs:**

a. **Improve coverage area:** Mobile nodes or sinks enhance coverage over a broader area owing to their inherent mobility characteristics.

b. **Improved Throughput and Data Fidelity:** The system can relocate to regions characterized by elevated data traffic, thereby offering supplementary bandwidth as required. Should the sink advance towards the area designated for event reporting, it will not only diminish the frequency of transmissions but also lower the likelihood of transmission errors and the potential for collisions.

c. **Prolonged Network Lifetime** [45]**:** Minimizing the communication distance between nodes and mobile sinks or collectors can cause a reduction in energy consumption, thereby extending their operational lifespan.

5.1.2 Mobility-based routing protocols:

- **Scalable Energy-efficient Asynchronous Dissemination (SEAD):** SEAD employs a data dissemination concept wherein sensor nodes transmit their collected data to various sink nodes within their operational range.

This process encompasses three primary stages: the construction of a dissemination tree (d-tree), the actual dissemination of data, and the ongoing maintenance of connections to mobile sink nodes. It minimizes energy consumption by reducing the need for frequent route rediscovery [46].

- **Advantages of SEAD:** The system effectively allocates most of the data while simultaneously reducing energy costs.
- **Disadvantage of SEAD:** The latency in delivering packets to the sink node.

5.1.3 Tree-Based Efficient Data Dissemination Protocol (TEDD):

The network is structured as a tree with a designated root node. Within this framework, there exist two categories of nodes: relay nodes and non-relay nodes. The function of the relay node is to facilitate the transmission of data from one node to its subsequent relay node. In contrast, the non-relay node is limited to sending its data exclusively to a relay node. Additionally, the sink node operates in a mobile capacity, collecting data from source nodes via the gateway node, which can function as either a relay node or a non-relay node.

- **Advantages of TEDD:** Throughput is very high, and there is less control packet overhead.
- **Disadvantages of TEDD:** Increased memory capacity is required for the processes of tree construction and sink management.

5.1.4 Mobile Data Collector (MDC):

In this protocol, mobile data collectors (like drones) move around the network and gather data directly from sensor nodes. This approach obviates the necessity for multi-hop communication, thereby decreasing energy consumption at the sensor nodes. The Advantages of MDC are that it is useful in large-scale networks where Data collection must be conducted effectively in remote regions, as shown in **Table 2**.

Table 2: Comparison of pros and cons of different routing protocols

Routing protocol	classification	pros	cons
SPIN	Flat	Topological changes are localized. Reduce overlap. Energy saving.	The dissemination of data in the network takes a long time. A node with much more computation consumes more energy.
DD	Flat	Save network energy. Increase lifetime.	Limit memory storage for data inside the sensor node. The matching process for data and queries causes overhead at the sensors.
GAF	Location-based	Scalability. A sensor node can be in three modes: active, discovery, and sleeping.	Accept only neighboring communication. High number of active nodes.
MECN	Location-based	Use mobile sensors. Minimum energy consumption.	Low scalability.
GEAR	Location-based	Limited power usage. Increase network lifetime.	Limited scalability.
LEACH	Hierarchical	Lesser energy consumption. Little overhead. Easy to execute.	Inapplicable to large scale network. Fixed BS.
HEED	Hierarchical	Energy efficiency. Flexibility.	Increase control message overhead in the cluster formation phase.
TEEN	Hierarchical	Scalability. Uniform distribution of CH.	High overhead. The algorithm complexity.
SEAD	Mobility-based	Minimize energy cost.	Packet delivery delay.
TEDD	Mobility-based	High throughput. Less overhead.	More memory consumption.

6. ROUTING FOR UAV NETWORKS

Unmanned aerial vehicles (UAVs) are aircraft that are controlled by remote radio or an autonomous program without a human presence. UAV technology has evolved and become widely used [47]. Utilizing Drones (UAVs) in WSNs helps in overcoming the routing challenges in WSNs and has a major role in increasing the WSN's performance in terms of network capacity, coverage area, data quality, WSN lifetime, and mobility.

- **UAVs enhance capacity:** they can move to areas with high traffic, providing additional bandwidth where needed.
- **Increase the coverage area:** as it can be deployed on demand to areas where additional coverage is temporarily needed.
- **Enhanced Data Quality:** With the use of high-resolution cameras and advanced software, drone surveying yields are highly accurate, improving the precision of the data collected by the drone.
- **Mobility:** mobility in UAV routing refers to the ability of UAVs to move freely and easily from one location to another. Which, in turn, improves connectivity and data transmission. Drones offer versatility and efficiency across various applications such as delivery, disaster response, and agriculture. However, their deployment comes with unique challenges, particularly in-flight path optimization, battery constraints, and coordination in multi-drone systems.
- **UAV Path Planning**: The major challenges are to minimize the UAV routing path, energy consumption, avoid obstacles, and minimize flight time from the starting point to the destination node while allowing each sensor node to upload data successfully.
- **Multi-UAV-Aided WSNs:** A multi-UAV network is a promising approach to reduce the time of collecting data, delay, and fault tolerance, as well as to increase communication reliability and the lifetime of the network. However, it has some challenges; high cost, has scalability issues, as the number of drones increases, computational and communication demands grow exponentially, complicating real-time coordination, and preventing drones from colliding with each other or other objects in dynamic, shared airspace is complex.
- **Battery constraint:** Drones rely on batteries for propulsion, sensors, and communication, making battery life a critical limiting factor.

6.1 Solutions for Enhancing Energy Efficiency

- **Energy-Efficient Design:** Optimize drone designs with lightweight materials and efficient motors.
- **Intelligent Energy Management:** Use energy-aware systems to monitor and adjust power consumption based on mission priorities.

6.1.1 Routing protocols for UAV networks

Several routing protocols have been proposed for UAV networks. UAV routing protocols are classified into two different sections: Network architecture-based routing protocols and based on data forwarding [48], as shown in **Figure 9**.

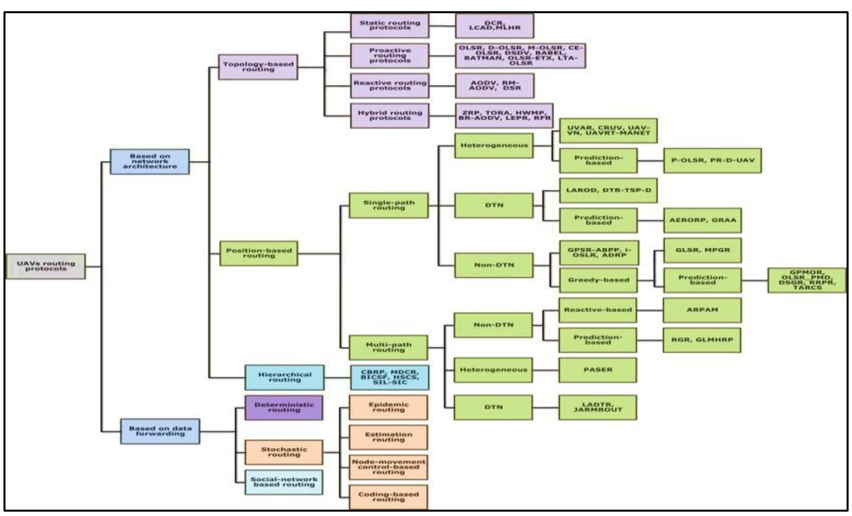

Figure 9. Routing protocols for UAV network

6.1.2 LOAR CARRY AND DELIVER ROUTING (LCAD)

It is a static routing protocol. This approach uses flying to transport data from the source ground station to the destination ground station. This approach has a high throughput and is secure. The disadvantage of LCAD is that transmission delays can be significant over long distances. It is possible to employ a multi-UAV system to reduce the transmission delay.

6.1.3 TEMPORARILY ORDERED ROUTING ALGORITHM (TORA)

TORA is a hybrid routing protocol for multi-hop networks where routes only maintain information about the neighboring routers. The main goal here is to highlight how the extremely dynamic mobile computing network restricts the transmission of the control message by reducing the responses to changes in the topology. It prefers to identify alternate pathways as fast as possible in the event of a broken link to improve network adaptability [49]. The benefit of TORA is that it is a multipath routing technique that forwards data without loops.

6.1.4 REACTIVE GREEDY REACTIVE PROTOCOL (RGR):

The source node must start an on-demand path to maintain communication with the intended destination node if there isn't a route to it. It is the most used protocol in UAV networks.

- **The advantages of RGR:** improving the delivery ratio and end-to-end delay.
- **The disadvantage of RGR:** it has packet loss issues.

6.1.5 BR-AODV Routing Protocol

BR-AODV (Boids of Reynolds–Ad Hoc On-Demand Distance Vector) is a routing protocol that combines on-demand routing with the Reynolds' Boids mechanism to maintain routing paths and network connectivity for data transmission. In the Boids-based BR-AODV navigation system, Route Request (RREQ) packets are disseminated according to node location distribution by dynamically adjusting precise positions and forwarding them to the nearest neighboring nodes of the source. If the receiving nodes are not directly connected to the ground point, they further forward the RREQ packets. Devices that are directly linked to the ground point respond by sending a Route Reply (RREP) packet as a unicast message along the shortest available path back to the source node. Finally, the source node selects the RREP associated with the nearest terrestrial base point. Despite its advantages, BR-AODV is not well-suited for large-scale networks, which limits its scalability [50].

7. CONCLUSION AND FUTURE DIRECTIONS

This survey has comprehensively reviewed various routing protocols used in WSNs, including single-hop and multi-hop routing strategies, and advanced drone-assisted mobile sink routing paradigms. Although traditional routing protocols exhibit good performance, they also experience various limitations, especially when used in large-scale networks. On the contrary, the use of drone-based routing paradigms can efficiently mitigate the limitations associated with the use of traditional routing protocols. This is because the use of drone-based routing paradigms can provide better network coverage, energy efficiency, and network adaptability compared to the use of traditional routing protocols. However, there are various open issues associated with the use of drone-based routing paradigms, including the development of efficient drone path planning, energy-efficient communication, and efficient coordination between multiple drones. Therefore, the development of intelligent and hybrid routing protocols that can efficiently integrate terrestrial and drone-based routing paradigms is important in the future. This will be important in advancing the efficiency and applicability of WSNs in various real-world applications.

ACKNOWLEDGMENTS

The authors sincerely thank the referees, Associate Editor, and Editor-in-Chief for their valuable comments and suggestions, which have greatly improved this paper. The authors also acknowledge the use of DeepSeek for assistance in improving the English grammar and language clarity.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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