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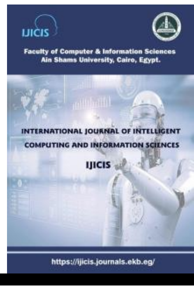

GIoTEH: GREEN IoT ENERGY HARVESTING

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Abstract: *The Green Internet of Things (IoT) is a critical research area aimed at addressing the substantial energy consumption of high-performance, interconnected devices in IoT systems. With the rapid increase in the number of IoT devices, energy demand becomes an increasingly pressing issue. Recent research focuses on reducing energy consumption in IoT systems to support environmental sustainability. Green IoT systems, combined with Energy Harvesting (EH) technologies, present promising solutions for powering IoT devices in an eco-friendly manner. This paper explores the latest advancements in energy optimization for IoT through EH techniques, which harness energy from the surrounding environment to decrease dependence on traditional energy sources and lower the total energy consumption of IoT devices. Furthermore, it introduces the Green IoT Energy Harvesting (GIoTEH) architecture, a comprehensive framework designed to create a sustainable and energy-efficient IoT ecosystem.*

Keywords: *Energy saving techniques, Green IoT, Energy Harvesting, Ambient energy, GIoTEH.*

1. Introduction

The IoT is an ever-evolving technology that is revolutionizing how we interact with our surroundings. As the number of connected devices continues to rise, the demand for sustainable power solutions has grown increasingly urgent [1]. IoT devices are now extensively used to monitor and control environments in ways that were once unimaginable. This growing demand has driven the advancement of green IoT systems, which utilize renewable energy sources like solar, wind, and geothermal power. Moreover, EH

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techniques enable the capture of ambient energy from the surroundings and its conversion into electricity to power IoT devices.

The widespread adoption of the IoT has driven significant advancements across various industries. IoT comprises a global network of devices, such as sensors and actuators, embedded into physical objects to sense, process, and exchange data over networks [2, 3]. This interconnectedness facilitates seamless communication and real-time decision-making, resulting in enhanced efficiency and automation. However, achieving system Quality of Service (QoS) standards often increases the energy consumption of these communication and networking devices, highlighting the need for energy efficiency as an essential element of sustainable IoT development.

To reduce energy usage, IoT systems must optimize energy usage across sensors, processors, and communication devices. Green IoT systems address this challenge by utilizing renewable energy sources like solar and wind power to lessen dependence on traditional energy grids and lower carbon emissions [6]. EH techniques further enhance these systems by capturing ambient energy from sources like solar radiation and RF signals to power IoT devices, enabling a self-sustaining and eco-friendly approach.
The integration of Green IoT systems with EH techniques holds immense potential to transform the IoT landscape. These technologies offer benefits such as reduced energy costs, extended device lifespans, and enhanced scalability, fostering a more sustainable IoT ecosystem aligned with global climate initiatives. However, several challenges must be addressed, including optimizing energy efficiency, developing efficient energy storage solutions, and resolving issues related to interoperability and energy availability. Overcoming these challenges is critical to unlocking the full potential of Green IoT systems and EH technologies [7].

This paper surveys various strategies to enhance IoT energy efficiency, focusing on two key approaches. The first approach, energy conservation, aims to reduce IoT device energy consumption through techniques such as data reduction and duty cycling, thereby extending device lifespans [8]. The second approach, EH, utilizes sustainable energy sources such as solar and wind to power IoT devices, reducing dependance on traditional power sources and enabling the development of self-sufficient, eco-friendly IoT systems. Additionally, this paper explores the current state of Green IoT systems and EH techniques, discussing their advantages and limitations. It also identifies the challenges that need to be tackled to fully realize the potential of these technologies. Finally, it introduces GIoTEH, an EH architecture designed for Green IoT systems.

The paper is organized as follows: Section 2 discusses the architecture of IoT layers. Section 3 introduces Green IoT systems. Section 4 focuses on EH. Section 5 evaluates various EH techniques. Sections 6 and 7 explore ambient energy sources and present the GIoTEH architecture, respectively. Finally, the concluding section summarizes the key findings and insights.

2. IoT SYSTEMS LAYERS ARCHITECTURE

The IoT comprises a wide range of smart devices linked to an extensive internet network through diverse networking technologies, most of which are wireless. This reliance on wireless technologies increases the complexity of IoT structures, making them more challenging to manage. To address this, a well-defined architecture is essential. Several IoT architectures have been created to facilitate the operation of IoT devices. The primary architecture of IoT system layers is illustrated in Figure 1.

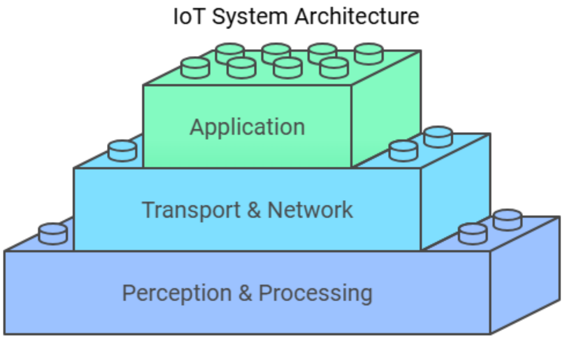

Figure. 1: IoT systems layers architecture

In the Perception and Processing layers of IoT systems, components like sensors and gateway nodes play crucial roles in data sensing, monitoring, filtering, prediction, and compression [9]. However, these components are known to be power-hungry, posing significant energy consumption challenges [9]. Additionally, sensors often rely on battery power, further emphasizing the need for energy efficiency improvements [10]. To address these issues, researchers in [9] have proposed a task scheduling algorithm that optimizes energy efficiency by utilizing the sleep intervals of sensor nodes. By strategically optimizing these sleep intervals, the algorithm effectively reduces the power usage of sensor nodes operating in these layers [2]. This technique is one of the approaches aimed at improving the overall energy efficiency of IoT systems, ensuring the sustainable and prolonged operation of devices involved in data perception and processing tasks.

The Transport and Network Layers are essential for addressing wireless sensing and networking aspects within IoT systems. These layers handle various functions, such as data transmission, neighborhood communication, retransmission, packet collision avoidance, and handshaking mechanisms [11]. However, these communication processes are known to be energy-intensive, raising concerns about the overall energy consumption of IoT systems [12].

The Application layer of IoT systems includes various components, such as web applications, mobile sensors, actuators, and control systems like Heating, Ventilation, and Air Conditioning (HVAC). These components often require high computational power and data processing, with HTTP (Hypertext Transfer Protocol) being the primary protocol used. However, power consumption in this layer can be substantial due to the verbosity and large parsing overhead associated with HTTP.

To address these challenges and optimize energy usage, researchers have explored various techniques. One such approach involves using Message Queue Telemetry Transport (MQTT) and the Constrained Application Protocol (CoAP) [2]. CoAP serves as an energy-efficient alternative to HTTP, providing a more streamlined communication mechanism. Additionally, tracking mechanisms and MQTT-S/MQTT SN have been studied as methods to optimize energy consumption at the Application layer [13]. By leveraging these optimization strategies and adopting energy-efficient protocols, the Application layer of IoT systems can enhance performance while reducing overall energy consumption, contributing to more sustainable and eco-friendly IoT implementations.

To address energy challenges, researchers in [14] have proposed energy optimization techniques for Wireless Sensor Networks (WSNs) in communication with base stations. These techniques involve multi-hop and cooperative multi-hop routing, which routes data through a series of shorter hops, reducing energy consumption compared to long-path transmissions. Additionally, [14] introduced a technique that optimizes communication paths by forming clusters of network devices and facilitating processing across multiple layers. This path optimization strategy leads to a significant reduction in energy consumption, contributing to the development of more energy-efficient IoT systems.

3. GREEN IoT SYSTEMS

Green IoT systems are designed to harness renewable energy sources such as solar, wind, and geothermal power to supply energy for connected devices. These systems offer significant benefits across a wide range of applications, such as smart homes, smart cities, and industrial automation, agriculture monitoring, and more. By replacing traditional power sources with renewable ones, Green IoT systems contribute to reducing carbon emissions. Furthermore, they can help lower electricity costs by utilizing renewable energy sources, which are often more cost-effective than conventional energy options.

Green IoT systems involve the integration of environmentally sustainable practices and technologies in the design, deployment, and operation of IoT networks and devices. Their primary goal is to reduce the environmental impact of IoT infrastructure by prioritizing energy efficiency, optimizing resource utilization, and embracing renewable energy sources. By minimizing energy consumption and adopting eco-friendly practices, Green IoT systems aim to foster a more environmentally sustainable IoT ecosystem.

Solar-powered Green IoT systems are particularly popular due to their ability to generate electricity from sunlight without requiring extra infrastructure or resources. Solar panels can be mounted on rooftops or other surfaces that receive direct sunlight, capturing solar radiation and converting it into usable electricity to power connected devices. Wind-powered Green IoT systems are also becoming increasingly popular for their ability to generate electricity from wind turbines, similarly requiring no extra infrastructure or resources [15].

Wind turbines harness the kinetic energy of the wind and transform it into usable electricity to power connected devices. Geothermal-powered Green IoT systems are also gaining popularity due to their ability to generate electricity using geothermal heat pumps, which require minimal infrastructure or resources. These heat pumps are installed underground to capture thermal energy from the Earth’s core and convert it into electricity for powering connected devices.

4. ENERGY HARVESTING

EH within the IoT context involves utilizing energy from the ambient environment to power IoT devices. Various EH techniques have been developed to capture ambient energy and transform it into usable electricity for powering connected devices [22]. These techniques include piezoelectric EH, thermoelectric EH, electromagnetic induction harvesting, RF harvesting, vibration harvesting, light harvesting, acoustic wave harvesting, magnetic field harvesting, chemical reaction harvesting, biofuel cell harvesting, and microbial fuel cell harvesting. Each technique has its own advantages and limitations, depending on the specific application. However, all of these methods share a common goal: to capture ambient energy from the surrounding environment and convert it into usable electricity to power devices, reducing reliance on conventional energy sources such as fossil fuels or nuclear power plants [23].

Instead of relying solely on conventional battery power or wired connections, EH techniques enable the extraction and conversion of energy from diverse sources converted into practical electrical power [16]. These techniques can harness a range of energy sources, including:

a) **Solar Energy:** Photovoltaic cells harness sunlight and transform it into electricity, offering a renewable and abundant energy source for IoT devices.
b) **Mechanical Energy:** Kinetic energy from vibrations, movements, or mechanical actions can be harvested using techniques such as piezoelectric or electromagnetic transducers.
c) **Thermal Energy:** Temperature differences can be harnessed through thermoelectric generators or materials, converting heat gradients into usable electrical energy.
d) **Radio Frequency (RF) Energy:** RF energy harvesters can capture ambient RF signals from Wi-Fi, cellular networks, and other wireless communication systems, converting them into electricity.

Advantages of Integrating EH Technologies into IoT Devices:

a) **Extended Battery Life:** EH can supplement or replace traditional battery power, significantly prolonging the functional lifespan of IoT devices and minimizing the frequency of battery replacements.
b) **Maintenance-Free Operation:** EH enables devices to function independently without the need for frequent battery replacements or wired power connections, reducing maintenance efforts and costs.
c) **Scalability and Flexibility:** EH allows IoT devices intended for deployment in remote or difficult-to-reach locations where power sources may be limited or expensive, enhancing scalability and flexibility.
d) **Environmental Friendliness:** By relying on sustainable energy sources and minimizing the use of disposable batteries, EH contributes to an IoT ecosystem that is more sustainable and environmentally friendly.

Despite these advantages, EH in IoT also presents several challenges:

a) **Energy Availability:** The amount of ambient energy available for harvesting can vary depending on location, time of day, and environmental conditions. Ensuring a consistent and sufficient energy supply remains a significant challenge.
b) **Energy Conversion Efficiency:** Optimizing the conversion efficiency of collected energy is essential to maximize the available power for IoT devices. Current research and development initiatives are aimed at enhancing this efficiency.
c) **Power Management:** Effective power management strategies are critical for balancing energy supply and demand. Efficient storage and utilization of harvested energy are necessary to meet the operational requirements of IoT devices.

Table 1 provides a broad overview of various EH methods, comparing their energy source, principle, applications, advantages, and challenges.

Table 1. A comparison between EH Techniques

Harvesting Type	Energy Source	Principle	Applications	Advantages	Challenges
Piezoelectricity Harvesting	Mechanical stress/vibration	Converts mechanical strain into electrical energy using piezoelectric materials.	Wearable devices, sensors, automotive, smart infrastructure	Small form factor, scalable, no need for batteries.	Low power output, sensitivity to frequency, environmental conditions.
Thermoelectricity Harvesting	Temperature gradients	Converts heat differences into electrical power via thermoelectric materials.	Industrial waste heat recovery, wearable tech, environmental sensors	Can utilize waste heat, no moving parts.	Limited by temperature differences, materials efficiency.
Electromagnetic Induction	Magnetic field changes	Generates electrical energy from the movement of conductors in magnetic fields.	Energy storage systems, automotive, home appliances	Works with both motion and magnetic fields, long-term power.	Requires relative motion between magnet and coil.
RF Energy Harvesting	Radio frequency signals	Captures RF signals from electromagnetic waves and converts them into DC power.	Wireless sensors, IoT devices, smart city applications	Works with existing RF signals (e.g., Wi-Fi, cellular networks).	Low power output, reliance on proximity to RF sources.
Vibration Harvesting	Mechanical vibration	Converts mechanical vibrations (from the environment or devices) into electrical energy.	Industrial monitoring, wearable devices, transportation	Can work in many environments with vibrations.	Low output, sensitive to frequency ranges.
Light Harvesting	Light (solar, ambient)	Transforms light energy into electrical energy through photovoltaic cells.	Solar-powered IoT devices, streetlights, outdoor applications	Widely used, reliable, scalable, and renewable.	Depends on sunlight, need for solar panel area, weather variability.
Acoustic Wave Harvesting	Sound waves	Converts sound vibrations into electrical energy using piezoelectric or MEMS devices.	Audio sensors, hearing aids, noise energy collection	Captures ambient noise energy in urban settings.	Low power output, sensitive to noise levels, environment-dependent.
Magnetic Field Harvesting	External magnetic fields	Converts energy from magnetic fields into electrical power via coils or magnets.	RFID, sensor networks, monitoring systems	Works in low-power applications like RFID.	Low output, requires strong magnetic fields or motion.
Chemical Reaction Harvesting	Chemical reactions	Converts chemical reactions (such as oxidation) into electrical energy.	Environmental sensors, medical devices, industrial applications	Works in remote, harsh environments (e.g., space, ocean).	Requires continuous chemical supply, limited power output.
Biofuel Cell Harvesting	Organic matter (biofuels)	Uses the oxidation of organic compounds in biofuels to generate electricity.	Medical devices, remote sensors, environmental monitoring	Can run on renewable organic materials, environmentally friendly.	Limited by fuel source, slow reaction rate, scalability issues.
Microbial Fuel Cell Harvesting	Microbial activity	Generates electrical energy through microbial	Wastewater treatment, biosensors,	Operates in waste materials, eco-friendly.	Slow power generation, depends on

		metabolism of organic material.	environmental monitoring		microbial activity, low efficiency.

EH, also known as energy collection or power harvesting, involves the process of extracting energy from external sources and storing it for use in small, wireless, independent devices, particularly in WSNs. These techniques are designed to harness energy derived from renewable resources [17]. An EH device captures and converts the collected energy into electrical form, which can then be used to power the device. Any surplus energy can be stored in storage devices for later use [18]. Figure 2 presents a simplified block diagram illustrating the components of an EH system [19].

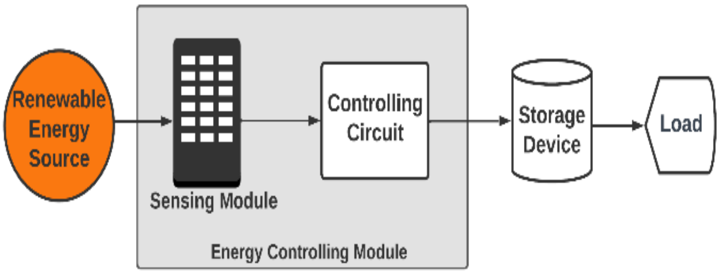

Figure. 2: EH systems Block diagram.

EH system components are:

a) **Energy Source:** To harness energy through EH, an ambient energy source is essential. There is a wide range of renewable energy sources available that can be utilized to meet the energy requirements of individual devices [20].
b) **Energy Collecting Module:** This module is responsible for extracting energy from the surrounding environment and converting it into a usable form [21].

- **Sensing Module:** To enable EH, ambient energy must first be captured and recorded. The specific type of energy to be harvested determines the need for a corresponding EH module. For example, to harvest solar energy, a solar panel is required to capture and collect sunlight. Similarly, different EH modules are needed depending on the type of ambient energy source to be utilized, ensuring that energy can be effectively harvested and converted into usable power.
- **Controlling Circuit:** After ambient energy is harnessed, it undergoes a conversion process to transform it into electricity for practical use. Depending on the application, circuits such as oscillators and rectifiers can be utilized to convert the harvested energy into Alternating Current (AC) or Direct Current (DC), respectively. This conversion step ensures that the energy can be effectively utilized by target devices.

c) **Storage Device:** The generated power can either be delivered directly to the load or channeled into a storage device for future use. When there is a need to store the harvested energy, it becomes essential to have a storage solution [17]. For example, solar energy is unavailable at night, so it needs to be stored for later use. Various storage devices can accommodate different application needs, enabling efficient energy storage and retrieval. Some examples of storage devices include hydrogen storage, flywheels, Compressed Air Energy Storage (CAES), Supercapacitors, Superconducting Magnetic Energy Storage (SMES), Pumped Hydro Energy Storage (PHES), and Battery Energy Storage (BES).

d) **Load:** The stored or directly harvested electricity is delivered to the devices that require power.

5. AMBIENT ENERGY

At the core of the EH concept lies ambient energy, which serves as the foundation for powering devices. This ambient energy, derived from renewable sources, forms the basis of the EH process. Numerous ambient energy sources can be harnessed to generate power for devices, contributing to more sustainable and eco-friendly operations. However, it is worth mentioning that the amount of electrical energy converted may not be equivalent to the total available ambient energy. The effectiveness of energy conversion depends on the sensor module and the specific conversion circuit employed. Different technologies used in the conversion circuits can yield varying levels of energy conversion efficiency. Figure 3 illustrates the diverse range of renewable energy sources that can be utilized in EH systems. By tapping into these sources, EH enables the generation of electrical power, supporting self-sustaining and energy-efficient operations for IoT devices and other applications [24].

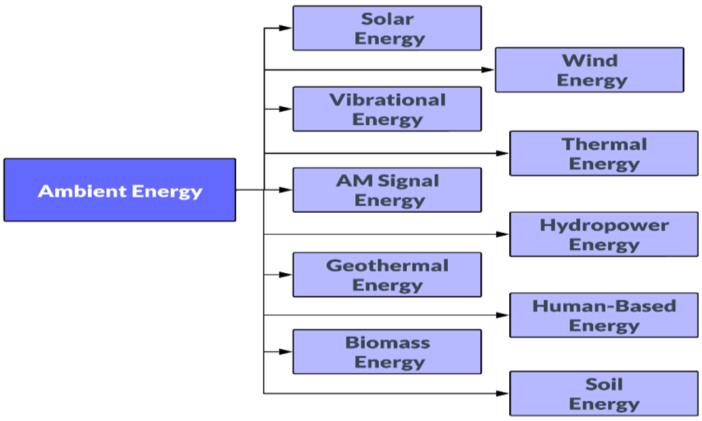

Figure. 3: Various Renewable Energies.

a) **Solar Energy:** Solar energy, abundant on sunny days, can be harnessed through technologies like Photovoltaic (PV) modules, Concentrated PV (CPV), and Concentrated Solar Thermal (CSP). PV is the most commonly used method for small-scale applications, particularly in sensor networks, due to its versatility and scalability. However, solar energy is unavailable during cloudy days and at night, requiring efficient storage for later use. While PV systems have lower conversion efficiency compared to other methods and may suffer from energy wastage, they remain a widely adopted and eco-friendly solution for wireless sensors, particularly in outdoor environments and certain indoor locations with adequate sunlight [25].

b) **Wind energy:** It is considered one of the fastest-growing renewable energy sources, offering several advantages, such as the ability to generate power without harming the environment. It is also cost-effective and can be used to produce electricity. Wind turbines are powered by the movement of their blades [17]. Several wind turbine technologies can be employed to generate electricity, including the Variable-Speed Concept using Full-Power Converter, the Variable-Speed approach using a Doubly Fed Induction Generator, and advancements in Semiconductor-Device Technology [26]. These innovative approaches play a crucial role in EH and conversion, promoting more efficient and sustainable energy utilization.

c) **Vibrational Energy:** Mechanical energy, generated by sources like stress and vibrations, can be converted into electrical power using an energy generator [27]. Various types of mechanical-to-electric generators are employed for this purpose, including piezoelectric, electrostatic, and electromagnetic devices. To achieve the highest power density, these generators often integrate multiple techniques for optimal energy conversion.

d) **Hydropower Energy**: Hydropower is one of the oldest and largest renewable energy sources used to generate electricity. It harnesses the strength of water flow in dams to produce electricity. Contemporary hydro turbines can achieve conversion efficiencies of up to 90%, making hydropower an efficient and reliable energy source. Small commercial units, ranging from 350 to 1200 watts, are now available for installation in rivers and brooks, broadening the accessibility of hydropower technology. Additionally, energy can be generated from moving liquids other than water, using small hydro-generators [28], further expanding the potential for sustainable electricity generation.

e) **Thermal Energy:** The Seebeck effect is used in thermal EH to generate electricity. A temperature difference between two surfaces causes thermal energy to be produced. This form of energy is considered a rich source due to its diverse processes. A variety of both small and large devices are capable of converting thermal energy into electrical power [29].

f) **Biomass Energy:** Biomass refers to organic matter generated by living organisms, including trees, plants, crops, animals, and more. It encompasses a wide range of materials, such as crops, wood, dung, fruits, and other biomass fuels. Biomass captures solar energy via the process of photosynthesis and can be used to generate heat, electricity, gases, and liquid fuels like methane.

g) **Geothermal Energy:** The Earth's core contains abundant energy, derived from primordial heat, the movement of tectonic plates, and the decay of radioactive materials. This energy can be accessed by drilling deep wells to extract heated subsurface water or by using geothermal facilities to generate electricity and heat. Geothermal energy has been commercially harnessed for over 70 years for both direct use and power generation.

h) **Human-based Energy:** It is increasingly used in healthcare systems, where sensors are often implanted in the human body for extended periods. As these sensors need to remain active for longer durations, EH from the human body becomes a priority over other power sources. Various methods, such as heartbeat, capturing body heat, movement, blood flow, and changes in finger position, can be used to collect human-derived energy [30].

i) **AM Signal Energy:** Amplitude Modulation (AM) signals have powered crystal radios without external batteries for nearly a century [20]. Researchers suggest that AM signals could be a more efficient renewable energy source compared to solar, thermal, and vibrational energy, which are intermittent. Unlike these sources, AM signals are broadcast continuously 24 hours a day, providing a reliable energy source. While their intensity may gradually diminish over time, they will never completely cease [17].

j) **Soil Energy:** In smart farming, sensors are used to monitor agricultural conditions, and soil energy can power these sensors. Exoelectrogenic bacteria in the soil can harvest energy from the environment. The efficiency of converting soil energy into usable power depends on various operational parameters.

Renewable energy sources provide a practical solution for powering IoT devices. When designing EH algorithms, both availability and feasibility should be taken into account. Numerous EH techniques have been developed by researchers, who are also focusing on enhancing the efficiency of energy converters. As a result, advancements in EH show promising potential for addressing energy deficiencies in sensor networks [31].

6. THE GIoTEH ARCHITECTURE

The increasing demand for a green IoT ecosystem, especially in environments where WSNs collect and transmit data from remote areas, has led to the development of innovative architectures that incorporate EH and wireless power transfer. To ensure continuous sensor operation, systems are being designed to capture and store energy when available, enabling sensors to function even during periods of power scarcity. The GIoTEH architecture, Figure 4, is specifically designed to create a sustainable and self-sufficient IoT ecosystem. It employs a layered approach that integrates EH, energy storage, and power management technologies. This division of the system into distinct parts allows GIoTEH to efficiently support IoT devices across various applications, reducing dependence on conventional power sources while maintaining high performance and energy efficiency.

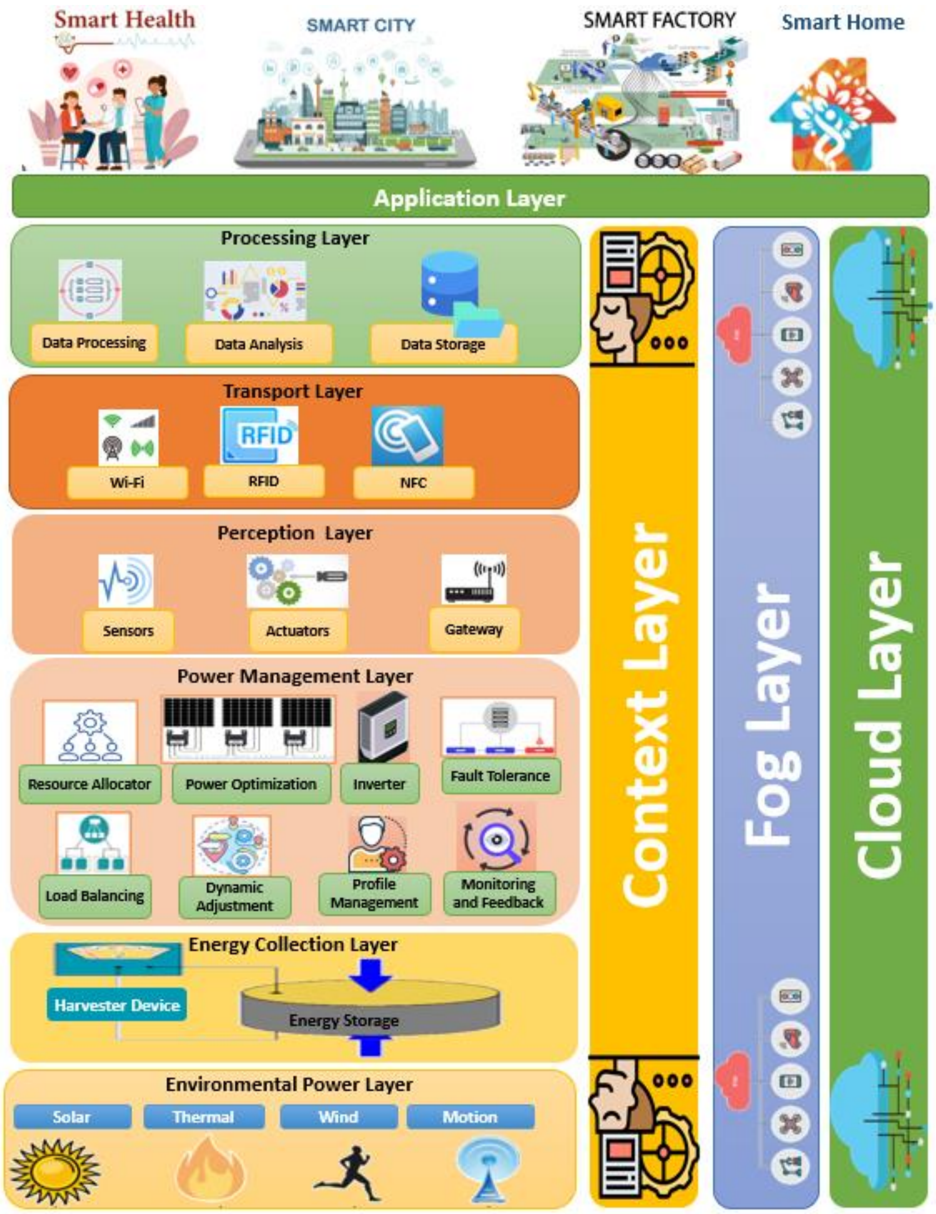

Figure. 4: GIoTEH Architecture

Table 2 provides a comparative overview of the GIoTEH architecture against recent publications, highlighting distinctions in EH methods, data processing capabilities, and adaptability in various applications. The referenced architectures focus on EH, sustainable IoT solutions, and power management systems.

Table 2: A comparison between GIoTEH and similar architectures

Feature	GIoTEH	[36]	[37]	[38]	[39]
EH Sources	Solar, thermal, wind	Solar, kinetic	Wind, solar	Solar, thermal, wind	Solar, vibration, kinetic
Energy Storage Solutions	Batteries, supercapacitors	Batteries, supercapacitors	Batteries, flywheels	Batteries, supercapacitors	Supercapacitors, batteries
Power Management Layer	Dynamic adjustment, load balancing, resource allocation	Basic power management	Advanced energy management	Adaptive control mechanisms	Resource allocation and optimization
Network Layers	Context, Fog, Cloud	Cloud-based architecture	Edge computing and Cloud	Hybrid networking approach	Hierarchical and decentralized architecture
Data Processing Capability	Real-time processing, advanced analytics	Real-time data analytics	AI-driven analytics	Data-driven decision-making	Advanced analytics with real-time processing
Application Areas	Smart cities, healthcare, industrial automation	Renewable energy systems	Energy-efficient buildings	Smart grids and Energy management	Smart environments, industrial applications
Adaptability and Scalability	Highly adaptable and scalable	Moderate scalability	Scalable but dependent on infrastructure	Highly adaptable with dynamic response	Highly adaptable and scalable
Environmental Impact	Focus on Reducing carbon footprint	Emphasis on sustainability	Focus on Renewable energy integration	Strong emphasis on eco-friendly solutions	Emphasis on Reducing Environmental impact

The GIoTEH architecture consists of ten layers, grouped into three parts: Power, Network, and IoT Application. The Power part includes three layers: the Power Layer, EH Layer, and Power Management Layer. The Network part consists of three layers: the Context Layer, Fog Layer, and Cloud Layer. The IoT Application part includes four layers: the Perception Layer, Transport Layer, Processing Layer, and Application Layer. The layers of GIoTEH are discussed as follows:

Part 1: The power Part

This part focuses on harnessing and managing ambient energy from the environment to power system components. The primary concept is to convert small amounts of surrounding energy into electrical power and store it until a sufficient amount is accumulated to energize electronic microsystems, such as sensors, wireless radio modules, or actuators. It includes the Power Layer, EH Layer, and Power Management Layer. Table 3 provides a comparison of the most commonly used energy sources in Green IoT environments.

Table 3: A Comparison between the Most Used Sources for Green IoT Environments.

Source	Device	Energy Conversion		Advantages	Trade-offs
		From	To		
Solar	Solar Panels	radiant light	electrical energy	- Renewable - Environmentally - friendly - Low operating costs	- dependent on sun-light - High initial cost
Thermal	Thermoelectric Generators	heat differentials	electrical energy	- Suitable for waste - heat recovery - have a long - operational life	- Limited efficiency - rely on a temperature - difference - which may be unavailable
Motion	kinetic wristwatches	movement	electrical energy	- capture energy from - everyday motion - Suitable for low- - power devices	- Limited energy capture - Low power output
Wind	Wind Turbines	kinetic energy of the wind	electrical energy	- Renewable - Environmentally - friendly - High potential	- dependent on wind - speed and consistency - High initial installation costs

a) **Power layer:** The Power Layer is accountable for harnessing energy from the environment and supplying it to the EH Layer. The choice of a power source is determined by the specific application's requirements, including energy needs, portability, environmental considerations, and reliability. The most used sources for Green IoT environments are, solar, thermal, motion, and wind. Each power source offers unique advantages and trade-offs [33].

b) **EH Layer:** The main function of the EH layer is to harness and transform ambient energy from the Power Layer into functional electrical energy. The general principle involves converting minute quantities of ambient energy into electrical energy and subsequently storing it. This layer includes two components, which are:

Harvester Devise: EH devices provide a diverse selection of ultra-low power Integrated Circuits (ICs) designed for EH applications. They are employed in IoT environments to provide sustainable and self-sufficient power sources for low-power actuators and sensors.

- **Storage:** Energy storage is crucial for storing electrical power for later use. It helps balance supply and demand, ensuring a stable power supply, optimizing the use of variable energy sources such as solar and wind, and providing backup power when needed. The type of storage required varies by application. For example, batteries are used to maintain sensor functionality during periods of intermittent energy, such as overnight for solar-powered systems. In contrast, supercapacitors are used for short, intermittent energy needs or when large energy bursts are required to support energy-intensive sensors or long-range communications. [34].

c) **Power Management Layer:** This layer ensures the efficient allocation, optimization, and management of energy resources. Key components include:

- **Resource allocator:** A component, which efficiently manages and allocates available power resources to various devices, systems, or applications.
- **Power Optimizer:** It aims to maximize the use of available power while minimizing wastage, ensuring that devices operate within their power constraints.

- **Inverter:** The function of the inverter is to transform the power into AC electricity, which is subsequently utilized by household appliances.
- **Load Balancing:** It distributes power evenly or according to specific requirements among different devices to prevent overloading or underutilization.
- **Dynamic Adjustment:** It can adapt power allocation in real-time based on the changing demands of different components or the availability of power sources.
- **Fault Tolerance:** It may incorporate mechanisms to ensure the continued operation of critical systems in the event of power source failures.
- **Profile management:** It refers to the process of creating, configuring, and maintaining resources/devices profiles to optimize and control energy consumption. This is often utilized in the context of IoT environments where efficient energy use is a priority. It helps in tailoring energy consumption to meet system preferences, operational requirements, and energy efficiency goals.
- **Monitoring and Feedback:** It includes energy monitoring and reporting features, allowing systems to track their energy consumption, provides feedback, and make informed decisions about efficiency improvements.

Part 2: The Network Part

This section handles the data flow and processing across the IoT system, ensuring energy-efficient network communication and processing.

a) **Context Layer:** This layer is responsible for gathering, processing, and utilizing contextual information to optimize EH and utilization. It is essential for making the most efficient use of harvested energy by adapting to changing environmental conditions and user requirements. It allows EH systems to be more adaptive and responsive, ensuring the continuous and sustainable operation of devices and systems while optimizing energy utilization.
b) **Fog Computing Layer:** As certain IoT data requires processing in proximity to IoT devices and meters, a proposed fog-computing layer, specifically designed for this purpose, can significantly decrease processing time. This layer is also referred to as the Edge computing layer.
c) **Cloud Computing Layer:** In this layer, the contextual data received from the fog layer is subjected to advanced analytics, machine learning, and big data processing. This deeper analysis can uncover insights, patterns, and trends that are not feasible at the edge [35, 40].

Part 3: The IoT application Part

This section is dedicated to the IoT application layers, where data is collected, transmitted, processed, and applied to various end-user services.

a) **Perception layer:** It is one of the essential layers in IoT architecture. It collects data from various sensors, devices, or sources, such as temperature sensors, cameras, motion detectors, RFID (Radio-Frequency Identification) readers, and more.
b) **Transport Layer:** It is responsible for ensuring the reliable and efficient transmission of data between devices, sensors, and systems within the IoT ecosystem. This layer is essential in managing data communication, error detection, and data transport control.
c) **Processing Layer:** It is a crucial component of IoT architecture, which handles data processing, analysis, storage, and decision-making. It is where the collected data from sensors and devices are transformed into actionable insights and valuable information.

d) **Application Layer:** It refers to the top layer of the IoT architecture, where end-user applications and services, like smart homes, smart cities, healthcare, industrial automation, are developed and deployed. This layer is where the collected and processed data from sensors and devices are used to create value, make decisions, and interact with users or other systems.

7. CONCLUSION

This paper presents a general view of key studies on IoT system energy optimization, highlighting the challenges faced and potential solutions. It emphasizes how incorporating EH techniques can improve energy efficiency, extend the longevity of IoT devices, and reduce the environmental impact of their energy consumption. The paper discusses the design principles, components, and applications of Green IoT systems, evaluating the advantages and drawbacks of various EH methods while reviewing recent research efforts. It also highlights potential areas for future research in this rapidly evolving field.

The paper introduces the GIoTEH architecture, which presents a layered framework aimed at creating a sustainable and energy-efficient IoT ecosystem. This architecture integrates EH technologies with advanced power management systems to ensure continuous and reliable operation of IoT devices, even in remote areas. The Power Part addresses energy availability by utilizing renewable sources like solar, thermal, and wind power, along with storage solutions such as batteries and supercapacitors. The Network Part ensures efficient data processing with contextual awareness, fog computing for real-time data management, and cloud computing for optimization and analysis. Lastly, the IoT Application Part connects sensor data collection, transport, processing, and application to enable smart services across sectors like healthcare, smart cities, and industrial automation.

In conclusion, this paper explores strategies to enhance energy efficiency in IoT systems through both energy conservation and EH techniques. By incorporating renewable energy sources like wind, solar, and geothermal, Green IoT systems can reduce dependence on traditional power grids and support more sustainable IoT operations. The importance of efficient energy storage and management systems is emphasized, as they are essential for the successful implementation of energy-harvesting solutions. The integration of EH technologies and power management ensures the long-term sustainability and scalability of IoT systems. Despite challenges such as energy availability, conversion efficiency, and power management, ongoing research is pushing the boundaries of this field. The GIoTEH architecture offers a promising path toward more energy-efficient and environmentally friendly IoT technologies.

References

1. G., Famitafreshi, M. Shahwaiz Afaqui, and J. Melià-Seguí. "A Comprehensive Review on Energy Harvesting Integration in IoT Systems from MAC Layer Perspective: Challenges and Opportunities", Sensors, 2021.
2. V. Tahiliani and M. Dizalwar. "Green IoT Systems: An Energy Efficient Perspective", 2018 Eleventh International Conference on Contemporary Computing (IC3), 2018.
3. M., Sirvanimoghaddam, et al. "Towards a green and self-powered Internet of Things using piezoelectric energy harvesting", Ieee Access, 7, pp.94533-94556, 2019.
4. "Green Mobile Cloud Computing", Springer Science and Business Media LLC, 2022
5. F.H., Panahi, et al., "Smart image-processing based energy harvesting for green internet of things", In 2018 Smart Grid Conference (SGC) (pp. 1-5). IEEE, 2018.

6. M.A., Albreem, et al., "Green Internet of Things (GIoT): applications, practices, awareness, and challenges", IEEE Access, 9, pp.38833-38858, 2021.
7. U.S., Toro, K., Wu, and Leung, V.C., "Backscatter wireless communications and sensing in green Internet of Things", IEEE Transactions on Green Communications and Networking, 6(1), pp.37-55, 2021.
8. M. H., Alsharif, et al. "Green IoT: A Review and Future Research Directions", Symmetry, 2023.
9. Kaur, Navroop, and Sandeep K. Sood., "An energy-efficient architecture for the Internet of Things (IoT) ", IEEE Systems Journal, vol. 11, no. 2, pp. 796-805, 2017.
10. W., Kun, et al., "Green industrial internet of things architecture: an energy-efficient perspective", IEEE Communications Magazine, vol. 54, no.12, pp. 48-54, 2016.
11. W., Yuqi, and H., Qi., "Research of intelligent transportation system based on the internet of things frame", Journal of Wireless Engineering and Technology, vol. 3, no. 03, pp. 160, 2012.
12. G., Aditya, et al., "Smart city architecture and its applications based on IoT", Procedia computer science vol. 52, pp. 1089-1094, 2015.
13. M., Vellanki, S. P. R. Kandukuri, and A. Razaque., "Node Level Energy Efficiency Protocol for Internet of Things", Journal of Theoretical and Computational Science 3, 2016.
14. S., Pallavi, and S. R., Sarangi., "Internet of things: architectures, protocols, and applications" Journal of Electrical and Computer Engineering 2017.
15. M. R, Prathyusha and B., Bhowmik. "IoT Evolution and Recent Advancements", 9th International Conference on Advanced Computing and Communication Systems (ICACCS), 2023.
16. S.H., Alsamhi, et al., "Green internet of things using UAVs in B5G networks", A review of applications and strategies. Ad Hoc Networks, 117, p.102505, 2021.
17. "Energy Conservation for IoT Devices", Springer Science and Business Media LLC, 2019.
18. "Intelligent Systems and Applications", Springer Science and Business Media LLC, 2019.
19. M. E., Yuksel and H. Fidan, "Energyaware system design for batteryless LPWAN devices in IoT applications", Ad Hoc Networks, 2021.
20. R.M., Ferdous, A.W., Reza, and M.F., Siddiqui, "Renewable energy harvesting for wireless sensors using passive RFID tag technology", Renew. Sustain. Energy Rev. 58, 1114–1128, 2016.
21. S., Zeadally, et al., "Design architectures for energy harvesting in the Internet of Things", Renewable and Sustainable Energy Reviews, 2020.
22. A. Raj and D., Steingart. "Review—Power Sources for the Internet of Things", Journal of The Electrochemical Society, 2018.
23. K., Messaoudi, et al. "A survey of UAV-based datacollection: Challenges, solutions and future perspectives", Journal of Network and Computer Applications, 2023.
24. D. Altinel, and G. K., Kurt. "Modeling of Hybrid Energy Harvesting Communication Systems", IEEE Transactions on Green Communications and Networking, 2019.
25. F.K., Shaikh, and S., Zeadally, "Energy harvesting in wireless sensor networks", a comprehensive review. Renew. Sustain. Energy Rev. 55, 1041–1054. https://doi.org/10.1016/j.rser. 2015.11.010, 2016.
26. J.M., Carrasco, et al., "Power-electronic systems for the grid integration of renewable energy sources", a survey. Ieee Trans. Ind. Electron. 53(4), 1002–1016. 1006.5277, 2006.
27. M.Y., Shams, et al. "A hybrid dipper throated optimization algorithm and particle swarm optimization (DTPSO) model for hepatocellular carcinoma (HCC) prediction", Biomedical Signal Processing and Control, 85, p.104908, 2023.
28. M., Lu, et al. "Green energy harvesting strategies on edge-based urban computing in sustainable internet of things", Sustainable Cities and Society, 75, p.103349, 2021.
29. "IoT as a Service", Springer Science and Business Media LLC, 2023.

30. E.H., Alkhammash, M., Hadjouni, and A.M., Elshewey, "A hybrid ensemble stacking model for gender voice recognition approach", Electronics, 11(11), p.1750, 2022.
31. Z., Tarek, et al. "Soil Erosion Status Prediction Using a Novel Random Forest Model Optimized by Random Search Method", Sustainability,15, p.7114, 2023.
32. E.H., Alkhammash et al., "Optimized multivariate adaptive regression splines for predicting crude oil demand in Saudi arabia", Discrete Dynamics in Nature and Society, 2022, pp.1-9, 2022.
33. A.M., Elshewey, wt al., "Weight Prediction Using the Hybrid Stacked-LSTM Food Selection Model", Computer Systems Science and Engineering, 46, pp.765-781, 2023.
34. B.B., Al-onazi, Nauman, et al. "Transformer-based multilingual speech emotion recognition using data augmentation and feature fusion", Applied Sciences, 12(18), p.9188, 2022.
35. S. A. Z., Hassan and A. M., Eassa, "A Proposed Architecture for Smart Home Systems Based on IoT, Context-awareness and Cloud Computing", International Journal of Advanced Computer Science and Applications(IJACSA), 13(6), http://dx.doi.org/10.14569/IJACSA.2022.0130612, 2022.
36. K.M., Al-Obaidi, et al., "A Review of Using IoT for Energy Efficient Buildings and Cities: A Built Environment Perspective", Energies, 15(16), 5991. DOI: 10.3390/en15165991, 2022
37. P. Pandiyan, et al, "A comprehensive review of advancements in green IoT for smart grids: Paving the path to sustainability", Energy Reports, 11, 5504-5531. DOI: 10.1016/j.egyr.2024.05.021, 2024.
38. M. I., El-Afifi, et al., "A review of IoT-enabled smart energy hub systems: Rising, applications, challenges, and future prospects", Renewable Energy, 21, 100634. DOI: 10.1016/j.ref.2024.100634, 2024.
39. A., Banotra,et al., "Decentralized Communication Networks for Energy-Efficient IoT Systems", Computer Networks, Volume 236, Issue C, DOI: 10.1016/j.comnet.2023.110011, 2023.
40. S. A. Z., Hassan et al., "Leveraging new Technologies for Building a Comprehensive Smart MIS: Integrating ERP, Blockchain, IoT, Context-awareness, and Cloud Computing", 6th International Conference on Computing and Informatics (ICCI), IEEE, 2024.