WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Green IoT Edge Computing Towards Sustainable and Distributed Data Processing

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DOI: https://doi.org/10.55248/gengpi.4.923.52454

A B S T R A C T

The fast expansion of Internet of Things (IoT) devices has resulted in an exponential growth in the collection of data, which poses substantial issues in terms of energy consumption and data processing. Green internet of things edge computing has emerged as a viable method to solve these difficulties. It does this by allowing data processing at the network's edge that is both sustainable and dispersed. This review article presents an in-depth study of the most recent research in the field of green internet of things edge computing. The work focuses on the relevance of this research in terms of attaining energy efficiency, lowering latency, and encouraging sustainability. Additionally, the study delves into related subtopics, such as energy-efficient communication protocols, edge device topologies, and various methods of resource management. This article emphasizes the potential for green internet of things edge computing to revolutionize data processing in internet of things systems by conducting a complete evaluation of current research as well as case studies. This will lead to a future that is both sustainable and efficient.

Keywords: Green IoT, Edge Computing, Sustainable Data Processing, Energy Efficiency, Latency Reduction, Resource Management

1. Introduction

The exponential expansion of connected devices connected to the Internet of Things (IoT) has brought about revolutionary change in a variety of fields, including medicine, transportation, and smart cities. These networked devices create large volumes of data, which need effective processing and analysis. However, typical methods of processing data in the cloud confront substantial hurdles in terms of latency, bandwidth restrictions, and the amount of energy required. As a consequence of this, there is a need for creative solutions that are capable of resolving these issues and enabling data processing that is both sustainable and dispersed.

The processing of IoT data presents a number of obstacles, which threaten to undermine both its effectiveness and its viability. First, the sheer amount of data created by Internet of Things devices may overload centralized cloud-based systems, which can result in difficulties with latency and increasing bandwidth needs. Second, sending all of the data to a centralized point for processing uses a large amount of energy and places a burden on the resources available via the network. Third, when sensitive data is moved to external servers for processing, privacy and security issues develop as a result of the transfer (G. Hong and C. Hanjing, 2021)..

The notion of green internet of things edge computing has evolved as a means of overcoming the constraints imposed by conventional cloud-based data processing. Green internet of things edge computing is a paradigm that involves executing data processing, storage, and analysis at the network's edge, which is closer to the source of the data production. Edge computing decreases latency, improves reaction times, and minimizes the quantity of data that is carried over the network by placing processing closer to the devices. Additionally, it makes it possible to make effective use of resources and supports sustainability by cutting down on energy usage and the amount of carbon footprint left behind (] M. Xu et al, 2021).

The purpose of this article is to investigate the design principles, problems, and possibilities related with environmentally friendly Internet of Things (IoT) edge computing. In addition to that, it intends to explore relevant subtopics such as energy-efficient communication protocols, edge device topologies, and various strategies for resource management (O. Salman, I. Elhajj, A. Kayssi, and A. Chehab, 2015). In addition, the paper demonstrates the practical uses of green internet of things edge computing via the use of case studies and actual world implementations. In conclusion, the study discusses some of the problems that now exist and provides some potential future research routes in order to encourage the development and broad implementation of this game-changing technology.

The purpose of this study is to give significant insights into the possibilities of green Internet of Things edge computing as a solution to the issues in IoT data processing by examining and synthesizing current literature and research efforts in the area. By conducting this investigation, we want to make a contribution to the current efforts that are being made to construct Internet of Things systems that are both sustainable and efficient, with the potential to propel innovation and to benefit society as a whole.

2. Objective

The study sought to achieve the following goals:

- Examine the green Iot edge computing: concept and principle.
- Study the energy efficient communication protocols for green Iot.
- Elaborating theedge device architectures for sustainable data processing.
- Examine the resource management techniques in green Iot edge computing.
- Study the challenges and future direction.
- Result and discussion

3. Methodology

The fast proliferation of Internet of Things (IoT) devices has resulted in exponential data collection, raising worries about energy and data processing. Green internet of things edge computing can solve these problems. Data processing at the network's edge is both sustainable and dispersed. This review looks at the most recent green internet of things edge computing research. This research is important in terms of energy efficiency, latency, and sustainability. The study also discusses energy-efficient communication protocols, edge device topologies, and resource management. This article examines current research and case studies to demonstrate how green internet of things edge computing may alter data processing in IoT systems. Futures that are both sustainable and efficient will emerge.

4. Green IOT Edge computing: Concept AND Principles

4.1. Definition of Green IoT Edge Computing:

Green IoT edge computing is a paradigm that refers to the practice of conducting data processing, storage, and analysis at the edge of the network, closer to the source of data production, in an energy-efficient and sustainable way. It entails installing computing resources at the network's edge, such as edge devices and gateways, in order to allow locally-based data processing and decrease reliance on centralized cloud-based infrastructure. Computing at the edge of the Internet of Things that adheres to the concepts of energy efficiency, optimization of resources, and sustainability makes it possible to achieve quicker reaction times, decreased network congestion, and lower overall energy consumption (D. G. Glance and R. Cardell-Oliver, 2021).

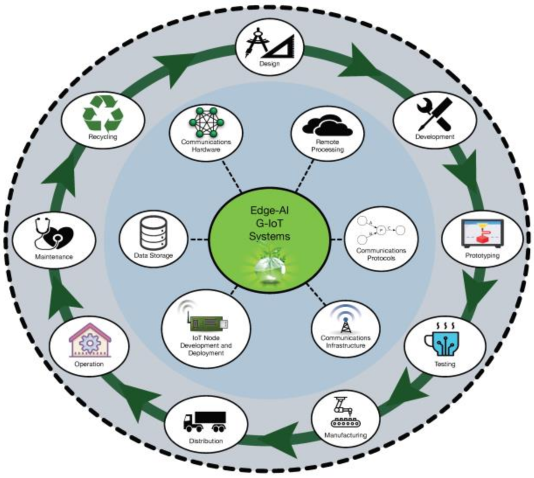

Fig. 1- GREEN IOT SYSTEM AND EDGE AI

4.2 Key Principles and Design Considerations:

• Energy Conservation: Energy efficiency is a fundamental aspect of green IoT edge computing. Edge devices use low-power components, energy harvesting methods, and clever power management algorithms to reduce power usage. Green IoT edge computing reduces energy usage, which reduces environmental impact and allows for longer battery life in resource-constrained devices.

• Reduced Latency: The goal of green IoT edge computing is to reduce latency by processing data closer to its source. Edge computing minimizes network congestion and increases reaction times by eliminating the need to transfer all data to a centralized location, allowing real-time and near-real-time applications. This is especially important for time-critical applications like driverless cars, industrial automation, and healthcare monitoring (M. Satyanarayanan, P. Bahl, R. Cáceres, and N. Davies, 2009).

• Resource Allocation: Green IoT edge computing maximizes computer resource usage by employing localized data processing. Only relevant information is transported to the cloud or data center after it has been analyzed and filtered at the edge, decreasing bandwidth needs and eliminating storage and processing overhead. This leads to more effective resource allocation and lower operating expenses.

• Scalability and Flexibility: Green IoT edge computing solutions are designed to expand effortlessly in response to the increasing number of IoT devices and data volumes. Edge devices are simple to install and connect into existing infrastructure, allowing for dynamic growth and adaptation to changing needs. In quickly expanding IoT environments, this scalability and flexibility allow efficient and agile data processing.

4.3 Benefits

• Reduced Network Traffic: Green IoT edge computing minimizes network traffic by doing data processing and analysis at the network's edge. This minimizes network congestion, bandwidth consumption, and overall network performance.

• Data Privacy and Security Enhancements: Edge computing protects sensitive data by keeping it locally and lowering dependency on data transmission to external servers. This improves data privacy and security, lowering the risks of data breaches and illegal access.

• Insights in Real Time and Context: Green IoT edge computing delivers real-time and context-aware insights by processing data closer to the source. This allows preemptive actions, aids rapid decision-making, and supports applications that demand immediate reaction and feedback.

• Reduced Operational Costs: Green IoT edge computing helps enterprises save money on operating expenditures by reducing data transmission and optimizing resource use. It decreases cloud service utilization, energy consumption, and the requirement for significant network infrastructure.

• Environmental Impact and Sustainability: Green IoT edge computing helps to achieve sustainability objectives by boosting energy efficiency and lowering energy usage. It assists enterprises in reducing their carbon footprint, conserving energy, and developing more environmentally friendly IoT technologies.

5. ENERGY-EFFICIENT COMMUNICATION PROTOCOLS FOR GREEN IOT

5.1 Low-Power Wide Area Networks (LPWANs)

Low-Power Wide Area Networks (LPWANs) are communication protocols built particularly for energy-constrained Internet of Things (IoT) devices. LPWANs are perfect for green IoT applications because they provide long-distance connection, low power consumption, and rapid information transfer (G. Peruzzi and A. Pozzebon,2020). LoRaWAN and NB-IoT, for example, operate in unlicensed or licensed frequency bands, respectively, and offer extensive coverage at modest data rates. This allows devices to communicate over vast distances while requiring less energy, prolonging IoT device battery life.

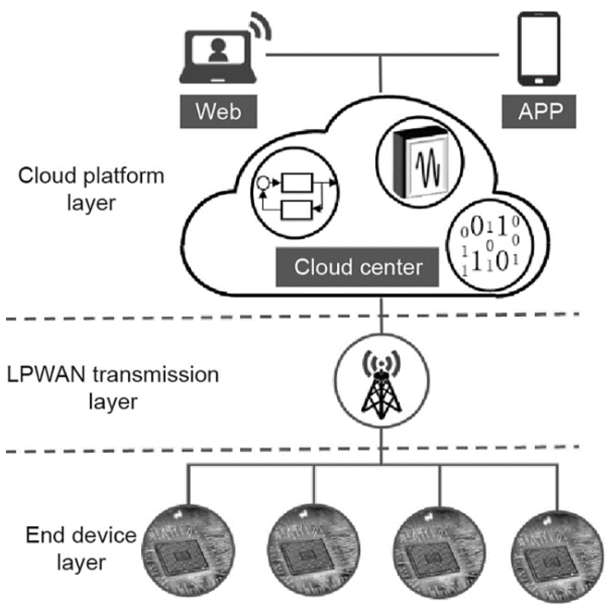

Fig .2 -Low Power Wide Area Network(LPWANS)

5.2 Protocol Design for Energy Optimization

The design of protocols is critical to achieving energy optimization in green IoT connectivity. To reduce energy usage while ensuring reliable communication, many ways are used:

• Duty Rotation: To save energy, IoT devices may switch between active and sleep modes. Duty cycle protocols set specified times during which devices may wake up, send or receive data, and then go to sleep. This method guarantees that devices use energy only when required, resulting in a considerable reduction in total energy usage.

• Power Control for Adaptive Transmission: Changing the transmission power dependent on the distance between devices may help to save energy. It is possible to reduce energy waste due to needless high-power transmissions by lowering transmission power when devices are close together.

• Aggregation and compression of data: Aggregating and compressing data at the source before transmission may minimize the quantity of data transferred over the network. This minimizes transmission time, energy usage, and bandwidth needs.

• Scheduling Sleep: Coordination of IoT device sleep patterns may increase energy efficiency in multi-hop communication circumstances. Collisions and idle listening may be reduced by ensuring that devices wake up and send or receive data at various times, resulting in energy savings.

6. EDGE DEVICE ARCHITECTURES FOR SUSTAINABLE DATA PROCESSING

6.1 Edge Device Connectivity and Integration

Connectivity and integration of edge devices with the larger IoT ecosystem are critical for long-term data processing (Y. Tong, X. Jia, H. Qiao, and X. Chen, 2022). Important factors include:

• Protocols for Wireless Communication: Edge devices should offer wireless communication protocols that are efficient and save energy, such as Wi-Fi, Bluetooth Low Energy (BLE), or Zigbee. These protocols allow smooth communication with other IoT devices and gateways while using the least amount of energy.

• Interoperability: To achieve smooth integration with multiple IoT platforms and systems, edge devices should comply to interoperability standards and protocols. This allows data interchange, interoperability, and cooperation among edge devices and other IoT ecosystem components.

• Integration of the Cloud:To provide hybrid processing and storage capabilities, edge devices should be built to connect with cloud computing platforms. This enables for the offloading of data and calculations to the cloud as needed, guaranteeing scalability and flexibility in data processing.

6.2 Design and Optimization of Edge Devices

Edge device design and optimization are critical for long-term data processing at the edge (N.-M. Ho, R. Vaddi, and W.-F. Wong, 2019). Considerations for designing and optimizing edge devices include:

• Energy Conservation: Edge devices should be energy-efficient by adopting low-power components, applying power management strategies, and leveraging energy harvesting technology. This enables them to run for long periods of time without the need for regular battery changes or recharging.

• Memory and processing power: Edge devices should have enough processing power and memory capacity to efficiently conduct data processing and analysis operations. This allows for local calculations and minimizes the need for data transfer to centralized servers, saving energy and decreasing latency.

• Privacy and security: To secure data and preserve privacy, edge devices should have strong security features. Encryption, authentication procedures, secure boot, and secure firmware upgrades are all part of this. The danger of data breaches during transmission or storage is reduced by safeguarding data at the edge.

6.3 Edge Computing Infrastructure

Edge computing infrastructure architecture is crucial for long-term data processing in IoT systems. It entails the installation of edge devices and gateways to enable localized data processing and analysis. The following are the most important factors to consider while designing an edge computing infrastructure:

• Location of Data Sources: Edge devices are strategically located near data sources to decrease latency and the volume of data transferred over the network. Because of this closeness, data processing and real-time analytics are quicker, making it suited for time-sensitive applications.

• Resilience and redundancy: Edge computing architecture should have redundancy and resilience methods to guarantee continuous operation and fault tolerance. Backup power sources, fault-tolerant structures, and failover systems are examples of how to limit the effect of device failures.

7. RESOURCE MANAGEMENT TECHNIQUES IN GREEN IOT EDGE COMPUTING

Green IoT edge computing focuses on excellent resource management approaches to maximize computing resource usage and increase energy efficiency (S. S. Saranya and N. S. Fatima, 2022). Key resource management approaches in green IoT edge computing include:

7.1 Offloading and Distribution of Tasks

Task offloading is the allocation of computing jobs between edge devices and centralized cloud or fog nodes. The goal of this strategy is to lessen the processing burden on resource-constrained edge devices while using the computing capabilities of more powerful cloud or fog servers. Task offloading increases energy economy, decreases latency, and improves overall system performance by offloading jobs to suitable resources depending on criteria such as processing needs, energy limits, and network circumstances.

7.2 Allocation of Dynamic Resources

Dynamic resource allocation refers to the dynamic distribution of computing resources to edge devices based on changing IoT application needs and priorities. This approach improves resource use by assigning resources in real-time or near real-time depending on workload, energy availability, device capabilities, and service quality needs. In green IoT edge computing systems, dynamic resource allocation offers optimal resource utilization, load balancing, and scalability.

7.3 Integration of Renewable Energy and Energy Harvesting

Solar, kinetic, and thermal energy harvesting methods may be incorporated into edge devices to allow self-sustainability and minimize dependency on other power sources [10]. Edge devices can power themselves and execute data processing operations without exhausting battery resources by gathering energy from the environment. The incorporation of renewables into edge computing infrastructure, such as solar panels or wind turbines, improves the sustainability and energy efficiency of green IoT systems. Energy harvesting and renewables integration help to reduce carbon footprints and promote environmentally friendly operations.

8. CHALLENGES AND FUTURE DIRECTIONS

8.1 Interoperability and Scalability

The primary hurdles in green IoT edge computing are scalability and interoperability. As the number of IoT devices and data volumes increase, it is critical to build edge computing systems that can expand easily and meet rising needs. This includes creating scalable architectures, effective resource allocation algorithms, and defining interoperability protocols to guarantee smooth integration and communication between diverse edge devices and cloud-based systems. Future research should concentrate on overcoming these obstacles in order to allow broad adoption of green IoT edge computing in large-scale installations.

8.2 Considerations for Security and Privacy

Given the scattered nature of data processing and the sensitive nature of IoT applications, security and privacy are crucial in green IoT edge computing. Because edge devices are more vulnerable to physical assaults and illegal access, it is critical to include strong security measures such as encryption, access control, and secure communication protocols. In order to preserve user data and comply with privacy requirements, privacy-preserving measures such as data anonymization and secure data exchange should be used. To preserve data integrity and confidentiality, future research should focus on establishing safe and privacy-enhancing technologies tailored to green IoT edge computing.

9. RESULT AND DISCUSSION

Green IoT edge computing has demonstrated encouraging results in sustainable and dispersed data processing, opening up new opportunities for energy-efficient and environmentally friendly IoT systems. We may make crucial findings and analyze the ramifications by assessing the present status of research and actual applications.

According to the findings, green IoT edge computing provides various benefits and advantages. It decreases network traffic dramatically by conducting localized data processing and analysis, resulting in enhanced network performance and lower bandwidth needs (R. Roman et al.,2018). The closeness to data sources allows for real-time and contextual insights, which supports time-sensitive applications and improves decision-making processes. Furthermore, green IoT edge computing saves energy by optimizing resource use and using energy-efficient communication protocols. This not only reduces operating expenses but also helps to achieve environmental objectives by reducing carbon footprint.

However, there are problems and places for development. Scalability and interoperability continue to be major concerns, as green IoT edge computing solutions must support a rising number of IoT devices while also ensuring smooth connectivity with cloud-based services. To preserve sensitive data and limit possible dangers, security and privacy concerns are crucial. To enhance data flow, load balancing, and resource management in hybrid systems, greater study into the integration of edge and cloud resources is required.

10. CONCLUSION

In this overview, the author investigate the idea of green internet of things edge computing in depth, as well as its potential to revolutionize data processing in internet of things systems. We give insights into the design principles and factors for sustainable and distributed data processing by examining energy-efficient communication protocols, edge device topologies, and resource management strategies. These topics allow us to provide insights into the design concepts and concerns. In addition, we illustrate the practical uses of green internet of things edge computing via the presentation of case studies and actual world implementations. In conclusion, we discuss the problems that now exist and provide an overview of potential future research routes in order to encourage the wider use of this game-changing technology and enhance its development. In this age of connected devices, the incorporation of environmentally friendly internet of things edge computing into internet of things systems offers enormous potential for increasing energy efficiency, decreasing latency, and supporting sustainability.

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