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# Comparison of Internet of Things-Enhanced Fog Computing Paradigms for Energy-Efficient Routing Protocols for Wireless Sensor Networks

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## Abstract

Wireless sensor networks and internet of things are responsible for tracking developments in environmental research. All sciences and technologies are searching for cost-effective and efficient ways to move forward to discover new strategies and ideas in the targeted field. The survey overview offers rapid and thorough access to these ideas in the recommended field. However, the main problem and idea for energy-efficient routing protocols for controlling and monitoring wireless sensor network energy use is this inspiration. Designing energy-efficient routing methods also necessitates optimizing network longevity and lowering energy use. This study presents energy-efficient protocols, their techniques, and performance metrics for routing data of wireless sensor networks and the Internet of Things. The paper also examines fog computing techniques and highlights their salient characteristics and performance indicators. Researchers can utilize this study as a starting point to rapidly comprehend the flaws and limitations in this sector to support further research.

**Categories:** Energy Efficiency and Sustainability, Cloud Networking, IoT Applications
**Keywords:** fog computing, internet of things, wireless sensor networks, energy efficiency, network lifetime

## Introduction And Background

Nowadays, in the age of the Internet of Things (IoT) era, wireless sensor networks (WSNs) are important. With the development in 5G and IoT networks, in recent years, WSNs have gained a lot of attention in both academia and industry [1]. The advancement of WSN technology sparked interest in more modern IoT applications, which led to the development of yet another crucial category of intelligent IoT applications. IoT is rapidly emerging as the next major trend [2]. In 1999, supply chain management was used to introduce the IoT to the general public. Numerous advancements made possible by the IoT [3] make networks dependable everywhere and for almost anything. IoT is predicated on the standards that require things or products to communicate and engage with one another through wireless connections to guarantee universal interchanges [4]. Additionally, IoT is being employed in several applications, including smart cities, agriculture, healthcare, transportation, and homes [5]. The IoT will be made up of billions of sophisticated devices, people, services, and other tangible objects that can all properly associate, communicate, and exchange personal and medical data [6]. This will create a computerized environment that is sensitive, adaptable, and responsive to human requirements, simplifying our lives. Among the many themes covered by IoT, one of the main obstacles to completing such a complicated setup is supplying enough energy to run the system freely without compromising the quality of service [7]. Therefore, increasing the usability and energy efficiency of different IoT devices is essential.

Energy efficiency is becoming a crucial component of WSNs and the IoT. Increasing WSNs' energy efficiency and network longevity has become a critical research focus for certain IoT scenarios [8]. The consumption of energy during routing may cause issues, as sensor nodes have limited battery life. Route selection is a challenging or significant problem in the routing process when sending data from one network node to another. Sensor nodes expend a significant amount of energy during the data transfer process. To effectively address the issue of maximum energy consumption, a variety of energy-efficient routing techniques are available. High energy consumption has caused some of the sensor nodes to malfunction. However, the majority of the focus is on how the loss of sensor nodes will result in a hotspot condition inside the network. To handle these kinds of severe situations, various techniques for the sensors that take the IoT framework's energy efficiency into account are fundamentally necessary.

The paper elaborates on the workflow, as shown in Figure *1*. Firstly, it introduces WSN and IoT. Furthermore, it presents the introduction, characteristics, and architectural design of fog computing-based IoT applications. It covers the comparison of various routing protocols based on energy consumption in WSNs-IoT using fog computing. It also presents the conclusion of the paper as final remarks.

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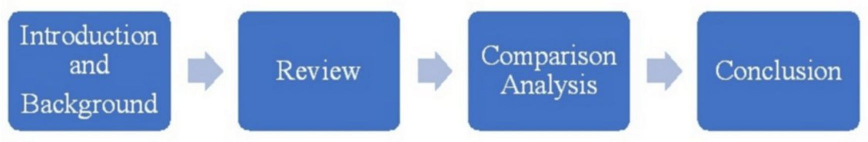


**FIGURE 1: Workflow of the Paper**

## Fog computing

*Introduction*

"Fog computing" was essentially coined by Cisco to describe and illustrate various IoT supporting applications. A cloud that is close to the ground is called fog and supports many kinds of services and applications. [9] As a new paradigm, Fog computing lies between sensor nodes and the cloud [10], allowing for local data processing, storage, and gathering. Data is only transferred to the cloud when necessary.

*Characteristics of Fog Computing*

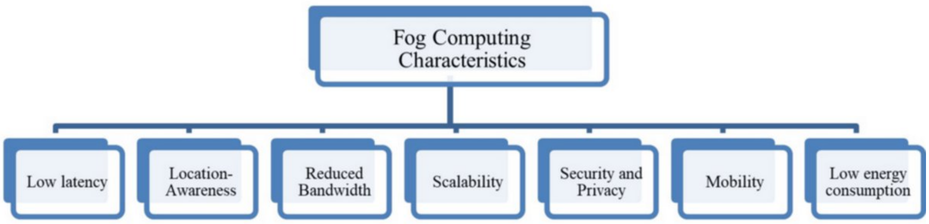


**FIGURE 2: Characteristics of Fog Computing**

The list of characteristics, as shown in Figure *2*, are as follows:

· Low Latency: The physical distance between IoT devices and fog nodes is extremely short. As a result, the fog offers reduced latency since it analyzes data locally, independent of the cloud.

· Location-Awareness: Fog computing enables device position awareness to deliver services to gadgets at the network edge, allowing for the active or passive monitoring of fog nodes.

· Reduced Bandwidth: The idea of fog computing conserves bandwidth and minimizes network traffic. It increases the network's edge's capabilities for processing, analyzing, and storing.

· Scalability: Large-scale IoT devices are enabled by the fog computing framework, which offers distant resources, storage, and data processing. On the other hand, extensive management is necessary for the integrated cloud to support a large deal of IoT apps and devices.

· Security and Privacy: For allocating resources to final clients and guaranteeing that data stays nearby, the fog computing paradigm ensures that data is always available. Furthermore, it offers the data strong security and privacy measures. However, with the cloud computing infrastructure, data is still stored, analyzed, and computed in the cloud. Thus, in contrast to fog computing, the cloud offers fewer security and privacy features.

· Mobility: In addition to connecting to mobile devices, the fog computing scenarios can support high mobility. It offers the ability to use different protocols to establish communication with mobile devices.

· Low energy consumption: In fog computing, fog nodes are dispersed geographically. No extra cooling system is needed because of the fixation, which prevents it from producing enough heat. Additionally, fog nodes help fog computing become more affordable by consuming less power and energy.

*Fog Computing Architecture*

The fog computing concept brings the capabilities of IoT applications closer to the end consumers. Its main goal is to ensure the dependable and secure real-time and time-sensitive services of IoT applications by minimizing latency and conserving bandwidth [11,12]. As shown in Figure *3*, the design of a fog-based IoT network consists of three layers: the cloud layer, the fog layer, and the IoT device layer [13]. On the other hand, the system includes six layers, which are referred to as the physical, monitor, pre-processing, transit, security, and transport layers [14-17]. An overview of the suggested tiered architecture for fog computing-based IoT networks is given in this part. To comprehend how fog computing functions concerning IoT applications, the fog nodes are placed closer to the network's edge to collect data from IoT devices. They might take the shape of straightforward network hardware like routers and gateways or intricate gadgets like embedded servers and security cameras. On the other hand, the data generated by extremely sensitive applications is stored, processed, and computed by intelligent devices. As a result, any indication of a problem can be found relatively near the IoT devices, allowing the fog nodes to respond at any moment to the IoT gadgets.

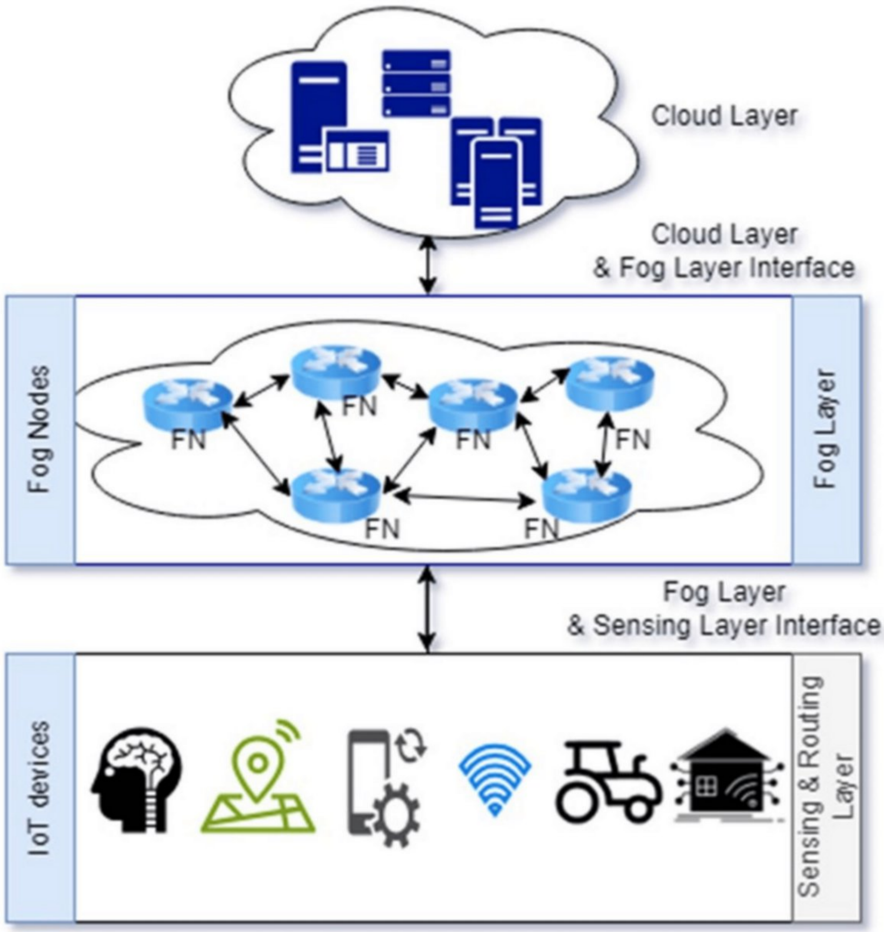


**FIGURE 3: Architecture of Fog Computing**

## Review

There is a wealth of studies on energy efficiency in WSNs-based IoT networks, with many studies concentrating on algorithms and strategies across different network levels. Figure *4* shows the logical flow of different articles based on WSNs, IoT, and fog computing techniques. Numerous methods have been developed for assessing network performance, energy consumption, and routing, among others.

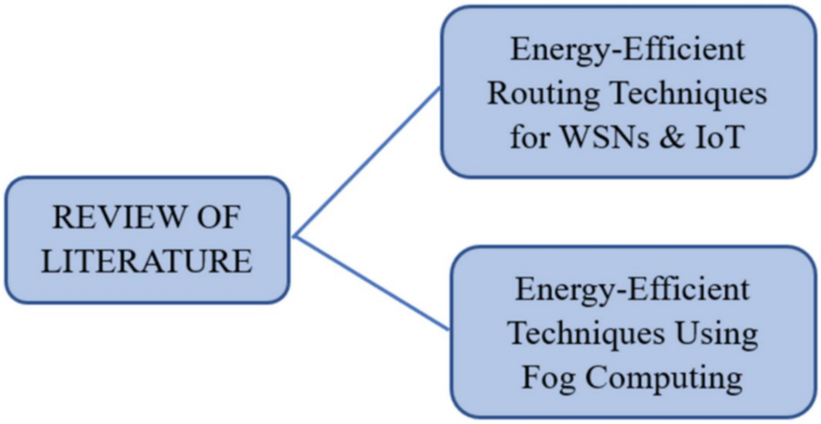


**FIGURE 4: Review of Literature**

IoT: Internet of Things, WSNs: Wireless Sensor Networks

## Routing protocols based on WSNs and IoT applications

Various routing protocols have been introduced for the selection of cluster heads in WSNs using different techniques to improve energy efficiency and extend network lifetime. Some of the studies have been presented as follows:

Bhatia et al. [18] introduced an evolutionary genetic algorithm, which is used in the suggested approach, called GADA-LEACH, to improve cluster head (CH) selection in WSNs using the traditional LEACH routing technique. The idea of a relay node is presented, which facilitates communication between the BH and CH by serving as an intermediate. The simulation results obtained validate the efficiency of our suggested technique concerning network lifetime.

Saadati et al. [19] presented a method that provides a graph neural network-based technique to establish equal-sized static clusters. Balancing the energy consumption of the nodes is one of the primary sub-goals in developing an energy-efficient WSNs clustering technique. A distributed CH selection process that operates independently within each cluster is also presented. Multi-hop routing, which assists in avoiding energy-intensive transmissions over long distances, is another essential component of energy efficiency in WSNs. For every cluster, our centralized routing technology creates the base station's distinct routes. This avoids the hotspot issue and guarantees that relay nodes use the same amount of energy.

Sood et al. [20] introduced Lines-of-Uniformity based Enhanced-Threshold (LUET). This study suggests a unique clustering method based on uniform connection to provide energy-efficient heterogeneous WSNs. In order to reduce the average isolated node count in WSN, this technique takes into account the node's leftover energy and closeness from either line of symmetry. In order to deal with the sharp decline that occurs after the first node dies, this research also suggests a version called rotation epoch-based LUET (LUET|R), which includes static epoch during the initial rounds of clustering till First-Node-Death.

Chowdhury et al. [21] offered a method that uses the sensors' ideal actions to achieve the smallest amount of energy feasible. This research uses the MSLG-RGSO (Movement Score based Limited Grid-mobility approach using Reverse Glowworm Swarm Optimization) algorithm to provide a Movement Score-based Limited Grid-mobility strategy for mobile WSNs. By carefully positioning the sensor networks on the appropriate gridpoints and using limited sensor motions based on movement score, the suggested approach increases the efficiency of sensor networks. It has been computed to vary sensor node velocities with respect to other sensor node distances.

El Khediri et al. [22] offered an integrated approach that blends artificial bee colony with ant colony optimization, created to improve the performance of WSNs. Using this method makes it easier to choose the best CH among a range of terminals. Ant colony optimization chooses the most effective path based on node degrees, remaining power, and distance to find the route from the BS to the cluster leader.

Mothku and Rout [23] introduced a method with the goal to reduce the volume of data transfers and boost reliable data collection. During the network coding procedure, the proposed system automatically selects the level of packet redundancy.

Patil and Kohle [24] aimed to develop an effective routing mechanism that will increase WSN's scalability. A perfect routing protocol would adjust to changes in the network topology. The Cluster-based Genetic Routing Protocol, a routing method based on genetic algorithms, is established in this proposal. With its ability to function effectively even under increased workloads, the Cluster-based Genetic Routing Protocol is especially well suited for networks that are widely dispersed and growing quickly.

Abdulzahra et al. [25] presented the fuzzy-based unequal clustering with a sleep scheduling protocol, an energy-efficient fuzzy-based uneven clustering with sleep scheduling method. for the IoT that makes use of WSN is put forth in this article. The network lasts longer and consumes less energy thanks to this protocol. Data transfer, scheduling, and clustering are the methods it uses to achieve this. This technique shortens the data transmission distance, so balancing the energy utilized, and forms unequal clusters based on fuzzy C-Means. Fuzzy logic is used in the CH selection process.

Abdul-Qawy et al. [26] introduced an approach that enables the nodes to be individually configured with transmission parameters based on their various tasks, regardless of the beginning energy, total number of nodes, or heterogeneity levels. This method guarantees that every node in the network functions at its best.

Manoharan et al. [27] showed the optimal data transfer in WSN using techniques based on soft computing. A network's nodes are first grouped together using density-based adaptive soft clustering. After that, a modified beetle swarm optimization method is used to choose the CH. When choosing the best CH, factors like throughput, energy, trust, and distance are all taken into account. Next, using these variables to calculate the entropy weight values for each node, the node with the highest entropy for data transmission is identified. Gathering of data from the sensor nodes is followed by data compilation by the CH. Lastly, the optimal data transmission technique is achieved by utilizing adaptive entropy value in EBES (Entropy Value based bald eagle search) optimization to carry out the highly energy-efficient routing.

Asiedu et al. [28] suggested that to maximize network energy efficiency in this system, we develop a novel multi-hop routing technique that takes into consideration interference, rate constraints and power budget. The interconnected duties of energy transmitter clustering, sensor node transmission power management, and WSN routing are all involved in this issue.

Chouhan et al. [29] created a reliable and energy-efficient protocol to extend network lifetime is a difficult undertaking. In this research, a unique hybrid optimization-oriented method for choosing the cluster head in IoT-assisted WSNs is developed.

Ghawy et al. [30] proposed an optimization strategy to construct a multipath protocol, known as PSO Routing Protocol. WSN-based IoT applications that experience high traffic loads and unjust network traffic employ the proposed protocol.

Kaur et al. [31] introduced a protocol that makes the ACO algorithm a multi-objective routing algorithm by considering the energy consumption impact and the end-to-end delay cost of the routing path as two optimization objectives.

Alabdali et al. [32] proposed a clustering strategy that is energy-efficient with the use of a wireless energy balancer. First, a method for completely leveraging and lowering the energy consumption of CHs-n-level clustering-is provided. Second, an energy balancer is used to zero the difference between the rest of the energy of CHs in order to minimize the amount of energy squandered.

Shyamsundar et al. [33] proposed applications for underwater sensor networks include the military and exploration. This paper aims to increase network lifetime by using effective routing techniques. The study highlights GSA’s performance advantages by contrasting it with other algorithms already in use. GSA optimizes energy usage to increase clustering efficiency and prolong UWSN lifetime. Reducing computing overhead and validating performance in real-world circumstances are the goals of future work.

Balamurali et al. [34] proposed an objective to create a new compressed sensing method based on clusters for balanced energy use. The proposed NHM-HCS (Novel Hadamard Matrix-based Hybrid Compressive Sensing) uses PSOGWO algorithms to address memory, network lifetime, and energy concerns.

Tawfeek et al. [35] introduced WSNs, which are used in various industries, including military and healthcare. The architecture of WSNs consists of distributed sensor nodes for data sensing and transmission. Energy obstacles, node variation, and fault tolerance are among the challenges. Self-organized WSNs seek to optimize bandwidth and reduce energy usage.

Sefati et al. [36] proposed an algorithm that presents by bridging the digital and physical realms, and IoT makes automation and data analysis possible. Generative Adversarial Networks are used to create clusters for realistic grouping. Ant Colony Optimization is used to choose CHs to improve communication. Using a congestion factor, pheromone-based routing finds the best routes and identifies congestion. The proposed hybrid Generative Adversarial Network-Ant Colony Optimization architecture enhances reliability, lowers latency, and increases energy efficiency. It works well for real-time applications in domains like smart cities and environmental monitoring.

Bebortta et al. [37] suggested a strategic CH selection paradigm. The model chooses the best CHs based on distance and energy using restricted linear programming. In heterogeneous networks, the proposed model lowers average delay and increases energy efficiency. According to performance indicators, strategic CH selection performs better than conventional models in terms of residual energy and energy usage.

## Routing protocols based on fog computing

Various routing protocols have been introduced using fog computing for the improvement of energy efficiency and extending network lifetime. Some of the studies have been presented as follows:

Potu et al. [38] introduced a technique that describes a new scheduling technique that enhances fog and edge nodes. This technique is based on supervised learning approach that measures statistical moving averages.

Wang et al. [39] suggested a fog structure made up of mobile sinks that bridge the distance between WSNs and the cloud by acting as fog nodes. Their goal is to decrease transmission latency and optimize throughput by working together to install a MIMO network. After designating sensors to the appropriate sinks, we designate collecting zones for each sink. Hops and energy usage are taken into consideration for those designated sensors to address the hopspot issue.

Sun et al. [40] proposed a method that projects the positions of fog nodes onto the sensing layer using an event-based approach, thereby creating an efficient virtual control node. Subsequently, the fog layer receives the control method of the sensor network's cluster routing technique, and fog processing is used to accomplish the event-field nodes' scattered clustering. On the other hand, the projectile fog nodes are centered by the efficient data aggregation route that is built.

Asghar et al. [41] proposed a fog-based health tracking system architecture as a way to lower delay and network utilization. In addition, we introduce a novel load balancing scheme designed to distribute the load evenly among fog nodes during extensive health tracking system deployment.

Moussa et al. [42] suggested an energy-efficient model that does not cluster repeatedly and adjusts CHs to fog nodes according to distance. Additionally, we suggest distributing unequal clustering to many fog nodes in manner to reduce the hotspot issue, in contrast to the previous works that either utilize a single or multiple fog nodes/sinks.

Ullah and Khan [43] introduced a wireless body area of network that is based on fog-based energy-efficient protocol -predicated LAEEBA protocol - which has previously been created. We put Fog-LAEEBA into practice, test it, assess it, and compare the outcomes in terms of different parameters.

Ramadan et al. [44] discussed how different fog network organizations can affect efficiency and energy savings. The main evaluation is if putting multi-sink networks near enough to the fog nodes can save energy and encourage consistent data transfer between WSNs and fog networks.

Idrees and Al-Qurabat [45] proposed an energy-efficient protocol and also introduced clustering-based protocol to reduce the quantity of datasets sent to the base station and eliminate duplicates, identical sets of data that are obtained from the sensors.

Dayana and Maria Kalavathy [46] introduced the Multi-Objective Secure Routing protocol for fog-based WSNs, based on Quantum Firefly Optimization. The primary goal of the QFO-MOSR technique is to find the best possible path between CHs and fog nodes inside the network.

Narla et al. [47] proposed that effective data aggregation is achieved through the use of machine learning algorithms. Sensor networks are improved using optimization methods such as Multi-objective Male Lion Optimization. Blockchain technology guarantees the security and validity of data. Data security and user query response time are not given enough attention in current efforts. BP-KMeans for energy efficiency and Merkle Tree for authentication are two suggested techniques. While GMCC secures sensed data, SGSOA improves user queries.

## Comparison analysis

Table *1* compares relevant reviews, guides, and survey articles that focus on WSNs, IoT, and fog computing. The following are some surveys of energy-efficient routing protocols.

| Reference | Author | Protocols Used | Area Focused | Performance Metrics | Simulator |
|---|---|---|---|---|---|
| [18] | Bhatia et al. | Distance-Aware routing protocol | Improve cluster head selection | Network lifetime | MATLAB |
| [19] | Saadati et al. | Graph Neural Network | Better cluster head selection | Network lifetime, throughput | Python |
| [20] | Sood and Sharma | LUET protocol | Better cluster head selection | Network lifetime, energy efficiency, throughput | NS2.35 |
| [21] | Chowdhury and De | Reverse Glowworm Swarm Optimization | Reduce energy consumption | Energy consumption | MATLAB 17a |
| [22] | El Khediri et al. | Ant colony optimization and artificial bee colony | Best cluster head | Energy consumption, network lifetime | MATLAB R2023a |
| [23] | Mothku and Rout | Markov Decision Process | To achieve reliable data delivery | Average delivery delay, energy consumption, and network lifetime | MATLAB |
| [24] | Patil et al. | Genetic Routing Protocol | Achieving lower latency | Energy consumption, latency, and scalability | MATLAB7 |
| [25] | Abdulzahra et al. | Fuzzy logic system - Fuzzy C-Means | Better cluster head selection | Network lifetime, scalability, and energy consumption | Python 3.9 |
| [26] | Abdul-Qawy et al. | Threshold-Enabled Scalable and Energy-Efficient Scheme | Saving energy | Network lifetime and energy consumption | MATLAB |
| [27] | Manoharan et al. | Eagle search optimization | Best cluster head | Delay, throughput, energy consumption and packet delivery ratio, lifespan of network | MATLAB |
| [28] | Asiedu et al. | Routing and ET clustering | Better network energy efficiency | SN's average transmit, average achievable rate, energy efficiency | MATLAB |
| [29] | Chouhan et al. | Taylor-PO protocol | Best cluster head selection | Delay, energy, and throughput | NS-2 |
| [30] | Ghawy et al. | Particle Swarm Optimization | Energy saving | End-to-end delay, packet delivery ratio, and throughput | NS2.34 |
| [32] | Alabdali et al. | n-level clustering | Best cluster head selection | Energy consumption, network lifetime | NS2 |
| [33] | Kaur and Kumar | ACO algorithm | Efficient routing | Delay, energy, and throughput | MATLAB |
| [38] | Potu et al. | Supervised learning approach | Better scheduling | Energy consumption, transmission load, average make-span rate | Fog-sim-based simulation |
| [39] | Wang et al. | DCF Algorithm | To solve the hopspot problem | Energy consumption, throughput, latency | MATLAB 2015a |
| [40] | Sun et al. | ECCM Method | Improve network performance | Energy consumption, network lifetime | MATLAB7.0 |
| [41] | Asghar et al. | FNPA and LAB protocol | Saving energy | Energy consumption, latency and network lifetime | iFogSim toolkit |
| [42] | Moussa and El Belrhiti El Alaoui | ACO-based routing (DACOR) protocol | To deal with the hotspot problem | Energy consumption, network lifetime | MATLAB |
| [43] | Ullah and Khan | Fog-LAEEBA protocol | Better network energy efficiency | End-to-end delay, throughput, residual energy and stability period | MATLAB |
| [44] | Ramadan et al. | Evaluation-Based Approach | Energy saving | Energy consumption, network lifetime, packet loss | CupCarbon |

| | | | | | |
|---|---|---|---|---|---|
| [45] | Idrees and Al-Qurabat | EDaTAP protocol | Energy saving | Energy consumption, accuracy | OMNeT++ |
| [46] | Dayana and Maria Kalavathy | QFO-MOSR protocol | Optimal set of routes | Residual energy, average delay, packet delivery ratio | NS3 |

**TABLE 1: Routing Techniques Based on Energy Efficiency of WSNs, IoT, and Fog Computing**

IoT: Internet of Things, WSNs: Wireless Sensor Networks, GNN: Graph Neural Network, LUET: Lines of Uniformity based Enhanced Threshold, MSLG-RGSO: Movement Score based Limited Grid-Reverse Glowworm Swarm Optimization, ACO: Ant Colony Optimization, MDP: Markov Decision Process, CGRP: Cluster-based Genetic Routing Protocol, EBES: Entropy-based Bald Eagle Search, PSO: Particle Swarm Optimization, DCF: Data Collection Algorithm, ECCM: Energy Efficient Cross Layer Sensing Clustering Method, FNPA: Fog Node Placement Algorithm, DACOR: Distributed Ant Colony Optimization-based Routing, EBA: Evaluation-Based Approach, EDaTAP: Energy Efficient Data Transmission and Aggregation Protocol, QFO-MOSR: Quantam Firefly Optimization-based Multi-Objective Secure Routing, Fog-LAEEBA: Link Aware and Energy Efficient Protocol for Wireless Body Area Networks, Taylor-PO: Taylor-Political Optimizer

## Conclusions

This paper has provided a thorough analysis of different routing protocols for WSNs, IoT and fog computing in this research. WSN-specific protocols must be able to manage mobility overhead and inconsistent topology changes by preserving optimal routes during route exploration, selection, and maintenance. Conserving the energy consumption of each and every network node should receive particular attention. However, in addition to creating and testing novel routing methods on simulators and testbeds, it is advised that studies be carried out on real sensor nodes in order to accurately assess the efficiency of the suggested algorithm or protocol. We firmly think that after reading this paper, research scholars will give more careful thought and develop more sophisticated and effective routing protocols that have been thoroughly evaluated with a range of parameters and are completely able to be flexible in real-world sensor networks.

## Additional Information

### Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

**Concept and design:** Loveleen Kaur, Rajbir Kaur

**Acquisition, analysis, or interpretation of data:** Loveleen Kaur, Rajbir Kaur

**Drafting of the manuscript:** Loveleen Kaur

**Critical review of the manuscript for important intellectual content:** Loveleen Kaur, Rajbir Kaur

**Supervision:** Rajbir Kaur

### Disclosures

**Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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