Green Internet of Things (Green IoT): A Systematic Overview of Technologies, Issues, and Future Study Directions

Amit Shringi[1], Krishan Kumar Soni[2]
[1,2]*Department of CSE, Rajasthan Technical University, Kota*

***Abstract*—The emergent era of Green Internet of Things (Green IoT) has brought about in billions of inter-connected devices that endlessly collect, process, and argument the worldwide database through cloud. While Green IoT allows groundbreaking applications in healthcare, smart cities, conveyance, agriculture, and engineering automation, its wide-ranging placement implicitly increases energy consumption and decrease carbon emissions. Green Internet of Things (Green IoT) has emerged as a hopeful paradigm expected at reducing energy consumption, minimizing environmental effect, and improving the sustainability of IoT ecosystems. Paper presents the review of a comprehensive study of IoT, including its architecture, enabling technologies, applications, challenges, and continuing research directions. The paper presents the energy-efficient communication protocols, wireless sensor networks, energy harvesting techniques, green cloud computing, edge computing, and renewable energy integration. In study we come up with major challenges related to security, scalability, interoperability, and electronic waste management are discussed and analyzed. The analyzed results propose recent emerging research trends such as AI-driven energy optimization, 6G networks, and sustainable edge computing are highlighted. The evaluation indicates that Green IoT will hold a crucial position in facilitating environmentally sustainable digital transformation.**

***Index Terms*—Green IoT, Energy Efficiency, Sustainable Computing, Wireless Sensor Networks, Edge Computing, Smart Cities, Communication.**

I. INTRODUCTION

The Green Internet of Things (Green IoT) attitudes as an innovative technological concept simplifying interactions among billions of organized smart devices. Multiple industries have been meaningly impacted by IoT advancements, such as healthcare, farming, industry, logistics, conveyance, and smart cities. Though, the rapid growth of IoT networks has familiarized significant concerns concerning energy consumption, greenhouse gas emissions, and electronic waste.

Recent studies indicate that billions of IoT devices continuously consume energy for sensing, processing, communication, and storage purposes. Even while a single sensor node uses very little energy, the combined impact of billions of devices leads to significant power needs. In order to guarantee the deployment of IoT in a sustainable and ecologically beneficial manner, experts have created the notion of " IoT."

The term "IoT" describes the development, deployment, use, and disposal of IoT systems in a way that preserves system performance while reducing energy consumption and environmental effect. The main goal is to generate energy-efficient approaches and technologies that lower carbon footpaths over the course of the Internet of Things.

This paper appraisals the fundamental concepts, permitting technologies, applications, challenges, and future directions of Green IoT.

II. GREEN IOT ARCHITECTURE

Green IoT architecture contains of multiple interconnected layers designed to enhance energy utilization.

A. Perception Layer

The perception layer comprises sensors, RFID tags, actuators, and entrenched devices accountable for gathering environmental data. Energy-efficient devices and low-power electronics are active to decrease power consumption.

Functions
- Data collection
- Environmental sensing
- Object identification
- Device monitoring

B. Network Layer
The network layer accomplishes communication among devices using energy-efficient procedures.
Technologies
- ZigBee
- Bluetooth Short Energy (BLE)
- Long Range Wide Area Network
- Narrow Band IoT
- Wi-Fi HaLow

The primary objective is minimizing transmission energy while maintaining communication reliability.

C. Processing Layer
This layer performs data processing through cloud computing, fog computing, and edge computing platforms.
Green Approaches
- Data compilation
- Energy conscious routing
- Load distribution
- Variable resource assignment

D. Application Layer
The application layer delivers services for smart cities, healthcare, agriculture, conveyance, and industrial automation while enhancing resource utilization.

III. ENABLING TECHNOLOGIES OF IOT

A. Energy-Efficient Wireless Sensor Networks (WSNs) Wireless Sensor Networks are important components of IoT systems. Energy efficiency can be skilled through:
- Sleep scheduling algorithms
- Clustering methodologies
- Energy-conscious Routing
- Duty cycle strategies

Benefits include prolonged network lifetime and reduced battery replacement requirements.

B. Energy Harvesting Technologies
Energy gathering allows IoT devices to produce power from ecological sources.
Sources
1. Solar Power
2. Wind Power
3. Thermal Power
4. Vibrational Energy
5. Radio Frequency Energy

Energy gathering reduces reliance on obsolete batteries and encourages sustainability.

C. Green RFID Systems
Radio Frequency Identification (RFID) technology is generally used in IoT applications.
Green RFID approaches include:
- Passive RFID tags
- Energy-efficient readers
- Low-power communication mechanisms

Passive RFID tags operate without internal batteries, meaningfully dropping energy feasting.

D. Green Cloud Computing
Cloud platforms handle vast amounts of data produced by IoT devices.
Energy-saving policies include:
- Virtualization
- Dynamic server consolidation
- Energy-aware scheduling
- Renewable-energy-powered data centers

These techniques diminish operational costs and carbon productions.

E. Edge and Fog Computation
Traditional cloud computation needs long-distance data transmission, collective energy ingesting.
Edge computing handles data processing close to its source, providing:
- Minimization of latency
- Decreased bandwidth consumption
- Lower energy usage
- Enhanced reliability

Fog computing improves cloud functionalities by carrying them quicker to end devices.

F. Machine-to-Machine Communication
Machine-to-Machine communication permits independent interface among devices without hominoid interference.
Green Machine-to-Machine techniques encompass:
- Adaptive transmission power management
- Sleep mode functionalities

- Optimized channel allocation
- Data compression techniques

IV. APPLICATIONS OF IOT

A. Smart Cities
Green IoT facilitates justifiable urban development through:
- Smart lighting systems
- Intelligent waste management
- Smart parking solutions
- Environmental monitoring

These applications improve energy efficiency and decrease operational costs.

B. Smart Grids
Green IoT facilitates the intelligent distribution of electricity through:
- Real-time monitoring of energy consumption
- Management of demand response
- Integration of renewable energy sources
- Detection of faults

Smart grids increase energy efficiency and minimalize transmission losses.

C. Healthcare Systems
Green IoT supports healthcare through:
- Wearable devices
- Remote patient monitoring
- Smart medical sensors

Energy-efficient health care systems improve patient care while reducing power requirements.

D. Agriculture
Smart agriculture applications include:
- Soil moisture monitoring
- Precision irrigation
- Livestock monitoring
- Crop disease detection

These resolutions enhance water and energy consumption.

E. Industrial IoT
Industrial applications benefit from:
- Predictive maintenance
- Asset tracking
- Smart manufacturing
- Process automation

Green IoT decreases industrial energy consumption and improves operative efficiency.

V. LITERATURE REVIEW

A number of researchers have explored methods to enhance the sustainability of IoT.
Alsharif et al. (2023) conducted a review of Green IoT technologies and identified four primary pillars: energy-efficient machine-to-machine communication, wireless sensor networks, RFID systems, and microcontroller units. Their research underscored the significance of energy harvesting and wireless charging as essential elements for the future of Green IoT systems.
Thilakarathne et al. (2020) accentuated the necessity of reducing energy waste produced by general IoT deployments and proposed sustainable architectures for future IoT ecosystems.
Almalki et al. (2021) examined Green IoT applications within smart cities and inspected the potential for reducing carbon emissions over advanced urban infrastructure.
Recent research published in 2025 has focused on the integration of renewable energy systems, sustainable HVAC control, artificial intelligence, and edge computing technologies into Green IoT frameworks.
In summary, the literature proposes that Green IoT has progressed from a focus on energy-efficient hardware enterprise to more comprehensive sustainability policies at the ecosystem level.

VI. CHALLENGES IN IOT

Despite significant progress, Green IoT faces numerous challenges.
A. Energy Constraints
Many IoT devices work on limited battery power.
Challenges include:
- Regular battery changes are necessary
- Operational lifespan is restricted
- Maintenance expenses are considerable

B. Security and Privacy
Energy-efficient safety mechanisms remain tough to implement.
Threats include:
- Data breaches
- DoS (Denial-of-service) attacks

- Unauthorized access

C. Scalability
Overseeing billions of interconnected devices poses considerable challenges concerning:
- Network congestion
- Resource allocation
- Device management

D. Interoperability
IoT systems utilize a variety of devices and communication standards.
Challenges faced include:
- Incompatibility of protocols
- Inconsistencies in data formats
- Implementations specific to vendors

E. Electronic Waste
The growing prevalence of IoT devices plays a major part in the growth of electronic waste production.
Effective recycling and sustainable manufacturing methods are crucial.

F. Cost and Infrastructure
Green technologies naturally necessitate a significant upfront investment.
Challenges encompass:
- Costs associated with the deployment of renewable energy
- Upgrades to existing infrastructure
- Requirements for advanced hardware

VII. FUTURE RESEARCH DIRECTIONS

A. AI for Enhancing Energy Optimization
AI and Machine Learning have the potential to enhance:
- Resource allocation
- Network management
- Predictive maintenance
- Energy scheduling

AI-driven solutions can greatly boost energy efficiency.

B. Green 6G Networks
The anticipated 6G communication systems are expected to deliver:
- Ultra-low latency
- Intelligent energy management
- Sustainable wireless communication

Green 6G is poised to emerge as a substantial area of research.

C. Sustainable Edge Computation
Future investigations should concentrate on:
- Energy-aware workload distribution
- Renewable-powered edge nodes
- Carbon-aware computing frameworks

D. Circular Economy Models
Researchers are progressively investigating:
- Device recycling
- Reusable hardware
- Sustainable manufacturing

These strategies can mitigate environmental impact through the IoT lifecycle.

E. Renewable Energy Integration
Future IoT systems may increasingly depend on:
- Solar-powered sensors
- Wind-powered gateways
- Hybrid energy harvesting systems

Such inventions could simplify self-sustaining IoT networks.

VIII. CONCLUSION

Green IoT has become an important solution for tackling the environmental matters linked to extensive IoT implementations. By participating energy-efficient communication protocols, energy harvesting technologies, green cloud computation, edge computing, and renewable energy centers, Green IoT can critically minimalize power consumption and carbon emissions. Despite the current challenges concerning security, scalability, interoperability, and electronic waste, continuous research is intensive on creating innovative solutions. Upcoming developments in artificial intelligence, Green 6G networks, and sustainable edge computing are anticipated to further improve the efficiency of Green IoT systems. As a result, Green IoT will be essential in facilitating sustainable digital transformation and aiding global environmental objectives.

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