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Balancing Energy Consumption and Connectivity through Energy-Efficient Protocols for Sustainable Networking in Smart Cities

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ABSTRACT

This paper focuses on the challenges and opportunities of achieving sustainability in smart cities. It depends on maintaining the balance between energy efficiency and connectivity through energy-efficient protocols. The study surveys systems with energy-efficient protocols, emphasizing their strengths and limitations in maintaining sustainability in smart cities. The need for energy-efficient protocols in smart city settings is that these protocols dynamically adjust operations to optimize energy consumption within sensor nodes in communication networks while considering parameters: like heterogeneity, traffic patterns, and environmental factors. Evaluation against key performance metrics such as energy consumption, data delivery ratio, network lifetime, and throughput identify promising technologies to achieve an optimal balance between connectivity and energy efficiency in smart cities. It concludes by proposing future research directions and considerations to make the development of sustainable networking solutions rapidly tailored to the evolving landscape of smart cities. This paper aims to present a comprehensive overview of the pivotal role played by energy-efficient protocols in fostering sustainable networking architectures.

Keywords: *Green IoT, Wireless sensor networks, Energy-efficient protocols, Smart cities, Machine Learning*

1. Introduction

In the dynamic landscape of urban development, the emergence of smart cities is a beacon of innovation, promising enhanced quality of life, resource optimization, and efficient service delivery. At the heart of these interconnected urban hubs lies a complex web of networking infrastructures, powering the seamless operation of diverse applications and services. Fig. 1. illustrates the basic smart city infrastructure. However, pursuing sustainable networking in these cities presents a pressing challenge: the delicate balance between energy efficiency and robust connectivity [1].

In recent years, several cities around the world have continued to implement innovative smart city initiatives aimed at enhancing energy efficiency and sustainability. For example, Copenhagen's ambitious goal to become the world's first carbon-neutral capital by 2025 has spurred numerous smart city projects. One notable initiative is the CityFlow project, which uses advanced data analytics and sensor technologies to optimize traffic flow and reduce congestion in the city center. By dynamically adjusting traffic signals based on real-time data, Copenhagen aims to minimize energy consumption and emissions from vehicles [3].

Smart cities, by their very nature, rely on interconnected systems fueled by data-driven technologies. From the Internet of Things (IoT) devices facilitating real-time information exchange to intelligent traffic management systems optimizing transportation, these networks underpin the functionality of urban ecosystems. Yet, this interconnectivity comes at a cost-significant energy consumption and the subsequent environmental impact.

Efforts to curtail energy usage often clash with the demand for uninterrupted connectivity, creating a dilemma that necessitates a paradigm shift in networking protocols.

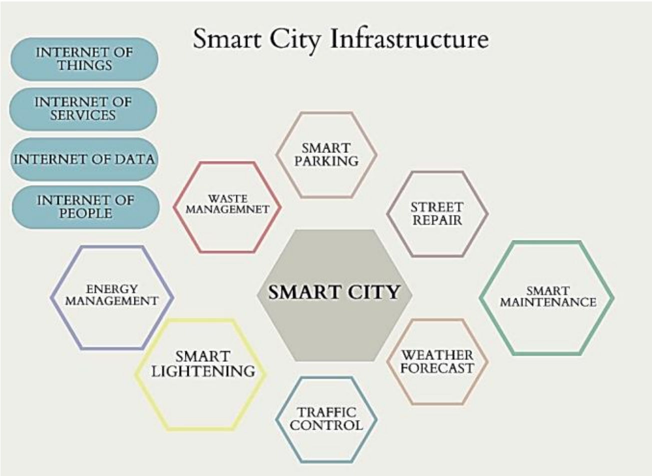

Fig. 1. Smart city's infrastructure.

The imperative lies in devising adaptive protocols that harmonize energy-efficient practices with the imperatives of sustaining high-level connectivity. These protocols dynamically adjust network behaviors, optimizing energy consumption while ensuring reliable connections for critical applications [2].

This paper delves into the critical juncture where sustainability, technological innovation, and urban development intersect. It seeks to explore the challenges posed by energy-intensive networking infrastructures in smart cities and propose adaptive protocols as a viable solution to achieve an equilibrium between energy efficiency and connectivity. By examining the significance of energy-efficient networking and the role of adaptive protocols in reconciling conflicting objectives, this paper aims to provide insights into sustainable networking practices tailored for the smart cities of tomorrow.

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This research paper presents a novel approach to addressing the energy efficiency and connectivity dilemma in smart cities through the development and implementation of adaptive networking protocols. Unlike existing studies that primarily focus on theoretical frameworks or individual case studies, this paper offers a comprehensive analysis of sustainable networking practices, specifically tailored for the complex and dynamic environments of smart cities. Additionally, the paper introduces a systematic methodology for evaluating the effectiveness of adaptive protocols in real-world urban settings, providing valuable insights for policymakers, urban planners, and technology developers. Through its interdisciplinary approach and practical recommendations, this paper contributes significantly to the existing body of knowledge on sustainable networking in smart cities, paving the way for a more sustainable and connected urban future.

The organization of this research paper is given as follows. The first section is an introduction that provides an overview of the challenges and opportunities in sustainable networking for smart cities and highlights the necessity for adaptive protocols. The second section is a literature review, in this section, a detailed review of sustainable smart cities is presented, these studies have been evaluated on networking mode between communication devices, technologies adopted to control energy consumption, and AI/ML technologies to provide a comprehensive solution to maintain sustainability in smart cities. After analyzing all these scenarios from a broader spectrum, we have narrowed down the communication technology to only wireless sensor networks, and protocols to energy-efficient protocols to embed them with AI mechanisms to provide an energy-efficient solution and produce better results than the conventional mechanisms. After that systems with heterogeneous energy efficient protocols are reported and analyzed on chosen parameters like energy consumption, data delivery ratio, network lifetime, and throughput to give a deep insight into their strengths and limitations. After that research objectives and research novelty are discussed. The main section is dedicated to protocol utilization in the communication of devices for maintaining sustainability in smart cities. After this evaluation discussion are available. In the end, this paper has concluded with future directions to motivate researchers to contribute and explore this domain further.

2. Literature Review

The IoT network necessitates the interconnection and establishment of communication links among a vast and diverse array of ubiquitous devices, resulting in the handling of substantial amounts of data. This is particularly challenging due to limitations in computing capacity and battery life, as well as other factors. Another aspect to consider is the environmental cost, of the global technological advancements that have occurred over the past few decades. The proliferation of billions of IoT devices necessitates a significant amount of energy, as these devices generate massive amounts of data that traverse networks. Additionally, the billions of batteries used to support these IoT devices are discarded and needed throughout their life cycle. The reviews based on sustainability measurements and measures for improvement are being analyzed to identify the gap in a specific domain.

Mohanty et al [1] have provided an introductory review of smart cities and explained their working. Traditional networks work more flexibly with the services and provide a sustainable environment. Smart cities provide smart infrastructure, energy, health care, and technology. Transforming traditional cities into smart cities highlights the importance of information and communication technology. These standards can help in maintaining growth, quality, efficiency, and most importantly safety. Challenges in designing smart cities are merely discussed in the paper which offers opportunities to work in cost maintenance, efficiency building, communication, and security.

Angelidou et al. [2] have delved into the capacity of smart city methodologies and tools in advancing sustainable urban development within the environmental sphere. Emphasizing the necessity for a more methodical inquiry into the interplay between smart and sustainable cities, the study predominantly centers on practical implementations. The research has scrutinized 32 smart city applications sourced from the Intelligent/Smart Cities Open Source (ICOS) community, specifically focusing on their relevance to environmental sustainability. The comprehensive analysis encompasses various elements such as addressed environmental concerns, strategies for mitigation, innovative mechanisms, the role of information and communication technologies, and the overarching outcomes. The outcomes highlight a fractured landscape in both policy and technical dimensions of smart and sustainable cities. The study has uncovered numerous unexplored prospects for smart sustainable development that remain largely undiscovered. This fragmentation is observed across all categories of environmental challenges in urban settings. However, it's crucial to acknowledge the study's limitations due to the relatively small number of applications examined. Nevertheless, the research underscores the potential for smart city applications to significantly influence sustainable urban development. The implications of these findings extend to policymakers, offering insights to bolster their proactive role on local and global stages. Furthermore, the delineation of market niches for smart city applications holds significance for developers, user communities, and digital entrepreneurs.

Alsamhi, Saeed [3] has delved into the concept that in the effort to make cities smart, greener (through the concept of green IoT), and sustainable, there are surely many challenges that need to be tackled. Carbon footprint, energy consumption, and pollution are the main challenges when sustainable infrastructures are discussed. Green cities should be eco-friendly for faster and more comfortable adaption. This paper has provided a comparative review of many strategies that aim to attain sustainable eco-friendly smart cities. Integration of IoT in many aspects like e-healthcare, home automation, industry digitization, and transportation autonomy are discussed. The main focus is to present IoT as a sustainable solution for maintaining public safety, energy efficiency, and minimizing pollution. Further, this paper has elaborated that combining AI with green ICT principles can be a very effective solution to decrease energy consumption and cutoff carbon emissions.

Bruneo, Dario [4] has emphasized that utilizing open technologies is the ultimate solution for transforming a city into a smart city. This paper has discussed an initiative in Italy to develop a smart city with great IoT technologies. Affordable sensor devices and intelligent services have been implanted to achieve the goals of green IoT with the Stack4Things framework. This paper in particular has discussed the challenges of integration in implanting the project and some specialized solutions for continuous monitoring of the environment and efficient management of parking facilities.

Alsamhi, Saeed H., et al. [5] have delved into the integration of IOT and the potential challenges associated with it. Besides the numerous benefits of IOT, many challenges are also embedded with it. It mainly includes pollution, e-waste generation, and energy consumption. To minimize carbon emissions and the generation of e-waste, the concept of "green IoT" is widely adapted to build sustainable cities. This paper provides a comprehensive review of potential technologies related to green IoT.

Pattnayak, et al. [6] have highlighted that cloud service with the combination of high-speed broadband networks provides potential research areas for further investigation. Simultaneously, sensor networks employing various wireless technologies in eco-friendly smart cities provide access to information regarding the flow of goods, equipment status, and environmental conditions. These networks also enable remote control, promoting the development of environmentally conscious smart cities that prioritize safety. Collaboration among these networks is encouraged as sensors, communication technologies, and control systems become more advanced and interconnected. Enabled by the Internet of Things (IoT), big data applications are becoming increasingly essential for smart sustainable cities' operational functioning and planning, contributing to their environmentally sustainable development goals.

Maccani, Giovanni, and colleagues [7] have focused on achieving harmony in the implementation of IT government (ITG) and incorporating smart city functions (SCF) with the help of local authorities. The paper has focused on the adaptation of the ITG mechanism in local governments and this case study is conducted in Irish cities' authorities. These types of structural mechanisms can be adapted in ITG. Integrated, Detached, and Traditional. Comparison is made based on parameters like decision-making authority, alignment with IT function, and overall governance. These observations can help make the decisions related to the adaptive challenges faced by SCFs.

Ahad, Mohd Abdul, et al. [8] have discussed that enabling technologies in smart cities is the most important factor in designing their infrastructure and providing facilities to comfort the users. This paper summarizes many frameworks and research that have been conducted in this area. Attaining sustainability is the biggest challenge in developing smart cities. The authors have discussed the main frameworks and technologies to build the architecture of smart cities while maintaining sustainability. The Internet of Things (IoT) provides a foundation for all of this. Still, the most concerning areas are providing security and privacy within the sustainable environment. For this, this paper has provided a comparison of security protocols and their implementation to give an insight into security frameworks in smart cities.

Razmjoo, and colleagues [9] have extensively reviewed the potential and limitations of enabling technologies in smart cities. It provides extended examples and categorizes the challenges in three categorical areas: technical, socio-economic, and environmental. This paper summarizes the best practices for building sustainable smart cities.

Verma et al. [10] have commenced by presenting an in-depth exploration of energy management within Green IoT, highlighting the challenges stemming from the extensive utilization of key IoT devices. The study has extensively examined diverse approaches aimed at reducing energy consumption in IoT ecosystems. These include the optimization of data centers for enhanced efficiency, the implementation of energy-conscious data transmission from sensors, and the innovation of energy-efficient solutions. Acknowledging the constrained energy sources powering IoT devices, such as batteries, the paper has delved into addressing energy efficiency concerns across various IoT networks. It introduces multiple framework models for Green IoT, alongside proposing energy-efficient designs to elongate the operational lifespan of IoT devices.

Moreover, the paper has scrutinized strategies for green IoT, offering recommendations to realize objectives in this domain. Additionally, it undertakes a comparative analysis considering techniques, classifications, constraints, and other pertinent factors. This endeavor aids researchers in acquiring comprehensive insights and refining existing methodologies for superior energy management in forthcoming practices.

Akin-Ponnle, et al. [11] have explored the crucial challenge of powering Internet of Things (IoT) nodes within smart cities using sustainable energy sources amid the COVID-19 pandemic's impact on remote interactions. The focus lies on energy harvesting as a viable solution for enabling IoT devices to harness energy from diverse environmental reservoirs. A comprehensive review is conducted of potential energy sources available within urban settings, drawing upon existing literature. By highlighting the significance of aligning

Table 1: A parametric analysis of previous works in green IOT

Ref	Major Contribution	RFID	WSN	M2M	Energy harvesting	Carbon Footprint	Social Impact	AI/ML	Recycling/ policies
[1]	Discusses the different components of a smart city, including smart infrastructure, smart transportation, smart energy, smart healthcare, and smart technology	✓	✓	✓	×	×	×	×	×
[2]	Emphasizes the importance of sustainability in smart city development and highlights the challenges and best practices associated with it	×	×	×	✓	✓	✓	×	×
[3]	Explores the integration of IoT technologies into various aspects of smart cities, including environmental monitoring, e-healthcare, transportation autonomy, industry digitalization, and home automation	×	×	×	✓	✓	✓	✓	✓
[4]	Strategically placing affordable sensor-powered devices throughout the urban landscape, a diverse range of intelligent services has been implemented	✓	✓	✓	×	×	✓	✓	✓
[5]	Green IT concepts to create sustainable and eco-friendly public services	×	×	×	✓	✓	✓	✓	✓
[6]	Highlights that the proliferation of IoT devices has led to increased energy consumption, electronic waste (e-waste) production, and carbon emissions	✓	✓	✓	✓	✓	✓	×	×
[7]	Sensor networks employing various wireless technologies in eco-friendly smart cities provide access to information regarding the flow of goods, equipment status, and environmental conditions	✓	✓	✓	✓	✓	✓	×	×
[8]	Three types of ITG structural implementation are identified: Detached, Integrated, and Traditional. These are compared in terms of their orientation, decision-making authority, alignment with the IT function, and the overall municipal organization	✓	✓	✓	✓	✓	×	×	×
[9]	Need for efficient computing solutions to reduce service response times in IoT applications.	×	×	×	✓	✓	✓	✓	✓
[10]	Demonstrates the effectiveness of using neuro-fuzzy logic for managing resources and creating dynamic clusters in sustainable IoT devices for green smart city applications	✓	✓	✓	×	×	✓	✓	✓
[11]	Computational optimization algorithms have proven effective in optimizing energy consumption and reducing pollution and greenhouse gas emissions	✓	✓	✓	×	×	✓	✓	✓
[12]	Categories challenges into three main areas: technical, socio-economic, and environmental, providing specific examples within each category	✓	✓	✓	✓	×	×	✓	✓
[13]	The identification of market niches for smart city applications is of interest to developers, user communities, and digital entrepreneurs	×	×	×	✓	✓	✓	✓	✓
[14]	Emphasize the importance of tailoring energy sources to specific applications and suggest that energy scavenging should occur in proximity to where it is needed for IoT devices and wireless sensor networks, ultimately contributing to the automation and optimization of smart cities	✓	✓	✓	×	×	✓	✓	✓
[15]	A comparative study based on techniques, types, limitations, and other factors to assist researchers in gaining insights into this domain and improving current practices for better energy management in the future	×	×	×	✓	✓	✓	✓	✓
[16]	The study emphasizes the need for machines, sensors, communication networks, clouds, and the internet to work harmoniously to enhance energy efficiency and mitigate carbon emissions.	✓	✓	✓	×	×	✓	✓	✓

energy sources with specific applications and advocating for localized energy scavenging to support the energy needs of IoT devices and wireless sensor networks, this localization is projected to play a pivotal role in the automation and optimization of smart cities.

Hasmawaty [12] has focused on the potential of ICT technologies to transform public services into sustainable solutions to protect the environment. The green smart cities combine the concept of smart cities with green IoT, in which we adapt technology with sustainable environment solutions to reduce energy consumption. This paper has taken the case study of the South Sumatra government and their adoption of green IoT in developing a greener smart city. The findings of this case study highlight the many sustainable solutions for achieving green IoT with controlled carbon emissions and lesser pollution. This study has provided many sustainable solutions and discussions for achieving sustainable growth by adapting the smart cities concept.

He, Ping, and colleagues [13] have embraced the fact that energy efficiency is a crucial need for a sustainable environment and a healthy society. Energy resource management and optimizing energy resource management should be the main focus of researchers to work on and draw mechanisms to achieve a sustainable and efficient environment with modern technologies embedded in smart cities. Cloud computing and IoT are enhancing the advancement in smart cities, making people's lives easier and more comfortable. This paper has provided comprehensive research in this area to enlighten the importance of incorporating energy consumption optimization and efficiency to reduce pollution and greenhouse gas emissions in smart cities.

Albreem, Mahmoud A. [14] has emphasized that with evolving technologies in Gulf countries, an energy crisis is arising. IoT technology benefits the people but it also damages the environment by producing massive CO_2 emissions. Energy consumption waste and CO_2 emissions are the massive challenges that the cities have to face in return for embedding technologies to convert their traditional cities into smart cities. Adapting green IoT is the solution to cut these damages down. The main aim of green IoT is to reduce the E-waste and CO_2 emissions due to increased technology adaptation these days. This paper mainly focuses on the challenges in adapting green IoT and strategies that can be embodied to overcome these challenges. It also gives insights into the government policies to overcome these challenges. Overall, this paper has summarized the challenges in adaption GIoT and strategies that have been taken by the government especially of Gulf countries to reduce the consequences of incorporating technology into lives.

Khanh, et al. [15] have highlighted the evolution of technology and the emergence of 5G technology which has revolutionized the connectivity in IoT scenarios and increased their performances dramatically. 5G technology changes the connectivity of IOT for the better in health, agriculture, education, military, and smart cities because it can make the IoT network work more rapidly than ever before and the number of devices that the technology can support, is also humungous. The main challenge addressed in the study is the need for efficient computing solutions to reduce service response times in IoT applications. An edge computing mechanism has been proposed to facilitate IoT technology in smart cities. A small database is established known as an "information map" which allows edge computing to manipulate and store information in smart cities and is utilized to transfer information within the edges. The results show that the proposed mechanism reduces energy consumption and CO2 emissions as compared to previous solutions. This paper concluded with the vision that the proposed system can be expanded to be embedded in smart cities in the future.

Chitahur's study [16] has elaborated on the significance the Internet of Things (IoT) for fostering sustainable smart city applications, each tailored to distinct necessities like energy efficiency, Quality of Service (QoS), and resource management. They present an energy-conscious Dynamic Clustering Routing (DCR) protocol employing a neuro-fuzzy approach to tackle resource limitations within IoT devices. This protocol leverages a dynamic self-organizing neural network for cluster creation within the network. The research encompasses a test-bed analysis that encompasses real-time event identification and sensor node clustering through TinyOS.

3. Research Novelty

Table 1 represents the comparative analysis of the previous review. Review [1] focuses on the communication modes. Some reviews are focused on communication modes and carbon footprint emissions [6-8]. Other reviews are based on energy consumption, CO2 footprints, and AI/ML-based techniques to make IoT mechanisms energy efficient [3,5,9,13,15]. While other reviews mainly focus on communication modes and AI/ML-based techniques to adopt green IoT [4,10-12,14,16]. There is not a single review that covers wireless sensor networks with energy-efficient protocols, energy consumption, and AI/ML-based mechanisms for maintaining sustainability in smart cities. This paper aims to combine all of these aspects in a single repository to give researchers an insight into important aspects related to achieving energy-efficient communication in smart cities.

4. Research objective

The research objectives of this review are as follows

- To report the previous reviews done by researchers on the sustainability of green IoT.
- To give a comparative analysis of previous reviews on chosen parameters.
- To find a gap in previous work and build our review on that.
- To propose a methodology to present our review of systems that combine wireless sensor networks, energy-efficient protocols, and AI/ML mechanisms to give a comprehensive solution to energy efficiency and maintainability in smart cities.

5. Protocols for Sustainable Smart Cities

In smart city deployments, selecting the appropriate communication protocol depends on factors such as power consumption, range, bandwidth, scalability, security, and interoperability requirements. Often, a combination of these protocols is used within the same ecosystem to ensure comprehensive coverage and effective communication between various devices and systems while maintaining sustainability.

Dbibih [17] has proposed an algorithm BMPriority-based CSMA/CA, based on battery energy level and message priority of sensors for accessing transmission channels with better precision. The proposed solution utilized a weighing function for window contention calculations, while the sensor node waits before starting the transmission. The authors claimed that the proposed algorithm protocol outperforms S-MAC, IEEE 802.15.4, and ECA-MAC protocols in terms of optimizing Packet Delivery Ratio (PDR), end-to-end latency, and throughput.

Rani, N, et al., [18] have demonstrated a cluster-based routing algorithm that uses different schemes to make energy consumption efficient. The high energy level nodes in the routing mechanism are used for transmissions and others are used to sense data. This phenomenon is known as cluster-based routing which is used to transmit data at the fastest rate. Hierarchical protocols like LEACH, HEED, TEEN, SEP are used in the proposed solution.

Nadia [19] has proposed an energy-efficient system based on reinforcement learning. The main protocols that are focused on in this solution are IEEE 802.15.4 and the Medium Access Control (MAC) to attain the minimum energy consumption through communication nodes. MAC protocol is used to compute the duty cycle that ensures optimal performance and minimum energy consumption in communication modes in IoT. The combination of reinforcement learning with energy-efficient protocol adaptation provides energy sustainability and Quality of Service (QoS).

Rana, A, K. et al. [20] have elaborated an Advanced Zone-Stable Election Protocol (AZ-SEP). Some information is transferred from the base station. The bunching method is utilized to transfer data to the base station. The proposed adaptive protocol is compared with the clustering hierarchy (LEACH) and it outperformed the conventional protocols by 64% and the simulation results have shown enhanced throughput, data aggregation, and minimal energy consumption.

Chithaluru, P., [21] has proposed Improved-Adaptive Ranking based Energy-efficient Opportunistic Routing protocol (I-AREOR). It is based on relative distance, residual energy, and regional density. It mainly focuses on a clustering approach that clusters the nodes into three categories, First-node death, half-node death, and last-node death. The proposed system gives a solution to the challenging task of extending the time of first node death by utilizing the regional density and residual energy of nodes. This system considers the energy parameters to provide optimal energy consumption between nodes' communication.

Haseeb, K., Din, et al., [22] have demonstrated a secure and intelligent model for sustainable cities using green IoT and it mainly functions on edge computing to achieve lower energy consumption rates. Deep learning has been utilized for data routing. Furthermore, distributed hashing is implemented with a chaining strategy to provide a secure as well as efficient system. These proposed systems outperformed the previous systems in terms of energy consumption, and network throughput.

Mishra, M, and colleagues [23] have elaborated on the importance of clustering mechanisms to group the nodes into clusters. The optimal energy consumption leads to the maximum network lifetime. In this paper, a multi-objective optimization approach is proposed to select the optimal route for data transmission among the transmitting nodes. The proposed system is a two-step approach. The first step is detecting cluster heads for data communication within nodes in clusters. Secondly, the combination of a particle swarm optimization (PSO) algorithm and a genetic algorithm (GA) is proposed to determine the optimal routing path between nodes. LEACH protocol-I is utilized in the proposed system. The simulations show that this system outperforms the conventional systems in terms of energy consumption and network lifetime.

Alvi, A. N., [24] has focused on an Optimal GTS Allocation Mechanism with an Adaptive Duty cycle (OGMAD). IEEE 802.15.4 standard is utilized to focus on low data rate communications within the sensor nodes. It adapts the optimal ‘guaranteed Time Slot” mechanism to improve the link utilization within communication nodes. The simulation results showed that the proposed system provides better duty cycles in the network and optimal energy consumption.

Abdul-Qawy, A. S. H., and colleagues [25] have proposed a scalable and energy-efficient system for wireless nodes in green IoT. It includes 3 main components: (1) a hybrid placement scheme, (2). A heuristic (MSWE) and (3). Cross-layer transmission model for minimum cost management. This model achieves a minimum energy cost from the bottom layer and moves towards to topmost layer for data transmission. The simulation results show that the proposed scheme is better than the conventional protocols regarding energy consumption, network throughput ns stability.

Sodhro, A. H., [26] has demonstrated a Hybrid Adaptive Bandwidth and Power Algorithm (HABPA), and Delay-tolerant Streaming Algorithm (DSA). This system is designed to control the power loss, packet loss ratio, and standard deviation. It is obvious from the simulations that the proposed system is an efficient approach for energy consumption within the communication nodes. This perspective enlightens the importance of sustainability in smart cities.

Alharbi, M. A., [27] has proposed a system that focuses on the combination of the clustering approach with the routing protocol to give a comprehensive solution for energy efficiency within communication nodes. The system relies on the area-based clustering that is derived from the transmission rate with the nodes. Cluster heads are chosen to avoid failure in the routing paths for finding the optimal routing path hop-count is utilized. The results of experimentation show that the system provides improved network lifetime, energy efficiency, and improved network density.

Iala, I., and colleagues [28] have developed an effective and energy-conscious protocol that is better in performance than the conventional protocols in terms of energy consumption and network lifespan. This paper has proposed a new mechanism based on 802.15.4 wireless sensor nodes called Kalman filter-based MAC protocol. It is designed to optimize the energy consumption on nodes. It extends the life span of network nodes. This new protocol optimizes the sleep intervals that happen on the network nodes. The awakening of sensor nodes should happen only when it is needed. It is a postponing-based transmission mechanism that resolves the network collision problem. This mechanism produces better results in terms of energy efficiency and packet delivery ratio.

Deepa, O., [29] has proposed Optimized QoS-based Clustering with Multipath Routing Protocol (OQoS-CMRP) for wireless sensors to reduce energy consumption in wireless sensor nodes. Particle Swarm Optimization (PSO)-based clustering algorithm is applied to create clusters. To find the neighbor nodes The Single Sink-All Destination algorithm is utilized. The performance of the proposed system outperformed the conventional protocols in terms of transmission delay, communication overhead, and energy efficiency.

Maheshwar's study [30] has focused on the clustering and routing algorithm to enhance the network lifetime and minimize the energy consumption within sensor nodes. Butterfly Optimization Algorithm (BOA) is utilized to create a cluster head and Ant Colony Optimization (ACO) is utilized to identify the base station. The mechanism identifies the optimal route based on node degree, residual energy, and distance. The performance metrics of this mechanism are alive and dead nodes, energy consumption, and data packet ratio.

Rami Reddy, and colleagues [31] have proposed a mechanism that is bad for energy recovery nodes in the network to propose an optimal energy consumption algorithm. The combination of Fuzzy-GWO method and energy-efficient routing algorithm is proposed to overcome the network overhead in the most energy-efficient way. The simulations have shown that the proposed mechanism is better than conventional protocols regarding data packet delivery ratio, network throughput, and energy consumption.

Sadek, R. A., [32] has elaborated on an energy-efficient protocol that is based on the combination of the grey wolf optimizer (GWO) and the Tabuse arch algorithm (TSA). this mechanism works on the clustering approach. The clustering heads are identified by utilizing GWO based on the residual energy of nodes and the average distance between the cluster head and the sink nodes. The proposed mechanism enhances the quality of service (QoS) that involves reliability and energy consumption. The simulations show that the proposed system outperforms the conventional protocols regarding network lifetime, throughput, and energy consumption.

Wang, Z., [33] has proposed an improved artificial bee colony algorithm (ABC) that focuses on the clustering of network nodes. By utilizing this algorithm, cluster heads are identified based on cluster head energy, density, and location. This mechanism optimizes the clustering process across the network nodes. The combination of the ABC algorithm with Fuzzy C-mean clustering provides an optimal clustering method to route between the cluster head and the base station. The experimental results have shown that the proposed mechanism is better than the conventional protocols regarding network throughput and energy consumption efficiency.

Elhoseny's study [34] demonstrates a novel swarm intelligent-based clustering and the multi-hop routing protocol to cluster the network nodes more proficiently. The grey wolf optimization algorithm (GWO) is utilized to identify the optimal paths in networks. the selection of cluster heads and their organization is the initial step. then the GWO algorithm is applied. this mechanism incorporates both clustering and the routing processes. This results in the better network throughput and energy consumption efficiency. The simulations show that the proposed mechanism outperforms the conventional protocols.

Sahoo, B. M., [35] has proposed a mechanism based on the clustering approach and a combination of genetic algorithm (GA) and particle swarm approach to provide optimal network performance. Cluster head is identified by utilizing the GA algorithm. GA helps in identifying the cluster head proficiently and PSO helps in finding the optimal route within the sensor nodes of the network. The experimental results show that the proposed system is better in network throughput and energy consumption efficiency.

6. Evaluation and discussion:

Evaluation of the various methods reveals their respective strengths and weaknesses. By analyzing their performance, we gain insights into their suitability for enhancing the sustainability of smart cities.

6.1 Analysis of existing approaches:

Table 2 depicts a diverse array of AI/ML techniques and clustering algorithms applied to improve routing protocols in wireless networks. Each referenced protocol introduces distinct methods to optimize network performance in terms of routing efficiency, energy consumption, data packet ratio, and network lifetime.

Reference [17] implements BMPriority-based CSMA/CA using clustering techniques, focusing on optimizing network throughput and energy consumption efficiency. [18] utilizes Fuzzy C-means clustering, aiming to enhance routing protocols, although specific performance metrics are not detailed. Meanwhile, [19] applies reinforcement learning on IEEE 802.15.4 and MAC protocols, potentially offering adaptive routing solutions. [20] presents the Advanced Zone-Stable Election Protocol (AZ-SEP), emphasizing stability in cluster-based routing.

Deep learning is leveraged in [22] to optimize MAC protocols, while [25] proposes a heuristic model using deep learning for weighted election heuristics, aiming for efficient routing. [23] combines particle swarm optimization and genetic algorithms for clustering, possibly indicating a robust optimization approach. [28] introduces the Multipath Routing Protocol (OQoS-CMRP) to enhance network lifetime and data packet ratio, focusing on multipath strategies.

6.1.1 Reduced Carbon Footprints

Table 2 outlines various technologies, performance metrics, AI/ML techniques, routing protocols, and their associated characteristics in the context of energy-efficient protocols for smart city networking. The following parameters influence the reduction of carbon footprints within smart cities.

Technology Used: The table lists a variety of clustering algorithms and routing protocols utilized in smart city networking. These technologies play a crucial role in optimizing energy consumption and reducing carbon footprints by efficiently managing data transmission and network operations.

Performance Metrics: The performance metrics outlined in the table, such as network throughput, network lifetime, energy consumption efficiency, and data packet ratio, are directly related to energy efficiency and carbon footprint reduction. Optimizing these metrics through the use of energy-efficient protocols can lead to significant reductions in energy consumption and associated carbon emissions.

AI/ML Techniques: The incorporation of AI/ML techniques, such as deep learning and reinforcement learning, enhances the capabilities of energy-efficient protocols by enabling adaptive and intelligent decision-making. These techniques contribute to optimizing network performance and reducing energy consumption, thereby mitigating carbon footprints.

Routing Protocols: The choice of routing protocols plays a critical role in determining the energy efficiency of smart city networks. By selecting routing protocols specifically designed for energy efficiency, such as those listed in the table, cities can minimize unnecessary energy expenditure and reduce carbon emissions.

Outperforms LEACH, HEED, TEEN, SEP Protocols: Several protocols in the table are noted to outperform traditional protocols such as LEACH, HEED, TEEN, and SEP in terms of energy efficiency and network performance. By adopting these advanced protocols, smart cities can achieve significant reductions in energy consumption and carbon footprints compared to conventional approaches.

To summarize all these findings, the technologies and protocols outlined in Table 2 offer valuable insights and tools for controlling carbon footprints in smart cities. By leveraging energy-efficient protocols, incorporating AI/ML techniques, and optimizing network performance metrics, cities can make substantial strides towards environmental sustainability and combatting climate change.

6.2. Limitations

However, limitations persist across these approaches. While the mentioned protocols target various performance metrics, a lack of comprehensive comparative analysis across all metrics exists. Real-world validation is also limited or absent, hindering a full understanding of practical feasibility and performance.

6.2.1 Field Trials in Urban Environments

Conducting field trials in actual urban settings provides an invaluable opportunity to validate the performance of energy-efficient protocols in real-world scenarios. A collaboration between researchers, city authorities, infrastructure providers, and industry partners to deploy prototype networks and IoT devices in urban areas is crucial to analyze network performance on real-time data. By collecting data on network performance, energy consumption, and environmental conditions over an extended period, the practical feasibility and effectiveness of the protocols can be assessed in diverse urban environments. Field trials also allow researchers to identify and address challenges such as signal interference, network congestion, and environmental factors that may impact protocol performance.

6.2.2 Simulation of Various Network Conditions

In addition to field trials, simulations offer a cost-effective and scalable approach to validate energy-efficient protocols under various network conditions. Researchers can leverage simulation tools and platforms to model different urban environments, network topologies, and traffic patterns. By adjusting parameters such as node density, communication range, and mobility patterns, researchers can evaluate protocol performance across a wide range of scenarios. Simulation studies enable researchers to systematically explore the impact of different factors on protocol performance, identify potential bottlenecks or vulnerabilities, and optimize protocol design accordingly.

6.2.3 Collaboration with Industry Partners

Collaborating with industry partners and stakeholders can facilitate the deployment and validation of energy-efficient protocols in real-world settings. Researchers can work closely with companies specializing in IoT devices, network infrastructure, and smart city solutions to integrate prototype protocols into existing systems or deploy pilot projects in urban areas. Industry partners can provide access to resources, expertise, and infrastructure needed for large-scale deployments, while researchers can contribute domain knowledge, technical expertise, and research insights. Collaborative efforts enable researchers to validate protocols in diverse operational environments, gather feedback from end-users, and iteratively refine protocol design based on real-world experiences and observations.

Moreover, scalability, adaptability, and computational complexity remain potential hurdles, impacting their deployment in diverse and dynamic network conditions.

6.3 Evaluation Metrics

Specific performance metrics like network throughput, lifetime, energy consumption, and data packet ratio have been mentioned, but a comparative analysis across all these metrics for each protocol might be lacking.

6.3.1 Real-world Validation

Limited or no real-world deployment and validation of these protocols could be a major drawback, hindering the understanding of their practical feasibility and performance.

6.3.2 Scalability and Adaptability

Some protocols might lack scalability or adaptability in dynamic network conditions, limiting their application in varying environments.

6.3.3 Complexity

Implementing AI/ML techniques or complex algorithms can result in increased computational overhead, affecting the feasibility of these protocols in resource-constrained devices.

7. Future directions

Based on the limitations identified in the existing protocols for wireless network optimization, several future directions could be pursued to advance the field:

7.1 Comprehensive Multi-Metric Evaluation

For future, researchers could focus on developing a unified evaluation framework that comprehensively assesses protocols across various metrics, including network throughput, energy consumption, lifetime, latency, and scalability. This holistic approach would provide a more nuanced understanding of protocol performance in diverse network scenarios.

7.2 Real-World Validation and Deployment

Prioritizing field trials and simulations that closely mimic real-world conditions is essential. Collaborations with industry partners or deploying these protocols in experimental testbeds can validate their efficacy, addressing the gap between theoretical proposals and practical implementations.

7.3 Adaptive and Self-Configuring Protocols

Designing adaptive protocols capable of self-configuration and dynamic adjustment to varying network conditions could be pivotal. These protocols would intelligently adapt to changes in network topology, traffic patterns, and energy availability, ensuring robustness and scalability.

7.4 Optimization for Resource-Constrained Devices

Streamlining protocols to reduce computational complexity and resource requirements is crucial, particularly for devices with limited processing power and energy reserves. Creating lightweight versions of these protocols or optimizing algorithms for efficiency could facilitate deployment in IoT devices and low-power networks.

7.5 Standardization and Interoperability

Establishing standardized protocols that ensure interoperability across different network architectures and devices is vital. This would promote seamless integration and adoption, fostering a more cohesive and efficient network infrastructure.

7.6 Security and Privacy Considerations

Integrating robust security mechanisms into these protocols to safeguard against vulnerabilities and ensure user privacy in data transmission is imperative. Future research should emphasize developing protocols with built-in security features to mitigate potential threats. By focusing on these future directions, researchers can address the limitations observed in existing protocols and pave the way for more efficient, adaptable, and practical solutions for wireless network optimization.

Table 2: Comparative analysis of mechanisms for balancing adaptive protocols and energy efficiency in IoT

Ref.	Technology used		Performance metrics				
	AI/ML techniques	Routing protocols	Network throughput	Network lifetime	Energy consumption efficiency	Data packet ratio	Outperforms LEACH, HEED, TEEN, SEP protocols
[17]	Clustering	BMPriority-based CSMA/CA	✓	✓	✗	✗	✓
[18]	Clustering	Fuzzy C-means	✓	✓	✗	✗	✓
[19]	Reinforcement learning	IEEE 802.15.4 and the Medium Access Control (MAC)	✓	✓	✓	✓	✓
[20]	Clustering	Advanced Zone-Stable Election Protocol (AZ-SEP).	✓	✓	✓	✗	✓
[21]	Clustering	Improved-Adaptive Ranking based Energy-efficient Opportunistic Routing protocol (I-AREOR)	✓	✓	✓	✓	✓
[22]	Deep learning	MAC protocol	✓	✓	✗	✗	✗
[23]	Clustering	particle swarm optimization (PSO) + genetic algorithm (GA) based protocol	✓	✓	✓	✓	✓
[24]	Clustering	IEEE 802.15.4+ an Adaptive Duty cycle (OGMAD)	✓	✓	✓	✓	✓
[25]	Deep learning	heuristic model for multi-stage weighted election heuristic (MSWE) based protocol	✓	✓	✓	✓	✓
[27]	Clustering	MAC protocol	✓	✓	✗	✗	✗
[28]	Clustering	802.15.4 + Kalman filter-based MAC protocol	✓	✓	✓	✓	✓
[29]	Clustering	Multipath Routing Protocol (OQoS-CMRP)	✓	✓	✓	✓	✓
[30]	Clustering	Butterfly Optimization Algorithm (BOA) + Ant Colony Optimization (ACO) based protocol	✓	✓	✓	✓	✓
[31]	Clustering	Fuzzy-GWO based protocol	✓	✓	✓	✓	✓
[32]	Clustering	Grey wolf optimizer (GWO) and the Tabuse arch algorithm (TSA) based protocol	✓	✓	✓	✓	✓
[33]	Clustering	Artificial Bee Colony algorithm-based protocol	✓	✓	✓	✓	✓
[34]	Clustering	Grey wolf optimization algorithm (GWO) based protocol	✓	✓	✓	✓	✓
[35]	Clustering	genetic algorithm (GA) and particle swarm optimization-based protocol	✓	✓	✓	✓	✓

8. Conclusion

This paper summarizes the primary studies related to energy consumption and connectivity through energy-efficient protocols for sustainable networking in smart Cities. The comparative analysis of ML-based systems shows that efficient protocols are better than conventional protocols to provide a secure and efficient communication path between the sensor nodes in wireless sensor networks. Moreover, the integration of these protocols with AI/ML-based mechanisms enhances the network throughput, lifetime, energy efficiency, and latency. These findings offer promising approaches to reduce energy dissipation in IoT-based smart cities and address the pressing need to mitigate carbon footprints associated with the rapid proliferation of sensor devices. Controlling these carbon footprints while developing smart cities is a crucial requirement that needs to be tackled with the utmost priority.

Efficient energy protocols offer enhanced performance metrics and contribute to the overall sustainability and resilience of smart city infrastructures. By optimizing energy consumption and improving network efficiency, these protocols play a crucial role in mitigating environmental impact while ensuring reliable connectivity and service delivery. Despite advancements in this field, there is still huge potential for improvement. This paper contributes in the same direction by providing a review of energy-efficient protocols to achieve maintainability in smart cities.

In conclusion, the review of energy-efficient protocols presented in this paper serves as a valuable resource for researchers, policy-makers, and practitioners striving toward the goal of sustainable networking in smart cities. For researchers, this review offers a comprehensive overview of the latest advancements in energy-efficient protocols for smart city networking. By synthesizing existing literature and analyzing various technologies and techniques, researchers gain insights into the state-of-the-art approaches and emerging trends in the field. This serves as a foundation for further research and innovation, guiding future studies aimed at optimizing energy consumption, enhancing network performance, and reducing carbon footprints in smart city infrastructures.

Policy-makers can leverage the findings of this review to inform the development of regulations, standards, and incentives aimed at promoting energy efficiency and sustainability in smart cities. By understanding the efficacy of different energy-efficient protocols and their potential impact on carbon emissions and environmental sustainability, policymakers can formulate evidence-based policies to support the transition towards greener and more resilient urban environments. Practitioners involved in the design, implementation, and management of smart city infrastructures can benefit from this review by gaining insights into best practices and practical considerations for deploying energy-efficient protocols. By adopting these protocols and integrating AI/ML techniques, practitioners can optimize network performance, enhance energy efficiency, and reduce operational costs while maintaining reliable connectivity and service delivery for smart city residents and businesses.

To summarize it all, the review of energy-efficient protocols serves as a valuable resource for advancing the sustainability agenda in smart cities. By fostering collaboration between researchers, policy-makers, and practitioners, this review facilitates the development and implementation of innovative solutions to address the challenges of energy consumption, carbon emissions, and environmental impact in smart city networking.

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