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Review

Energy Inefficiency in IoT Networks: Causes, Impact, and a Strategic Framework for Sustainable Optimisation

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Abstract: The Internet of Things (IoT) has vast potential to drive connectivity and automation across various sectors, yet energy inefficiency remains a critical barrier to achieving sustainable, high-performing networks. This study aims to identify and address the primary causes of energy wastage in IoT systems, proposing a framework to optimise energy consumption and improve overall system performance. A comprehensive literature review was conducted, focusing on studies from 2010 onwards across major databases, resulting in the identification of eleven key factors driving energy inefficiency: offloading, scheduling, latency, changing topology, load balancing, node deployment, resource management, congestion, clustering, routing, and limited bandwidth. The impact of each factor on energy usage was analysed, leading to a proposed framework that incorporates optimised communication protocols (such as CoAP and MQTT), adaptive fuzzy logic systems, and bio-inspired algorithms to streamline resource management and enhance network stability. This framework presents actionable strategies to improve IoT energy efficiency, extend device lifespan, and reduce operational costs. By addressing these energy inefficiency challenges, this study provides a path forward for more sustainable IoT systems, emphasising the need for continued research into experimental validations, context-aware solutions, and AI-driven energy management to ensure scalable and resilient IoT deployment.

Keywords: Internet of Things; energy efficiency; IoT networks; communication protocols; resource management; fuzzy logic; bio-inspired algorithms; network optimisation; sustainable deployment

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1. Introduction

1.1. Background

The Internet of Things (IoT) is transforming numerous sectors by enabling interconnected devices (also known as nodes) to communicate and perform tasks seamlessly over the Internet. This advanced connectivity is driving unprecedented convenience and efficiency across various domains, from healthcare to smart cities and industrial automation. The rapid expansion of IoT is underscored by its projected requirement of three to six devices per person in the near future, highlighting its integration into daily life [1]. However, the increased complexity of these systems, driven by efforts to boost security, accuracy, and functionality through sophisticated algorithms, has led to challenges such as heightened power consumption and energy inefficiency [2].

The complexity of IoT systems demands considerable processing power, which can strain devices and networks, especially given the need to process vast data volumes. These challenges are compounded by the reliance of IoT networks on efficient communication protocols, task scheduling, and resource allocation strategies. Addressing these issues has become a priority to ensure sustainable IoT deployment, making energy optimisation critical for balancing functionality with efficiency [3].

1.2. Objective

To provide a more comprehensive evaluation of energy performance in IoT networks, this systematic review aims to not only assess energy efficiency but also consider its relationship with key performance metrics including data rate, bandwidth, coverage, processing time, security, and overall system performance. By synthesising findings across these parameters, this review will address how each factor contributes to or impacts energy usage in IoT environments, thereby offering a holistic understanding of the interdependencies among these aspects.

1.3. Rationale

As IoT networks become more widespread, the demand for advanced, energy-efficient, and sustainable solutions intensifies. Improved energy efficiency directly impacts operational costs, environmental sustainability, and the usability of IoT systems. Specifically, lowering power consumption is crucial to reducing environmental impacts such as air pollution. Enhancing energy performance could also incentivise broader adoption of IoT by government entities, including the Ministry of Health and the Ministry of Transportation, to enhance service delivery across sectors, from public health to transportation. Sustainability considerations are essential, not only for lowering costs but also for encouraging long-term investments in IoT technology.

1.4. Contributions of the Review

This review contributes to research with a comprehensive analysis of IoT technologies, organised around five critical aspects:

- Explores the core structural layers that comprise IoT systems, including data collection, transmission, processing, and service delivery layers.
- Examines the diverse methods—such as Wi-Fi, Bluetooth, and cellular technologies—used for data exchange and connectivity in IoT networks.
- Analyses the variety of contexts in which IoT devices operate, from healthcare and agriculture to smart homes and industrial settings.
- Investigates the application layer standards, such as CoAP and MQTT, that support seamless data exchange and integration in IoT ecosystems.
- Identifies and discusses the primary obstacles currently faced by IoT networks, including issues, such as energy inefficiency, latency, and network scalability.

Through this structured approach, the review will provide insights into the current IoT landscape and suggest strategies for overcoming key challenges to improve energy efficiency and system effectiveness.

2. Background for IoT Architecture

IoT systems are structured through a multi-layered architecture that allows seamless data collection, processing, transmission, and application. As illustrated in Figure 1, the architecture typically includes four essential layers: the Perception Layer, Network Layer, Middleware Layer, and Application Layer [4]. Each layer has specific roles and faces unique challenges related to energy consumption, security, data accuracy, and speed.

This paper focuses on improving energy efficiency across these layers, which is critical to sustaining IoT deployments, particularly as the number of connected devices continues to grow exponentially.

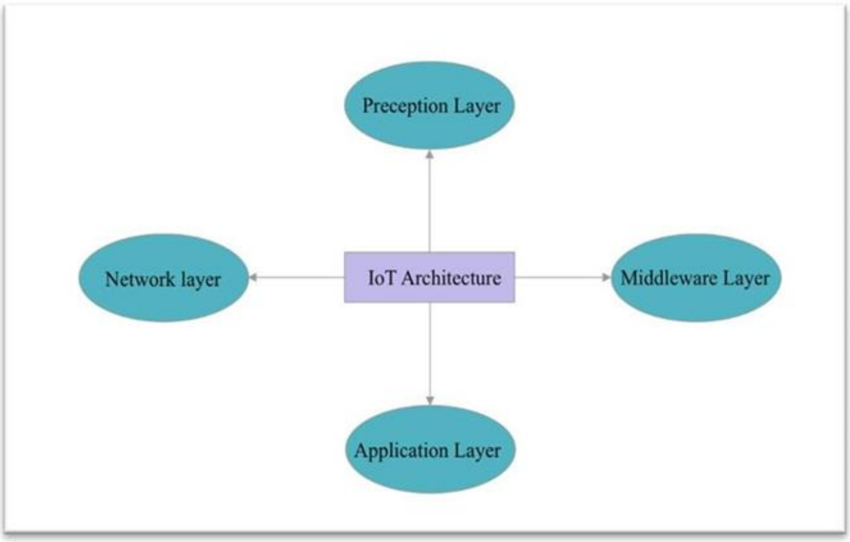

Figure 1. IoT architecture.

2.1. The Perception Layer

The Perception Layer initiates IoT system functionality by enabling the collection and monitoring of data from the physical environment. Analogous to the physical model of the OSI model, the main components of this layer are sensors and actuators. Sensors detect and measure various environmental parameters—such as temperature, humidity, motion, and light—and transmit this data to the Network Layer for further processing [5]. Actuators, in turn, enable devices to perform specific actions based on data received, such as adjusting temperature settings or activating alarms [3].

IoT devices in the Perception Layer typically generate two types of data: measurement data from sensors, reflecting real-time environmental conditions, and context data, which provide information on device status, including battery life and connectivity strength [6–8]. This layer heavily relies on standards such as IEEE 802.15.4, which supports low-power, low-data-rate wireless personal area networks, optimising communication in scenarios where energy conservation is a priority [9].

Due to the constant need of the layer to gather data, energy consumption is a critical concern. Energy efficiency techniques in this layer often involve managing sensor duty cycles, optimising data transmission, and implementing protocols that allow sensors to enter low-power states during inactivity. These approaches aim to extend device battery life, especially for remote or inaccessible deployments.

2.2. The Network Layer

The Network Layer serves as the backbone for data transmission in IoT systems, functioning as a central hub for aggregating data from the Perception Layer and transmitting it to the Middleware Layer. This layer employs a range of communication technologies, including Wi-Fi, RFID, Bluetooth Low Energy (BLE), cellular networks, and Low Power Wide Area Networks (LPWANs), to enable seamless data flow between devices [10]. In particular, technologies such as Narrowband IoT (NB-IoT) and Sigfox support low-power, long-range communication, which is ideal for applications in remote or hard-to-reach areas [11–13].

The energy efficiency of the Network Layer is influenced by the choice of communication protocols and routing mechanisms. For instance, NB-IoT offers a low-cost solution with extended battery life for devices by limiting data rates and coverage [14]. Similarly, LPWAN protocols are designed to optimise energy usage by reducing power requirements while maintaining sufficient communication range. Routing algorithms, which determine data paths based on factors such as distance, node energy levels, and bandwidth availability, also play a crucial role in minimising energy consumption. Efficient routing strategies can significantly reduce the power consumed by IoT devices, especially in large-scale, dense networks.

2.3. The Middleware Layer

The Middleware Layer acts as a bridge between the Network Layer and the Application Layer, responsible for data storage, management, and pre-processing before information reaches end-user applications. This layer connects IoT networks to computing resources, databases, and analytics platforms, preparing data for further analysis and use. In many IoT systems, the Middleware Layer integrates machine learning and artificial intelligence techniques to analyse data, automate decisions, and detect patterns, which can enhance service quality and decision-making processes [15].

In terms of energy efficiency, the Middleware Layer contributes by optimising data processing workflows, which reduces redundant data transmissions and processing loads on individual devices. Techniques such as data compression, data aggregation, and batch processing minimise the amount of data that need to be transmitted and stored, saving energy and network resources. Machine learning algorithms can further enhance energy efficiency by enabling predictive data analysis, which allows IoT devices to operate proactively rather than reactively, reducing unnecessary actions and conserving energy [16].

2.4. The Application Layer

The Application Layer is the topmost layer in IoT architecture, delivering tailored services to end-users through applications in fields, such as healthcare, agriculture, smart cities, and industrial automation. This layer processes data aggregated by the Middleware Layer, ensuring that it meets quality and relevance standards for specific applications. End-users access services through Internet-enabled devices, such as smartphones, computers, and tablets, which facilitate interaction with IoT systems in real time [17].

Energy efficiency in the Application Layer often focuses on optimising data presentation and reducing computational requirements for end-user applications. By employing data filtering and prioritisation techniques, the Application Layer can minimise the amount of data transferred and processed by end-user devices, which helps conserve energy, particularly in applications that involve large data volumes. Furthermore, efficient design and implementation of user interfaces ensure that application interactions are intuitive and reduce the energy burden on devices accessing the IoT services [18].

3. Methodology

This review follows a structured methodology to comprehensively assess current research on energy efficiency in IoT networks. The primary objectives were to identify key challenges to energy efficiency, evaluate the effectiveness of existing solutions, and synthesise findings to provide practical insights for improving energy performance across IoT applications.

Figure 2 illustrates the step-by-step review process for integrating bio-inspired algorithms and adaptive fuzzy logic systems in IoT architectures. An extensive literature search was conducted to capture relevant studies on IoT energy efficiency. Keywords and phrases were chosen based on an initial literature exploration, focusing on critical areas such as energy-efficient communication protocols (e.g., CoAP, MQTT), routing strategies, resource allocation, and optimisation algorithms. Boolean operators and exact phrase matching were used to ensure relevant and specific results.

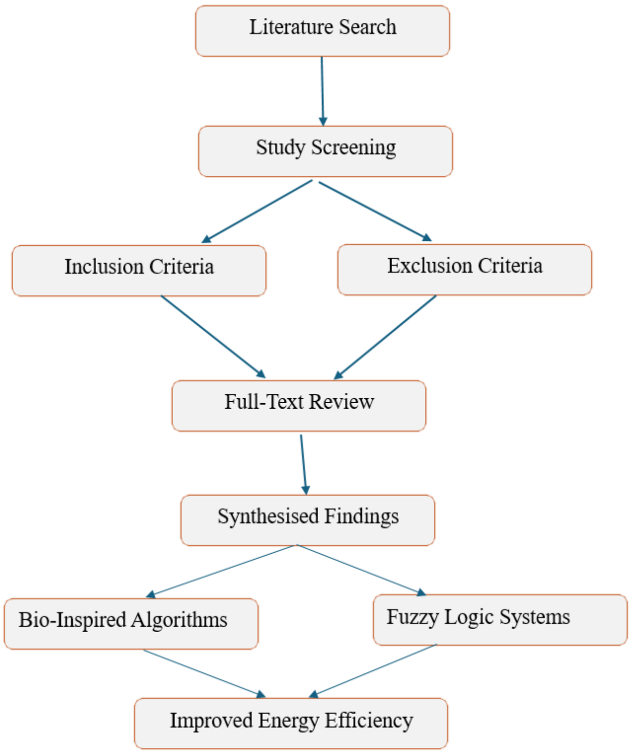

Figure 2. Review process for integrating bio-inspired algorithms and fuzzy logic systems to enhance IoT energy efficiency.

Studies were then screened and selected based on predefined inclusion and exclusion criteria. Inclusion criteria required studies to directly address energy efficiency in IoT networks, with a focus on protocols, algorithms, or resource management strategies relevant to IoT applications. Only peer-reviewed research published from 2010 onward was included, and studies were required to present empirical data demonstrating measurable energy performance improvements. Exclusion criteria eliminated articles that did not focus on IoT-specific energy issues, lacked empirical data or methodological rigour, or were non-peer-reviewed. Publications not available in English were also excluded to maintain consistency.

Following the initial screening of titles and abstracts, a detailed full-text review ensured that only high-quality, rigorously tested studies were included. This methodology enabled a comprehensive synthesis of energy efficiency measures in IoT networks, establishing a robust foundation for practical recommendations and future research directions.

4. Results

This section provides a comprehensive summary of findings on energy efficiency in IoT systems. Following a structured selection process, the selected studies were analysed in depth, focusing on critical components of IoT energy efficiency, such as application protocols (e.g., CoAP and MQTT), routing and clustering methods, and resource allocation strategies. Each study was evaluated to identify its contributions to energy optimisation, the methodologies employed, and the challenges addressed, offering a detailed understanding of existing solutions and areas needing further exploration. The findings are organised into several key categories in the following subsections

4.1. Results of Individual Studies and Synthesis

The findings from the individual studies were synthesised and organised into key categories, providing targeted insights into protocols, algorithms, and strategies for enhancing energy efficiency in IoT systems. Each category represents a crucial aspect of IoT network functionality, where energy performance directly influences system sustainability and operational costs. By grouping studies into these core areas, the review highlights current advancements, challenges, and effective approaches for optimising energy use in IoT networks.

4.1.1. Application Protocols: CoAP and MQTT

Several studies examined the role of CoAP and MQTT protocols in enhancing energy efficiency in IoT networks, proposing various modifications and strategies to address the energy demands of data transmission and processing:

- Jin W et al. [19] explored a sleep scheduling method for CoAP to improve energy efficiency by managing the sleep–wake cycles of IoT nodes. In this approach, nodes were programmed to enter low-power states when not actively transmitting or receiving data, significantly reducing energy use during idle periods. By integrating resource directories and message queues, this method allowed for better synchronisation across nodes, ensuring that they only activate when necessary for specific tasks. Although this strategy showed potential for energy savings, the study lacked experimental validation, limiting its robustness and calling for further empirical research to confirm the effectiveness of sleep scheduling in real-world applications.
- Gupta S et al. [20] proposed a task offloading schema for MQTT, aimed at enhancing energy efficiency by categorising tasks based on their urgency and offloading them accordingly. This approach prioritised high-urgency tasks for immediate processing, while less critical tasks were deferred or offloaded to external resources, thus balancing workload distribution and reducing the energy strain on IoT devices. While the method demonstrated promise for conserving energy, especially in resource-constrained environments, the study noted that additional empirical testing is necessary to assess its practical implications and ensure that the offloading mechanism can adapt to varied network demands without compromising performance.
- Peralta G [21] leveraged machine learning algorithms in MQTT gateway nodes to predict data transmission needs, proactively adjusting transmission schedules to avoid unnecessary data exchanges. This predictive analytics approach enabled the system to forecast data requirements and manage transmission times, which reduced redundant data exchanges and conserved device energy. By aligning data transmissions with actual needs, this method minimised power consumption, illustrating the value of predictive techniques in managing energy use in IoT networks. Peralta's study underscores the potential of machine learning in optimising IoT communication protocols for energy efficiency, particularly in applications with fluctuating data demands.
- Schutz B et al. [22] addressed the challenge of packet loss in wireless sensor networks (WSNs) by incorporating random linear network coding with MQTT. This coding approach was designed to improve data reliability by compensating for packet loss, which is common in remote or resource-constrained environments. By reducing the need for retransmissions, the approach decreased radio frequency updates, leading to a 38.24% reduction in energy consumption in agricultural IoT applications. This finding demonstrates the effectiveness of network coding techniques in conserv-

ing energy, especially in settings where consistent data transmission is crucial yet prone to disruption.

- Randhawa R et al. [23] introduced OSCoAP (Object Security for CoAP), a secure version of CoAP intended to enhance both data security and energy efficiency. This protocol incorporated lightweight encryption techniques that minimised processing demands while maintaining robust security measures, which are essential in sensitive IoT applications. By securing data with minimal overhead, OSCoAP not only protected information but also extended device battery life by 30%, demonstrating that security protocols can be designed to support energy efficiency. This dual benefit is particularly valuable in applications where data integrity and energy conservation are paramount, such as healthcare or industrial IoT.

4.1.2. Routing and Clustering Approaches

Several studies have explored innovative routing and clustering algorithms to extend the operational life and reduce the energy consumption of IoT networks, particularly in Wireless Sensor Networks (WSNs) and Body Sensor Networks (BSNs). These approaches often involve adaptive strategies that respond dynamically to network conditions, ensuring efficient data transmission and balanced energy distribution across nodes.

- La Q et al. [24] developed a machine-learning-based classification model specifically designed for patient monitoring in Body Sensor Networks (BSNs). This model utilises patient status information to adjust transmission levels according to situational needs, reducing power consumption when high transmission rates are unnecessary. For instance, the system conserves energy during periods of low patient activity, such as rest, by lowering transmission frequency. In contrast, it increases the transmission rate in response to critical changes in patient vitals, ensuring timely data delivery to healthcare providers. This adaptive strategy is particularly beneficial for healthcare IoT applications, where balancing energy efficiency with reliable data delivery is crucial to ensure continuous patient monitoring without frequent device recharging.
- Zhang X et al. [25] introduced the Optimal Path Selection Method (OPSM), inspired by ant colony algorithms. OPSM uses the natural foraging behaviour of ants to identify optimal data paths, efficiently balancing load across the network. By selecting the shortest and least congested routes, OPSM minimises energy-intensive retransmissions and reduces latency, thereby enhancing both network performance and longevity. Simulation results demonstrated that OPSM reduced transmission delays and extended network lifetime, making it highly effective for applications requiring continuous data flow, such as environmental monitoring or smart agriculture.
- Pereira H et al. [26] proposed a routing approach that incorporates the Node Importance and Active Path (NIAP) metric. This metric prioritises nodes based on their remaining energy and role in the network topology, enabling more effective load balancing and extending the lifetime of WSNs. By focusing on power consumption at each routing decision, NIAP allows the network to avoid overburdening low-energy nodes, distributing energy use more evenly. The study found that implementing the NIAP metric led to a marked increase in network lifespan, making it particularly suitable for IoT applications in remote or challenging environments where battery replacement is difficult.
- Abdullah S et al. [27] developed an energy-scheduling algorithm that organises sensors into clusters with designated brokers for improved message management. Unlike traditional clustering methods such as LEACH (Low-Energy Adaptive Clustering Hierarchy), which selects cluster heads randomly, this algorithm strategically selects cluster brokers based on their energy levels and proximity to other nodes. By employ-

ing a structured approach to cluster formation and message handling, this method enhances energy management and maintains more operational nodes over time. The study demonstrated that this algorithm outperformed LEACH in energy efficiency and network longevity, making it ideal for energy-constrained environments where maximising node uptime is critical.

- Shen J et al. [28] proposed the Energy-Efficient Centroid-Based Routing Protocol (EECRP), which organises IoT nodes into clusters based on their spatial positions and distributes workload evenly. This protocol calculates the centroid of clusters and assigns it as the routing path, ensuring that each node participates equally in data transmission, which prevents premature energy depletion in any single node. they even workload distribution of EECRP allows for optimised energy usage across the network, extending its lifetime. This protocol is particularly advantageous for long-duration IoT applications, such as environmental and industrial monitoring, where consistent and prolonged network performance is essential.

4.1.3. Resource Allocation and Scheduling Strategies

Research on resource allocation and scheduling in IoT networks has examined various strategies to optimise task management, aiming to reduce energy consumption while meeting Quality of Service (QoS) requirements. By implementing adaptive scheduling and resource allocation mechanisms, these studies address the challenge of managing computational resources across cloud, fog, and edge environments in IoT systems.

- Gai K et al. [29] introduced the Energy-Aware Fog Resource Optimisation (EFRO) model, designed to allocate computing resources based on workload demands. The EFRO model considers energy efficiency alongside QoS requirements, prioritising tasks based on both their energy demands and the service quality they require. This approach enables fog nodes to dynamically adjust their resource usage, optimising energy consumption without compromising performance. By minimising energy usage through strategic workload distribution, EFRO demonstrates the potential of resource-aware models in achieving a balanced, energy-efficient IoT environment that still meets end-user demands for reliability and responsiveness.
- Luo J et al. [30] compared the energy efficiency of containers versus virtual machines in fog computing environments. Containers, which are more lightweight than virtual machines, showed improved energy performance by reducing service delays and enhancing resource utilisation. The study concluded that containers, due to their lower overhead and faster deployment times, are more suitable for IoT applications where rapid, efficient resource allocation is needed to handle fluctuating workloads. This comparison highlights the advantage of containerisation in fog computing, which supports IoT networks by allowing for more flexible and efficient use of computational resources, ultimately reducing overall energy expenditure.
- Abdel-Basset M et al. [31] applied a metaheuristic algorithm for task scheduling in Industrial IoT (IIoT) applications to improve QoS and reduce energy consumption. This algorithm dynamically allocates tasks based on environmental factors and resource availability, allowing the system to adapt to changing demands in real time. The study demonstrated that metaheuristic scheduling provides a robust approach to task management, especially in complex industrial environments where workload patterns are highly variable. By tailoring task allocation to specific contexts, this strategy minimises unnecessary energy use while ensuring that critical tasks are prioritised, making it highly applicable for IIoT settings where both efficiency and performance are critical.

- Ghanavati S et al. [32] proposed a dual-algorithm approach combining ant mating optimisation with an optimised distribution mechanism for scheduling tasks. This hybrid approach proved effective in fog environments, significantly decreasing processing time and reducing energy consumption by managing tasks in a manner that balances load across available resources. The ant mating optimisation algorithm mimics the natural process of mating in ant colonies to select optimal paths for task distribution, allowing the system to adaptively respond to workload fluctuations. This dual-algorithm strategy shows promise in reducing energy usage in fog computing by allocating tasks to nodes in a way that minimises both computational delay and power consumption.
- Hassan H et al. [33] developed a service placement policy tailored for cloud and fog environments, designed to reduce response times and conserve energy by prioritising specific service categories in resource allocation. This policy categorises tasks based on their resource intensity and urgency, allocating higher priority to services that are time-sensitive while conserving energy by delaying non-urgent tasks. By optimising service placement across cloud and fog layers, this approach enhances the overall energy efficiency of the network. The study emphasises the importance of prioritising resource allocation in multi-layered IoT architectures to maintain QoS standards and improve energy performance.

4.2. Subgroup Analyses and Sensitivity Analyses

Subgroup analyses were conducted to examine differences in energy efficiency improvements across various IoT applications and environments. For instance, studies focused on healthcare IoT applications generally demonstrated significant energy efficiency improvements compared to agricultural or industrial IoT applications. Sensitivity analyses revealed that network conditions and specific application requirements greatly influenced outcomes, highlighting the necessity of adaptable energy management strategies that can be tailored to diverse IoT use cases. Overall, the subgroup and sensitivity analyses highlight the necessity of context-specific energy management solutions in IoT networks. Tailoring energy optimisation strategies to the distinct characteristics of each application can improve system performance, extend device lifespan, and promote sustainable IoT network expansion across various sectors.

4.3. Certainty of Evidence

The assessment of evidence in the included studies highlighted variations in the reliability of findings on energy efficiency in IoT systems. Studies employing rigorous experimental designs with consistent methodologies provided reliable insights into the efficacy of energy-efficient IoT technologies. Such studies offered credible evidence on effective strategies, potentially applicable to real-world scenarios in diverse IoT applications.

Conversely, studies based on observational data, theoretical models, or pilot implementations often showed inconsistencies across different conditions, sample sizes, or settings, leading to lower reliability ratings. This variation indicates a need for additional research with standardised methodologies and metrics to improve the generalisability of findings.

Overall, this evaluation underscores the importance of high-quality, well-designed studies that employ consistent metrics, supporting a deeper understanding of energy efficiency strategies in IoT systems. Maintaining rigorous standards in research design will be essential for advancing effective, sustainable solutions for energy optimisation across IoT ecosystems.

5. Discussion

This section discusses the various factors that contribute to increased power consumption in IoT networks, drawing from the comprehensive analysis of related works presented in the Results section. Power inefficiency is a critical concern in IoT systems, as it directly impacts device longevity, network reliability, and operational costs. A thorough understanding of the underlying factors driving excessive energy consumption is essential for developing effective energy management strategies. Based on the literature survey, the causes of power inefficiency are categorised into eleven primary technical issues, each playing a substantial role in determining the overall energy performance of IoT systems. Numerous technical issues can lead to power inefficiency in IoT systems. Addressing these issues is crucial for minimising energy consumption and enhancing the operational efficiency of IoT networks. Based on the result analysis in the previous section, this discussion highlights eleven common technical issues that impact energy consumption in IoT environments, as illustrated in Figure 3.

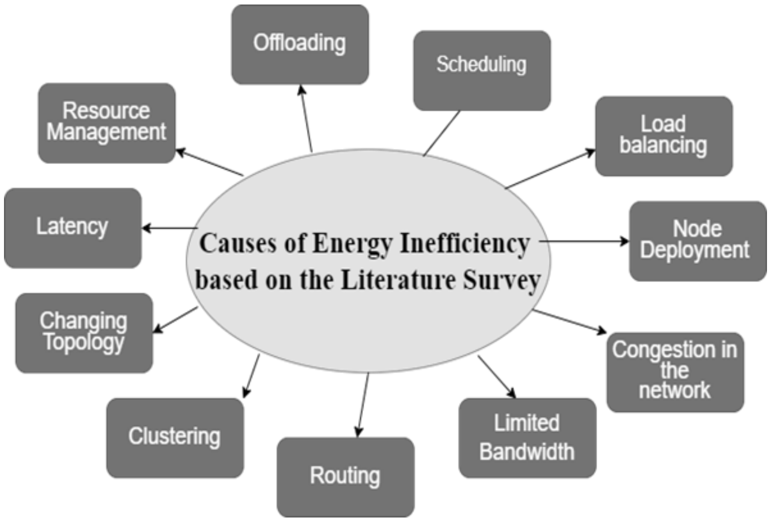

Figure 3. Causes of energy inefficiency.

5.1. Offloading

Offloading in the context of IoT refers to the process of transferring tasks from one computational entity, such as a fog node, to another entity, often a cloud server. Efficient task offloading is fundamental to enhancing the Quality of Service (QoS) while optimising various parameters including energy efficiency, latency, and data throughput. When offloading is executed ineffectively, it can significantly increase processing times and lead to higher power consumption. For instance, if tasks are disproportionately allocated to certain fog nodes while others remain underutilised, this can result in an imbalance that exacerbates energy waste [34].

The implications of inefficient task offloading extend beyond mere processing delays; they can increase the load on specific fog nodes, causing them to consume more power than necessary while underutilised nodes languish unused. Therefore, it is imperative to develop and implement effective offloading strategies that can facilitate informed decision making about where tasks are processed—whether on local fog nodes or in the cloud. Research into these offloading strategies has highlighted the importance of optimising resource allocation and ensuring equitable distribution of tasks to minimise energy use and enhance overall system performance [35].

5.2. Scheduling

Task scheduling in IoT systems involves allocating tasks to various resources in a manner that respects time constraints and performance objectives. Scheduling mechanisms are crucial for improving QoS in IoT systems, particularly given the heterogeneous nature of tasks and their varying requirements [36]. Effective scheduling can lead to a more organised system, reducing complexity and ultimately resulting in lower power consumption.

5.3. Latency

Inefficient task scheduling complicates operations in IoT environments, leading to prolonged processing times and increased power demands. Research indicates that poor scheduling practices can cause significant delays and energy waste, underscoring the need for advanced scheduling algorithms that consider the specific characteristics and requirements of IoT tasks. By optimising task scheduling, researchers can improve energy efficiency and enhance other critical parameters such as bandwidth utilisation and data rates, leading to more sustainable IoT operations.

5.4. Changing Topology

The dynamic nature of IoT environments necessitates frequent updates to wireless network topology. Changes in topology, such as the addition or removal of nodes, can significantly impact data transmission efficiency and reliability [37]. When IoT devices join or leave a network, additional energy and time are consumed during the transition, exacerbating power inefficiencies.

Maintaining a stable network topology is essential for minimising the energy consumed during these changes. Research suggests that predictive algorithms capable of estimating node requirements and anticipating changes in network topology can help mitigate energy inefficiencies by reducing the frequency of node transitions. For example, in applications such as smart buildings, the number of required network nodes may vary seasonally, with greater demand in winter than in summer. Therefore, employing predictive models to estimate the necessary network topology under varying conditions can enhance stability and reduce unnecessary energy consumption.

5.5. Load Balancing

Load balancing refers to the distribution of workloads across multiple resources to ensure optimal performance and prevent any single entity from becoming overloaded. In the context of IoT systems, effective load balancing is crucial for minimising traffic and optimising resource utilisation [38]. As the volume of data and the number of processes in IoT networks increase, load balancing plays a pivotal role in distributing workloads across computing services and routes.

When load balancing is executed effectively, it allows for a more even distribution of energy consumption among devices, reducing the likelihood of power wastage and prolonging the lifespan of IoT networks. Conversely, inefficient load balancing can lead to underutilised nodes and increased energy consumption, as overloaded nodes struggle to manage excessive workloads while others remain inactive. Two primary types of load balancing exist: static, where load distribution is based on predetermined data, and dynamic, which adjusts in real-time based on current workloads [39]. Dynamic load balancing is particularly beneficial in IoT environments characterised by fluctuating demands, ensuring optimal resource utilisation and extending the operational lifetime of the network.

5.6. Node Deployment

The structure and configuration of network nodes are fundamental considerations when establishing an IoT network. Three primary deployment architectures are commonly utilised in IoT systems: cluster-based, peer-to-peer, and master–slave configurations [40]. Selecting the appropriate deployment structure is critical for enhancing QoS and optimising various performance metrics such as data rate, bandwidth, and energy consumption.

An inefficient choice of node deployment can lead to unnecessary energy consumption and prolonged processing times. For instance, deploying an excessive number of nodes can strain network resources, while certain nodes may become overloaded while others remain idle. To optimise the performance of IoT communications, designers should carefully consider factors such as the type and quantity of tasks, the number of IoT devices, and the anticipated workloads when selecting deployment structures [41]. Proper planning in node deployment can lead to significant improvements in energy efficiency and overall network performance.

5.7. Resource Management

Effective resource management is a critical determinant of the performance and QoS satisfaction of OoT systems. IoT devices typically rely on lightweight operating systems, such as TinyOS, FreeRTOS, and Contiki, to manage key resources [42]. Each device requires management across five main components: process management, memory management, energy management, communication management, and file management.

Focusing on energy management can significantly reduce power consumption in IoT systems. For instance, implementing strategies that leverage CPU sleep modes during inactivity can lead to substantial energy savings. Moreover, understanding the various layers of IoT architecture and their interactions is essential for optimising energy usage and enhancing system efficiency. Inefficient resource management can result in increased power consumption, reduced operational time, and ultimately a shorter network lifespan.

5.8. Congestion in the Network

Congestion presents a significant challenge in IoT networks, particularly those incorporating diverse network types, such as wireless sensor networks and vehicular ad hoc networks. The increasing complexity and size of these networks often lead to congestion, resulting in delays in communication and degraded system performance [43].

Congestion negatively impacts QoS in IoT systems by increasing power consumption and reducing the overall efficiency of network operations. Effective routing protocols play a crucial role in mitigating congestion by optimising the paths data take through the network, selecting the shortest and least congested routes for data transmission [44]. Addressing congestion effectively requires robust control over routing paths and balanced workloads among network nodes to maintain the longevity and reliability of IoT networks [45].

5.9. Clustering

Clustering is a key strategy for optimising energy consumption and enhancing communication efficiency in IoT networks. In non-clustered IoT networks, individual nodes transmit data directly to a base station or central hub, leading to high energy expenditure as nodes engage in frequent, often long-range transmissions. This approach can quickly deplete battery life, especially in nodes located far from the base station, and may also overwhelm network resources, causing congestion and reduced network performance. By implementing clustering, IoT networks can reduce these demands and extend the operational lifetime of individual nodes and the network as a whole [46].

In a clustered network, nodes are organised into clusters, with each cluster assigned a cluster head (CH). The CH is responsible for aggregating data collected from member nodes in the cluster and transmitting this aggregated data to the base station. This aggregation minimises the number of direct transmissions to the base station, significantly reducing energy consumption across the network. The centralised structure of clustering conserves energy by reducing the total number of long-distance data transmissions, allowing non-CH nodes to operate in low-power modes until it is time to transmit data to their CH.

5.10. Routing

Routing is a crucial component of IoT communication, determining the pathways through which data packets are transmitted from source nodes to their intended destinations. In IoT networks, where devices are often dispersed over wide areas and operate under limited power and processing constraints, efficient routing becomes essential for achieving optimal network performance and energy conservation. Given the heterogeneous and often dynamic nature of IoT deployments—ranging from urban smart city applications to rural agricultural monitoring—identifying the shortest and most efficient routing paths is necessary to meet Quality of Service (QoS) requirements, including latency, reliability, and throughput.

Longer or suboptimal routing paths can lead to increased energy consumption, as data packets must pass through multiple intermediate nodes, each consuming energy during packet forwarding. These longer paths can also result in processing delays, impacting the real-time responsiveness required in applications such as healthcare monitoring or industrial automation. Consequently, route optimisation is vital for reducing the network's overall energy demand and ensuring timely data delivery [47]. Energy-efficient routing protocols help extend device lifetimes, reduce operational costs, and minimise the need for frequent battery replacements, which is especially valuable in remote or inaccessible areas.

5.11. Limited Bandwidth

Effectively managing bandwidth is essential to optimise the performance and energy efficiency of IoT networks [48]. Bandwidth limitations are common in IoT environments, as these systems often rely on low-power, low-bandwidth communication protocols designed to conserve energy and extend device lifetimes. However, limited bandwidth can restrict the data transmission rates, impacting the ability of IoT networks to support high-throughput applications and affecting the overall network efficiency.

Effective bandwidth management is essential to prevent bottlenecks that can hinder data flow, cause packet loss, and increase retransmissions—all of which lead to higher power consumption and slower processing speeds. In typical IoT networks, the available bandwidth is around 200 kbit/s, significantly lower than traditional network standards. This constraint means that even moderate data traffic can lead to congestion and degrade network performance if not managed effectively. To accommodate this limitation, IoT systems must prioritise bandwidth optimisation techniques to ensure smooth communication, particularly in dense or high-traffic environments.

6. Implications

Each of the technical issues discussed in the previous section contributes uniquely to energy inefficiency in IoT systems. Addressing these challenges requires tailored strategies that align with the specific characteristics and demands of each IoT application. The implication underscores the necessity for a holistic, multi-faceted approach to IoT energy management, combining innovative algorithms, adaptive protocols, and efficient resource allocation frameworks. By developing solutions that account for the eleven causes of power consumption, IoT networks can achieve improved energy efficiency, extended operational lifespans, and reduced maintenance costs, thus supporting sustainable IoT deployment across various sectors.

6.1. Multifaceted Causes of Energy Inefficiency

This review has identified eleven critical factors contributing to energy inefficiency in IoT networks: offloading, scheduling, latency, changing topology, load balancing, node deployment, resource management, congestion, clustering, routing, and limited bandwidth. Each of these factors has a distinct role in influencing the overall energy consumption of IoT systems. By understanding these underlying causes, researchers and practitioners can develop targeted strategies to reduce energy usage and enhance IoT network efficiency.

The findings underscore the importance of a holistic approach to energy optimisation:

- Offloading strategies are essential for balancing workload across devices and cloud/fog resources, ensuring tasks are processed in the most energy-efficient manner possible.
- Advanced scheduling mechanisms can streamline operations by prioritising tasks based on urgency and resource availability, thereby reducing processing time and minimising unnecessary energy expenditure.
- Minimising latency is vital to maintaining system responsiveness, particularly for applications with real-time requirements. By reducing latency, IoT systems can operate more efficiently, as less energy is spent on retransmitting data.
- Stable network topologies help reduce power wastage, as devices avoid frequent reconnections and reconfigurations.
- Load balancing ensures a fair distribution of workloads, which prevents any single device or node from becoming overburdened and consuming excess energy.
- Optimal node deployment minimises data transmission distances and enhances communication efficiency, directly impacting energy use.

Additional factors such as resource management, congestion control, and clustering techniques have been shown to significantly impact energy performance by optimising data flow and reducing transmission redundancies. Moreover, optimised routing protocols can lower energy consumption by identifying the shortest, least congested data paths, while effective bandwidth management prevents bottlenecks and enhances system throughput.

6.2. Main Challenges

Despite advancements in understanding the causes of energy inefficiency, several challenges remain that hinder effective optimisation. Addressing these issues requires ongoing research and the development of adaptive, scalable solutions that cater to the diverse nature of IoT applications:

- Developing sophisticated offloading and scheduling algorithms is challenging, particularly in heterogeneous environments with diverse task requirements and dynamic conditions. Efficient task management demands real-time adaptability, which can be resource intensive.
- Minimising latency is critical for real-time IoT applications. However, achieving low latency without sacrificing energy efficiency is difficult, as shorter response times often require additional processing resources.
- IoT networks are inherently dynamic, with devices frequently joining or leaving the network. Managing these topology changes without increasing power consumption remains a major challenge, and predictive algorithms are needed to anticipate and adjust to these changes.

- The diversity of IoT devices in terms of capabilities and communication paths complicates load balancing. Failure to balance workloads effectively can lead to energy inefficiencies and degrade overall system performance.
- Coordinating resources across communication, memory, and energy management layers is critical for IoT performance. Balancing these resources to avoid bottlenecks while maintaining system efficiency is a complex task.
- As IoT networks expand, congestion becomes a growing issue, affecting data transmission rates and increasing power consumption. Effective congestion control requires adaptive routing protocols that can dynamically respond to changing traffic patterns.
- Clustering reduces energy consumption by aggregating data at designated cluster heads before transmission. However, selecting optimal cluster heads and defining cluster sizes remains challenging, and techniques such as machine learning and fuzzy logic show promise but need further refinement.
- Identifying energy-efficient routing paths in heterogeneous IoT networks is essential. Developing advanced routing protocols that adapt to varying conditions and minimise energy usage is an ongoing challenge.
- Optimising bandwidth allocation is critical for maintaining Quality of Service (QoS) in IoT systems. Balancing bandwidth without compromising service delivery is particularly challenging in networks with limited capacity.

6.3. Recommendations for Optimising Energy Efficiency in IoT Systems

To optimise energy efficiency in IoT networks, an integrated framework is necessary to guide the development of sustainable and high-performance systems. This framework should include the following:

- Clearly defining and analysing the specific energy-related challenges in IoT networks is crucial for targeted interventions.
- Understanding the unique requirements of different IoT applications and environments enables customised solutions.
- Addressing current limitations in IoT systems, such as insufficient offloading mechanisms or inadequate scheduling protocols, is essential for developing efficient solutions.
- Integrating advanced technologies, such as machine learning, artificial intelligence, and bio-inspired algorithms, can enhance adaptability and predictive capabilities, enabling proactive energy management.
- Ongoing validation through real-world testing and simulation is essential to ensure the practical effectiveness of energy-efficient protocols and algorithms across diverse IoT applications.

Implementing these recommendations can provide a comprehensive roadmap for enhancing energy efficiency in IoT systems, facilitating the development of robust, cost-effective, and sustainable networks.

6.4. Problem Identification and Gap Addressing

The first step in establishing an effective framework for IoT energy efficiency is identifying existing problems and addressing gaps in current systems. A thorough analysis of technical issues contributing to energy inefficiency is essential. Key issues include the following:

- Inefficient Offloading and Scheduling Mechanisms: Current systems often lack effective task offloading and scheduling protocols, resulting in suboptimal energy usage.
- High Latency and Dynamic Topology Changes: The challenge of reducing latency and managing changing network topologies persists, impacting energy consumption and system responsiveness.

- Inadequate Load Balancing and Node Deployment: Ineffective load distribution and suboptimal node placement can lead to increased energy consumption and reduced network performance.
- Resource Management: Effective resource coordination across IoT layers remains challenging, with current systems often struggling to balance energy, memory, and processing resources efficiently.
- Network Congestion and Clustering Inefficiencies: Managing congestion and optimising clustering structures are critical for improving IoT system efficiency. Issues such as inefficient cluster head selection reduce energy performance.

To address these gaps, researchers and practitioners should conduct detailed reviews of the literature, identify technological limitations, and develop targeted strategies to reduce energy consumption. By systematically addressing these challenges, IoT networks can achieve improved energy efficiency without compromising QoS levels.

7. Recommended Framework

The recommended framework outlines key strategies to enhance energy efficiency in IoT systems, focusing on optimising protocols, leveraging adaptive algorithms, and designing resilient network architectures. By implementing these components, IoT networks can achieve improved energy performance, scalability, and adaptability across various applications.

7.1. Optimising Communication Protocols

Efficient communication protocols are fundamental for reducing energy consumption in IoT networks. Two critical protocols, Constrained Application Protocol (CoAP) and Message Queuing Telemetry Transport (MQTT), play a central role in IoT data exchange. Challenges, such as high latency and inefficient bandwidth usage, arise when protocols like CoAP and MQTT are not optimised for energy efficiency. By modifying these protocols to better align with energy efficiency requirements, IoT networks can achieve significant improvements. For example, implementing a centralised resource model in CoAP can minimise the frequency of server updates, thereby conserving energy by reducing redundant transmissions. Similarly, fine-tuning MQTT configurations, such as adjusting Quality of Service (QoS) levels and employing message queuing, can reduce network load and lower power consumption.

7.2. Implementing Fuzzy Logic Systems

The lack of adaptive mechanisms for real-time task prioritisation creates inefficiencies in load balancing, scheduling, and resource allocation, particularly in dynamic IoT environments. Fuzzy logic systems enhance decision making in IoT networks by dynamically adjusting operations, such as offloading, load balancing, scheduling, and clustering. In scenarios such as healthcare IoT applications, fuzzy logic enables prioritisation of tasks based on urgency and resource availability, which leads to faster processing and optimised energy use. The adaptability of fuzzy logic allows IoT networks to respond to changes in workload and device status in real time, thus extending device lifetime and improving system responsiveness.

7.3. Utilising Bio-Inspired Algorithms

Routing and clustering inefficiencies in IoT systems lead to higher energy consumption and reduced performance. Bio-inspired algorithms draw from natural processes to address complex optimisation problems in IoT. Techniques, such as the Bat Algorithm and Ant Colony Optimisation, are effective in solving resource management challenges by identifying optimal task paths and distribution strategies. These algorithms enhance energy efficiency by adapting to the dynamic needs of IoT networks, balancing tasks and resources, and enabling efficient routing and clustering. For example, Ant Colony Optimisation can be used to dynamically select the shortest, least congested routes, reducing energy consumption across IoT systems.

7.4. Enabling Technologies

IoT systems encounter significant challenges, including inefficient clustering, poorly planned node deployment, and the lack of effective coordination among limited resources. Addressing these issues is essential for improving energy efficiency and overall system performance. Several enabling technologies offer promising solutions to these challenges, playing a crucial role in advancing energy-efficient and high-performing IoT systems. These technologies are particularly effective in tackling the complex demands of modern IoT networks:

- Wireless Sensor Networks (WSNs): WSNs are comprised of sensor nodes that detect and relay data. Improving WSNs through optimised clustering, strategic node distribution, and efficient path selection can increase energy efficiency while meeting Quality of Service (QoS) requirements. By managing constraints such as limited energy resources and memory, WSNs can significantly contribute to sustainable IoT operations.
- Fuzzy Logic Systems: As a predictive technology, fuzzy logic is adaptable for various IoT tasks, such as load balancing and task scheduling. Its ability to adjust to specific system requirements makes it a valuable tool for energy optimisation, allowing for tailored solutions that reduce unnecessary power use while ensuring task prioritisation and resource allocation.
- Bio-Inspired Algorithms: These algorithms provide solutions inspired by biological processes to solve computational problems in IoT. By implementing bio-inspired optimisation techniques, IoT systems can improve routing and clustering efficiency, leading to better energy management and enhanced overall performance.

7.5. IoT Network Design Concepts

IoT networks frequently face challenges such as bottlenecks, single points of failure, and suboptimal routing protocols that contribute to increased energy consumption. To enhance energy efficiency, it is essential to thoughtfully design IoT networks with a focus on robust architectures and effective routing mechanisms. Key network design concepts include the following:

- Centralised vs. Distributed Networks: In centralised networks, data processing occurs through a single gateway, which can create bottlenecks and single points of failure. Conversely, distributed networks utilise multiple gateways, enhancing flexibility, scalability, and resilience while reducing latency. Transitioning to distributed architectures is recommended for achieving robust, energy-efficient IoT networks capable of handling diverse and dynamic applications.
- Routing Mechanisms: Effective routing protocols are essential for minimising energy consumption by optimising data flow between devices. By implementing adaptive routing algorithms that dynamically select the shortest and most efficient paths, IoT systems can reduce communication delays and energy usage. Developing adaptive protocols that can respond to real-time changes in network conditions is critical for maintaining energy-efficient operations.

7.6. Simulation Tools for Validation

Validating energy-efficient strategies presents challenges due to the limited availability of effective testing and simulation in real-world IoT scenarios. Simulation tools play a critical role in overcoming this limitation by enabling the validation and optimisation of proposed strategies for IoT networks. The following tools are recommended to test the effectiveness of the framework:

- Data Collection for CoAP: Using historical environmental data (e.g., temperature and humidity metrics) from sources such as the Intel Berkeley Research Lab can help evaluate CoAP modifications and assess how protocol adjustments impact energy efficiency.
- Eclipse 4.19 and MATLAB 2020b for Fuzzy Logic Systems: These platforms enable the simulation of IoT environments to test fuzzy-logic-based solutions. MATLAB, in particular, can generate fuzzy outputs that inform resource allocation and task prioritisation, providing insight into how fuzzy logic improves energy performance.
- PureEdgeSim for Bio-Inspired Algorithms: PureEdgeSim is effective for modelling IoT environments across various computing layers. It allows researchers to test algorithms such as the IoT-Mist Bat-Inspired Algorithm (IMBA) under different workloads, providing a clear assessment of energy savings and system efficiency improvements in real-world scenarios.

7.7. Integrating the Framework

By integrating the above strategies and technologies into a cohesive framework, IoT stakeholders can create energy-efficient, high-performing networks. This holistic approach not only targets reductions in energy consumption but also facilitates the development of more sustainable and adaptable IoT ecosystems capable of supporting the diverse needs of modern applications. The recommended framework encourages the IoT community to adopt a data-driven, adaptable approach to address the complexity and energy demands of growing IoT networks, thereby contributing to sustainable innovation and broad adoption across various sectors.

8. Future Directions

This systematic review has identified several key gaps in current research and areas that warrant further exploration to advance energy efficiency in IoT systems. Addressing these gaps can support the development of more robust, sustainable, and scalable IoT solutions. The following recommendations outline the primary areas for future research:

- Many of the reviewed studies lack experimental validation, as proposed methods are often tested only in simulated environments. While simulations offer valuable insights, real-world testing is essential to assess the effectiveness and scalability of energy-saving techniques under practical conditions. Experimental validation would help determine how well proposed algorithms, protocols, and strategies perform in diverse settings, from industrial IoT to smart cities and healthcare applications. Conducting field studies and pilot projects will provide the IoT community with critical data on potential deployment challenges, practical energy savings, and long-term impacts on device lifespan and maintenance costs.
- A significant barrier to synthesising findings across studies is the lack of standardised metrics for evaluating energy efficiency in IoT networks. Current studies use varying criteria and metrics to measure energy consumption, making it difficult to compare results and draw generalisable conclusions. Standardised metrics, such as energy per transmitted bit, energy per task completion, or lifetime energy usage, would facilitate a more uniform evaluation framework. Establishing a common set of performance indicators for energy efficiency will enable researchers to better assess the effectiveness of different approaches and support consistent, repeatable experiments that build on each other's findings.

- Future studies should incorporate a wider range of contextual factors, such as environmental conditions, device density, network topology, and application-specific requirements. For instance, the energy demands of IoT systems can vary significantly based on environmental factors such as temperature and humidity, which may affect sensor accuracy and power consumption. Similarly, application requirements differ across fields—healthcare IoT systems, for instance, may prioritise real-time data processing and reliability, while agricultural IoT systems might prioritise low-cost, long-range deployments. By considering these diverse factors, researchers can develop more adaptive, context-aware solutions that perform well across various environments, contributing to more versatile and resilient IoT systems.
- The integration of advanced technologies, including artificial intelligence (AI) and machine learning (ML), presents promising opportunities for adaptive energy management in IoT networks. AI and ML can enable real-time energy optimisation by dynamically predicting workload, adjusting task scheduling, and automating resource allocation based on historical data and current conditions. For example, machine learning algorithms could predict data transmission needs and optimise sleep–wake cycles, reducing unnecessary power consumption. AI-driven energy management systems could also facilitate self-healing networks that detect and mitigate issues such as node failure or congestion, improving both energy efficiency and system reliability. Future research should further explore how these technologies can be leveraged to make IoT systems more responsive and energy-efficient, especially in complex, large-scale deployments.
- While most studies focus on optimising battery-based energy use, hybrid energy solutions that combine traditional batteries with renewable sources (e.g., solar or kinetic energy) have potential for extending IoT device lifespans. Research on integrating hybrid power systems with energy-efficient protocols and algorithms could enable IoT deployments in remote areas where regular maintenance or battery replacement is difficult. Hybrid solutions also align with global sustainability goals by reducing dependency on conventional power sources. Future studies could investigate the feasibility of hybrid energy solutions, the technical challenges of integrating them with IoT devices, and the cost–benefit analysis for different applications.
- Edge and fog computing play a significant role in reducing data transmission energy costs by bringing data processing closer to the data source. However, more research is needed to understand the optimal distribution of computational tasks between edge, fog, and cloud layers, especially in multi-layered IoT architectures. Future studies should explore how to balance workload distribution across these layers for maximal energy savings while maintaining Quality of Service (QoS). By investigating adaptive frameworks that leverage the strengths of each layer, researchers can develop more efficient task allocation strategies, minimising latency and energy consumption in high-density IoT deployments.
- As IoT systems continue to expand, securing data becomes increasingly crucial; however, traditional security protocols often impose high energy costs. Future research should focus on designing lightweight, energy-efficient security protocols that protect data integrity and privacy without significantly impacting energy performance. For instance, researchers could investigate adaptive security mechanisms that adjust protection levels based on data sensitivity or network conditions. This would allow IoT networks to balance security and energy efficiency, supporting applications with high security demands, such as healthcare or finance, while minimising energy usage.
- Establishing standardised testing frameworks and benchmarking tools for energy efficiency research in IoT would streamline comparisons across studies. Such frame-

works could include guidelines on experimental setup, data collection, and analysis, as well as standardised datasets for benchmarking purposes. Benchmarking tools could facilitate consistent testing of algorithms, protocols, and hardware components, offering researchers a baseline for evaluating energy performance. Standardised tools and frameworks would encourage reproducibility, foster collaboration, and accelerate progress in energy-efficient IoT research.

9. Conclusions

This systematic review has provided a comprehensive examination of the factors contributing to energy inefficiency in Internet of Things (IoT) networks. By analysing a broad spectrum of literature, we identified critical technical challenges, including issues with offloading, scheduling, latency, dynamic network topology, load balancing, node deployment, resource management, congestion, clustering, routing, and limited bandwidth. These findings underscore the complexity and multifaceted nature of energy consumption in IoT systems.

The results of this review highlight the urgent need for targeted interventions to optimise energy efficiency in IoT networks. To address these challenges, the proposed framework emphasises the importance of utilising advanced communication protocols, implementing fuzzy logic systems, and leveraging bio-inspired algorithms. In addition, the framework incorporates enabling technologies and thoughtful network design principles to improve overall system resilience and performance.

Key recommendations derived from this review include the following:

- Modifying protocols, such as CoAP and MQTT, to enhance energy efficiency without compromising data integrity and responsiveness.
- Using fuzzy logic to improve decision making for resource allocation, task prioritisation, and load balancing in dynamic IoT environments.
- Applying nature-inspired algorithms to optimise resource management, routing, and clustering, thereby improving energy distribution and network longevity.
- Transitioning towards distributed network designs that reduce congestion, improve scalability, and minimise single points of failure for more resilient IoT networks.
- Utilising simulation tools to validate the proposed strategies and assess their impact under various IoT network scenarios, ensuring that the framework remains robust and adaptable.

By systematically addressing these challenges, stakeholders in the IoT ecosystem can significantly improve energy efficiency and overall system performance. This structured approach not only supports the sustainability of IoT networks but also contributes to the broader goal of developing intelligent, scalable systems capable of meeting future demands.

In conclusion, this review has laid a solid foundation for future research and development in IoT energy optimisation. The insights gained provide a roadmap for advancing energy-efficient solutions and encourage further exploration of innovative strategies to address ongoing challenges. As IoT continues to expand across sectors, adopting sustainable practices and refining frameworks such as the one we proposed will be essential to supporting the growth and widespread adoption of IoT technologies.

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