Solar Energy Harvesting and Wireless Communication Technologies for Internet of Things Applications: A Review

Nutan Tawar, Rajiv Dey

BML Munjal University, Guru Ghasidas Vishwavidyalaya, India

Corresponding author: Nutan Tawar, Email: nutan.23pd@bmu.edu.in

The purpose of Internet of Things (IoT) communications technologies is to establish connections between disparate objects in order to provide explicit smart services. This study attempts to give a thorough overview of the most recent wireless technologies and protocols for Internet of Things applications which employ solar energy harvesting (SEH). The study focuses on long-range communication and low power wireless technologies used in SEH for Internet of Things applications. A thorough and in-depth discussion of the IoT system's wireless technology and solar energy harvesting process with its classification for IoT applications is provided. Additionally, we detailed the specific difficulties with the prevalent communication technology used in IoT applications. This study compares the architecture, features (such as data rate, energy consumption, and range), protocol structure, and security of several wireless communications used in SEH. The study's methodology is centered on connectivity range, energy consumption, data rates, applications it also emphasizes the difficulties associated with each technology and future research. The suitability of the specific protocol for echo-system applications is categorized.

Keywords: Wireless Communication, Wi-Fi, Sigfox, LoRaWAN, NB-IoT, ZigBee, Bluetooth.

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1 Introduction

The intelligent network known as the Internet of Things (IoT) links every physical object that can be used to collect and exchange data. Human society is endowed with intelligence and ease by these physical objects that possess the capacity for sensing and communication. All of these features are together referred to as Internet of Things devices (IoTDs). Smart sensors, wireless meters, wearable technology, mobile devices, and even smart home appliances are a few examples of these IoTDs [1]. Most places in the globe produce electricity through the use of non-renewable energy, which may have detrimental effects on the environment. The Paris Climate Deal came into being as a result of efforts to minimize energy emissions and take into account the finite supply of fossil fuels. Given the escalating effects of global warming and other environmental problems, designing an effective system for gathering renewable energy is the biggest technological challenge of the twenty-first century. Corporate firms like as Texas Instruments, ST Microelectronics, and Linear Technology, USA are currently putting forth power management technologies for internet of things (IoT) node that are based on green power harvesting. Extended lifespans of solar energy harvesting based IoT networks require the design of an effective solar energy harvesting technology.

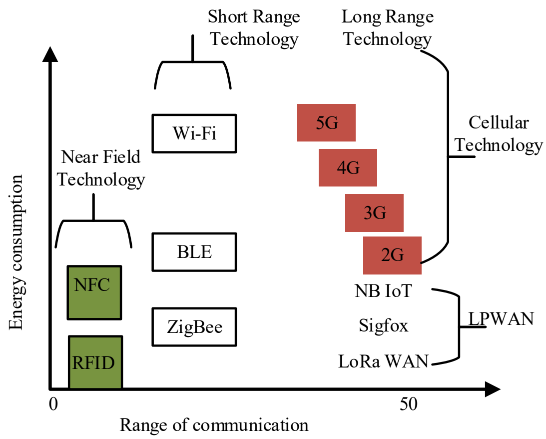

Figure 1. Wireless technology categorization: power usage against communication range [2].

The harvester mechanism in solar energy harvesting (SEH-IoT) nodes uses photovoltaic solar power as an input and transforms it into electrical energy.This electrical power subsequently charges the IoT node's battery and provides the operational voltage for the sensor node. Energy harvesting in IoT nodes has the benefit of lowering the labour-intensive task of changing the batteries of a large number of sensor nodes by venturing into remote locations for applications such as forest, combat, volcano, and glacier monitoring, etc. [3].The Internet of Things is expected to have a huge economic impact and grow dramatically. It is anticipated that more internet-connected devices and sensors will be added to the Internet of Things, leading to the emergence of new IoT applications such as industrial IoT, smart cities, smart agriculture, etc. According to Gartner, there were 30 billion internet-connected gadgets in use worldwide in 2018, an increase of about 32% from 2016.By 2025, it is predicted that there will be more than 75 billion people on the planet, and the rapid increase will continue in the years to come [4]. The increasing quantity of objects or gadgets that need to be connected raises significant concerns for their connectivity. Many Internet of Things (IoT) applications are utilized in constrained areas, and they may depend on short-range wireless technologies for connectivity, including WiFi, Bluetooth, Zigbee, and optical wireless communication (OWC). However, successfully managing and supplying power to each node continues to be a significant difficulty. All of this suggests using wireless power transfer (WPT) and energy harvesting (EH) whenever practicable. Previous papers provide a range of methods for enhancing battery-powered gadget functionality. Some focus on ways to achieve energy independence by combining EH with rechargeable batteries [5], [6], whereas others explore strategies to completely reduce energy usage during the standby period [7]. These findings do actually increase device autonomy, aid in downsizing, or do both, but they are insufficient to address the root causes. Contrarily, battery-less devices avoid the drawbacks of batteries, such as their limited lifespan, the high expense of physical substitution, and their sensitivity to environmental factors [8][9]. However, long-range wireless communication technologies are needed since more Internet of Things applications demand a large coverage area. For instance, long-range connectivity is required for unmanned aerial vehicles (UAV) and outside sensors used for tracking the environment to be connected to networks. Different long-range wireless technologies are created as a result. For instance, BLE [5], Sigfox [10] and LoRa [11] make use of unlicensed channels and have independent base stations (BS) that interlinked to the objects or devices in a manner akin to traditional cellular networks as shown in Figure 1. In general, smaller data rates and low energy consumption applications are supported by Sigfox and LoRa, allowing most devices to have a long lifespan (about ten years). The benefits of communication methods like ZigBee, SigFox, LoRa, and NB-IoT include low power consumption, wide coverage, the usage of license free band frequencies, suitability for IoT network features, and growing popularity when used in IoT applications. Additionally, there are other cellular-based low-power long-range communication methods. Long-term evolution (LTE) technologies such as LTE MTC (LTE-M) as well as narrowband IoT (NB-IoT) are used for MTC connection inside LTE networks.NB-IoT and LTE-M, in contrast to Sigfox and LoRa, use licensed bands and are compatible with existing cellular network to support devices. Furthermore, 5G is anticipated to improve current mobile wideband connections but also to meet the various connectivity needs of emerging Internet of Things applications, including ultra-high transmission efficiency and low latency. The truth is that every wireless networking method has pros and cons of its own. Cellular IoT connectivity methods are generally appropriate if IoT applications need data rates ranging from moderate to high, low latency, and extensive coverage.

We focus on the recent advancements in wireless communication used in solar energy harvesting technologies for IoT connectivity and their applications in this survey article. In summary, we present the most recent assessments of both established and developing technologies in this paper, together with an analysis of their advantages and disadvantages as well as fresh avenues for future research. We highlight the advantages of our survey article while summarizing the characteristics of other important survey article on IoT connection in Table I to further elucidate the contribution of this study. The rest of the paper is arranged as follows: Section II, various wireless technologies used for the IoT nodes are discussed. In Section III solar energy harvesting and the in general process of energy harvesting challenges of wireless technologies for IoT applications is presented followed by conclusions in Section IV.

2 Wireless Technologies for IoT

From the 1G to the present 5G mobile generations, there have been 5 stages of evolution [12]. From 1G to 3G networks, it has been evident how services and speeds have continued to advance. The early 2000s saw the proposal for 4G. The 4G network generation was the first to be fully reliant on the IP packet switching technique [13]. Following over a decade of deployment, the initial benefits of 4G have given way to drawbacks. These days, 4G has excessive latency and too slow of an access speed [14]. A way for humanity to connect at Gbps or higher is required. Later during the 2020s, 5G will become available, signalling the beginning of a fully digital world. Specifically, the Internet of Things (IoT) under 5G is a novel notion[11-12]. An integrated network of state-of-the-art technologies and remedies, the Internet of Things (IoT) allows people, systems, devices, software, and applications to be connected over the Internet [12-13]. Nevertheless, the review findings also revealed that IoT networks that uses 5G technology have a number of difficulties, including enhancing performance, supporting QoS, conserving energy, maintaining privacy, and maintaining security [14-15]. To address these issues, several communication strategies have been put forth, including as architecture, protocol, spectrum, and routing algorithms. Presently, wireless technologies being utilized in the IoT applications today depend on a number of factors, including duty cycle, mobility, energy consumption, local radio restrictions, availability of transmission power, and specific needs. Future Internet of Things applications will involve billions of different types of linked devices, so it is imperative to build a variety of technologies to support their communication subject to their range of reach, the wireless technologies that are accessible for Internet of Things connectivity are discussed in this study and divided into two categories: Both long-range and short-range technology. It is necessary to talk about technologies that have shorter range like Bluetooth, Wi-Fi, ZigBee, and the newly developed OWC technologies. LTE and 5G, as well as LoRaWAN technologies, are introduced for long-range communication depending upon the type of service features and requirements.

2.1 LoRaWAN (Low Power Wide Area Network)

LoRaWAN utilizes a spread spectrum modulation that operates in the Sub-GHz range and has enormous network capabilities (one million nodes or more), safe, reliable communication, and localisation capacity. Currently, it's used to link sensors to the cloud in order to facilitate real-time data and analytics exchange. LoRa wireless communications technology uses low-power communication of small packets of data (0.4 kbps to 36.4 kbps) over a long range. Hundreds of devices can be connected to a gateway simultaneously [15]. LoRa network contains nodes, gateway, a network server, plus a server that runs applications, just as the majority of other wireless communication systems do.Perhaps the LoRa network server is built on a public or private network architecture. The LoRaWAN Network architecture may be used in a star topology and allows for bilateral interaction among gateways as well as end nodes. "Uplink" refers to data transmitted by end nodes to the gateway, and "Downlink" refers to data transmitted by the gateway to the end node. But there isn't any direct exchange of information between end nodes. Through the provision of several protocol classes, the protocol serves a range of applications [16]: Class A: these devices uplinks to the gateway, and receive the downlink signal from two receiving windows. Class B devices have added windows for downlink signals at predetermined periods, same like class A devices. Since Class C devices are always listening, they consume more power and frequently don't have batteries. Protected bi-directional communication, flexibility, and localization services are the three main needs that the LoRa security protocol aims to address [17]. In [18]authors have created, unveiled an open LoRa technology for Internet of Things networks.

The work has three contributions:

1. Designing and building a hardware-based LoRa gateway;
2. Utilizing LoRa freely available codes on GitHub;
3. Enhancing server LoRa by utilizing the messaging system to ensure scalability and flexibility in module interactions. According to the experimental results, the suggested system outperforms the conventional LoRa network in terms of network performance. Lee et al. (2018) examined the suitability of LoRa networks for urban settings by designing and assessing the performance of a LoRa mesh network in [19]. In order to complete this project, 20 mesh LoRa devices were placed in a [800x600] range on a university campus, and a gateway was set up to gather data every minute.According to tests, the star LoRa design only managed 58.7% of packet deliveries under the same circumstances as the suggested LoRa system, which obtained a mean of 88.49%. LoRa has become one of the most widely used LPWAN (Low-Power Wide-Area Network) technology. It is excellent for Internet of Things (IoT) applications and allows reliable low power long-distance connections. Additionally intriguing for industrial IoT situations is LoRa. Nevertheless, real-time data transfers are not supported by a LoRa constraint. In order to address this issue,The authors of [20] introduced RT-LoRa, a revolutionary LoRa medium access technology, with the intention of facilitating real-time Internet of Things applications determined by LoRa. The outcomes of

the simulation showed that real-time faults for Internet of Things applications might be supported by RT-LoRa.

2.2 Sigfox

The network and technologies of Sigfox have been developed to satisfy the needs of widespread Internet of Things applications. These requirements include lengthy device battery lives, inexpensive gadgets, cheap connectivity fees, large network capacity, and excellent coverage. It makes use of a narrowband technique called Ultra-Narrow Band (UNB) wireless transmission at the perception layer [16]. Furthermore, it also uses Binary Phase-Shift Keying (BPSK), a common radio transmission technique that modifies the phase associated with the carrier waves in order to encode data. BPSK employs a very small portion of the spectrum. To achieve long range communication, Sigfox wireless devices carry relatively little data of 12 bytes per packet at data rates of (300 baud). Applications that need to send a brief, occasional burst of data use this [20]. Bidirectional communication is possible with Sigfox, both to and from the end device. When devices that are connected use energy-efficient upstream and downstream transmission, a typical battery can endure for years [21]. Since it should be the one to initiate communication, the end device needs to connect to the Sigfox network via a Sigfox modem. Sigfox protection: It is secure that the connected endpoints with the Sigfox cloud offer an end-to-end authentication mechanism that combines a public PIN stored in read-only storage on the endpoints with a security password stored in non-accessible storage[22]. A self-sustaining SigFox sensor node was developed by the authors in [23] which can collect information from a sensor zone and transmit it to a cloud for usage in intelligent agricultural applications. To increase the usefulness of the system, the sensor nodes are designed to use solar energy. Under ambiguous conditions, the gadget could send data every five minutes, according to investigational data.Authors in created a self-sustaining SigFox sensor node that can gather data from a sensor region and send it to the cloud for use in smart farming applications. The sensor nodes are built to utilise solar energy in an effort to improve the system's functionality.Investigational data suggests that the machine might transmit data every five minutes in unclear conditions. Authors in [24]examined how responsive SigFox was to varying sensor densities and scale circumstances for Internet of Things networks. According to the figures, there is a maximum of about 100 sensors that may send data simultaneously. The findings suggested that network efficiency may suffer when the total number of sensors rises above 100. Additionally, this study suggests ways to enhance the huge-scale, higher-density, and performance of sensors in Sigfox has IoT networks.

2.3 Narrow Band Internet of Things (NB-IoT)

NB-IoT, or the Narrow Band Internet of Things, refers to LPWAN radio technology that was developed to provide distant communication cellular connectivity between devices and services [15]. Existing LTE functions serve as the foundation for NB-IoT [25]. To keep this standard simple and lower the cost of the device and battery consumption, several functionalities have been omitted. It may be implemented in three distinct modes and makes use of orthogonal frequency division multiple access (OFDMA) in the downstream and frequency division multiple access (FDMA) in the upstream link. It also uses QPSK and BPSK modulations. Three options are available: (1) independent as a devoted carrier, (2) In-band inside a broadband LTE carrier's filled bandwidth, and (3) inside a guard-band of an already-operational LTE carrier [26],[20]. NB-IoT places particular emphasis on low battery usage and maximum availability, or deep interior penetration. The majority of NB-IoT devices have a high connection density and a lengthy battery life. The NB-IoT physical layer fits inside a part of the LTE norm, however it limits bandwidth to a specific 200 kHz narrow band that is used for both uplink and downlink. NB-IoT has the advantage of deeper indoor penetration and better coverage (20 dB better than GPRS). NB-IoT Security: LTE's protocols are the source of NB-IoT encryption and authentication [27].In the NB-IoT network, data is secure; however, as it leaves the network, it's made accessible to external parties. Considering IoT in 5G applications, In [28] created a working example of NB-IoT network utilizing free software. Relying on the freely available eNB of LTE technology, three of the providers EURECOM, B-COM, and NTUST collaborated to create the freely available NB-IoT. This study proposes a technique to send the sensor data gathered to the Internet over the freely available NB-IoT network using the already available commercial NB-IoT module. Authors in [29]assessed the NB-IoT protocol's effectiveness and made improvements for IoT networks in 5G. This paper emphasis encompasses the following: Probabilistic network can be used to: (1) Analyze the NB-IoT system's latency measurement; and (2)enhance the algorithm known as k-means, that categorizes NB-IoT devices and implements a priority-based sequence plan, in order to improve the NB-IoT protocols. According to the experiment's findings, the suggested uplink traffic planning schema outperformed previously developed uplink traffic scheduling schemas in terms of performance.

2.4 Wireless Fidelity (Wi-Fi)

The Wi-Fi family of wireless communication technologies is well recognized as the IEEE 802.11 standards. It is often employed for LAN equipment's and Internet connectivity under 100 meters [30]. It uses the 2.4 and 5 GHz frequency range to function. Wi-Fi is a workable communication solution for IoT networks since it is appropriate for short-range communication. The goal of a Wi-Fi access point is to speed up the access point's response time. In order to lessen downlink channel access conflict and regular stations' queuing delays in Internet of Things systems, it offers a downlink packet scheduling technique. The outcomes showed that, in comparison to conventional methods, the suggested approach reduced energy usage by over 38% and delay by over 41%. The most important issues with IoT applications are real-time tracking and location. Applications for GPS-based locating in outdoor settings are widely known. But it's not usable for indoor situations, though.For home IoT access points, researchers in [32] offered a Wi-Fi-based queuing planning method. The goal of this work proposal is to decrease the Wi-Fi access point's reaction time through the use of an adaptive authentication mechanism. The outcome of the trial showed that the suggested solution is more reliable than conventional Wi-Fi-based home IoT systems. Authors in [31]presented a WIOTAP-based energy-saving communication solution for Wi-Fi-based Internet of Things (IoT) systems. This work focuses on using an intelligent wireless access point. In order to lessen downlink channel access conflict and regular stations' queuing delays in Internet of Things systems, it then proposes a downlink packet scheduling technique. The outcomes showed that, in comparison to conventional methods, the suggested approach reduced energy usage by over 38% and delay by over 41%.

2.5 ZigBee

Utilizing the IEEE.802.15.4 standard, ZigBee is a communication system that operates in the ISM bands. It is an IoT network wide-area connectivity solution with low power consumption. Because of its affordability, ease of use, and versatility, ZigBee technology offers advantages over other communication technologies in Internet of Things networks. ZigBee has a transmission range of approximately 100 meters and a data rate of approximately 250 kbps, contingent upon power output and surrounding environmental factors. Extremely low data rate, less coverage, and prolonged battery backup applications including industrial equipment control, medical device data gathering, and home automation are common uses for ZigBee [32] presented a novel security scheme for ZigBee networks that protects against replay attacks by using a timestamp. With this solution, energy usage is greatly improved. Additionally, this system employs powered devices to supply energy for power-constrained devices with the current date, improving feasibility. All ZigBee networks are intended to be compatible with the proposal. According to the trial results, the suggested technique considerably strengthens an IoT network's defense against ability respond attacks using ZigBee technology. Researchers in [33]presented a Wi-Fi-based queue administration solution for residential IoT access points. The goal of this work proposal is to decrease the Wi-Fi access point's reaction time through the use of an adaptive authentication method. The outcome of the trial showed that the suggested solution is more reliable than conventional Wi-Fi-based home IoT systems. The outcomes showed that, in comparison to conventional methods, the suggested approach reduced energy usage by over 39% and delay by over 42%. The most important issues with IoT applications are continuous monitoring and location.

Applications utilizing GPS for locating are widely recognized in outdoor settings. It is not practical for indoor situations, though. Wi-Fi signals are used by the authors of [36] to provide an Internet of Things (IoT) solution for interior space monitoring and positioning. The 802.11-REVmc2 Wi-Fi standard has a message type that is used in this study. Next, by measuring the signal intensity and back and forth time, the navigation system's accuracy and capability are enhanced. The outcomes of the experiment showed that the suggested method improved performance and, for interior scenarios, attained a mean positional accuracy of 1.435 meters with a revision time of every 0.19 seconds.

2.6 Bluetooth Low Energy (BLE)

The IEEE 802.15.1 [34] has standardized Bluetooth, which was first developed by Nokia as an internal project in the late 1990s. But it soon gained popularity as a wireless technology, are mostly used for communications among compact devices spread out over a short area with a coverage range of no more than 100 meters. In principle, Bluetooth transfers small data packets at an average speed of 1 Mbps to 3 Mbps via a number of bands with a 1 MHz bandwidth within 2.402GHz and 2.480GHz [35]. However, for some new IoT use-cases that demand low-power transmissions for small and battery-limited devices, conventional Bluetooth's significant power consumption renders it unfeasible [36]. The majority of the time, wireless sensor nodes run on batteries and frequently experience issues with energy use. In actuality, engineers are constantly searching for elusive ways to reduce costs and size without sacrificing performance, such as battery life extension or increased range.An continuing development in this respect is the deployment of license-free industrial, scientific, and medical (ISM) band radio frequency (RF), Bluetooth Low Energy (BLE), and ZigBee, which are energy-efficient technologies for communication [37].

3 Energy Harvesting Process

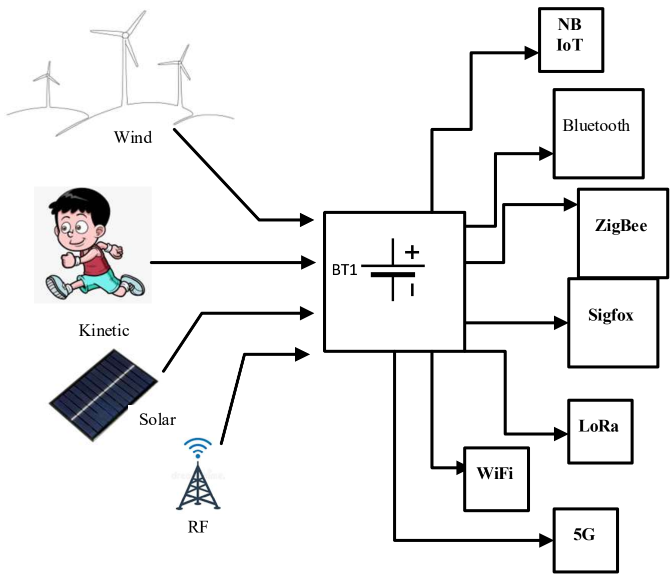

Figure 2. Representation of general energy harvesting procedure.

In order to generate the environmental energy around us and convert it to electrical power for usage in a variety of wireless sensor networks, energy harvesting techniques can be applied [5]. The energy harvesting procedure in multiple wireless technology network is depicted in Figure 2. The Figure 3 displays a block schematic of SEH-IoT system. An energy storing device like battery/super-capacitors, a IoT node, a power converter and management unit (PCMU), and a photo voltaic cell acting as a transducer make up a standard PV-EH-IoT. The voltage regulator, an MPPT algorithm, a DC/DC converter, and load control circuitry make up the PCMU. Additionally, there are three primary components to an Internet of Things sensor: an external interface, signal-conditioning circuitry, and a sensor unit. The light from the environment, whether it be indoor or outdoor, is converted by the solar PV cell into heat and energy. The PCMU serves as the PV cell's and IoT sensor's interface. With the use of MPPT, the DC-DC converter harvests the extreme amount of energy from photovoltaic cells. Due of its ability to draw a reasonable quantity of energy even while the circuit is indoors, the latter is the most important part of the PCMU. In alongside the energy required to operate the Internet of Things sensor at the proper voltage level, the voltage regulator also supplies extra energy to the device that stores data.

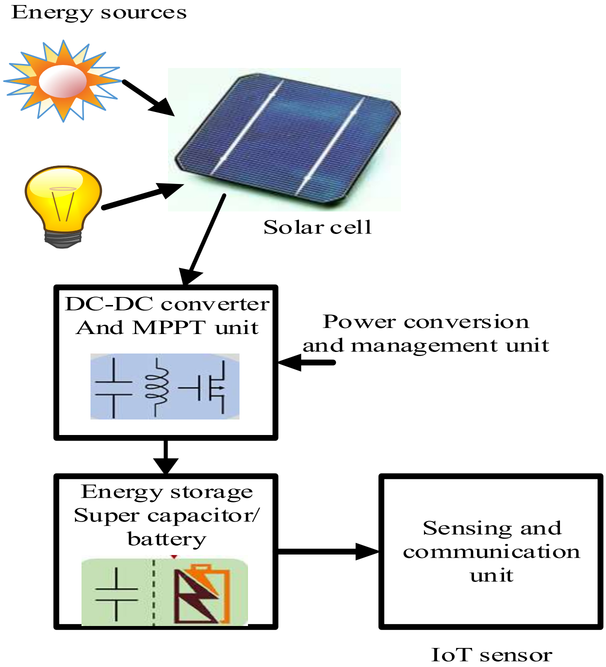

Figure 3. Representation of solar energy harvesting.

3.1 Classification of SEH-IoT

The process of turning ambient light energy, whether it be artificial or natural, into electricity is known as solar energy harvesting. It makes it possible for the researchers to create a solution that would allow the sensor node to run continuously [38]. The energy harvest method usually consists of 4 stages: energy asset, conversion of energy, energy storage, and energy consumption. One aspect of the energy source stage is the abundant availability of energy sources in the study's implementation setting, which includes indoor/outdoor light. Energy conversion is the process of changing energy using power electronic circuits, sometimes known as PCMUs, and transformers. Batteries or super-capacitors are used to store excess energy during the energy storage phase for later usage. The final stage involves IoT devices using the energy they have captured or stored. The right choice and ideal SEH-IoT design are crucial for meeting the energy needs of IoT nodes. In general, SEH-IoT can be divided into two groups according to its capacity for energy storage: Harvest-Usage (reduced storage) additionally Harvest-Store-Usage (with a storage unit attached).

3.2 Energy Harvest and Use

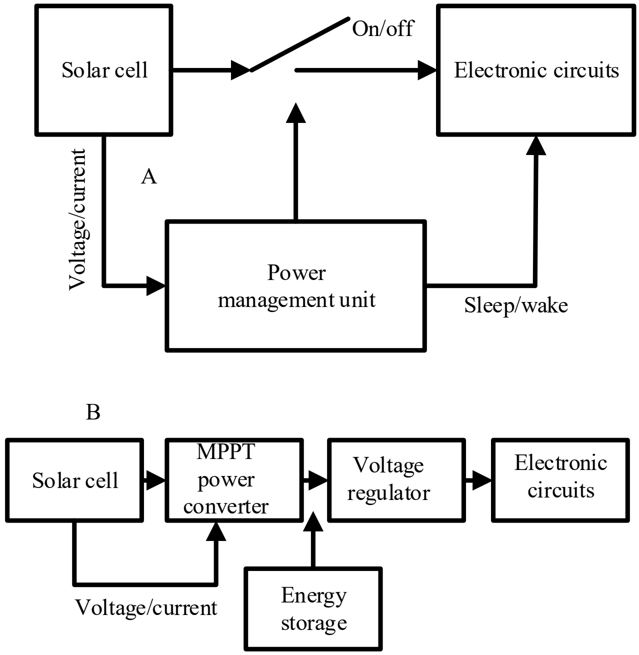

Figure 4. SEH-IoT classification: (A) Harvest and usage, (B) Harvest store and usage.

In reference to the configuration depicted in Figure 4(A), the captured energy is utilized straight for the process, negating the requirement for a storage device. It lowers the price of IoT devices and boosts efficiency. The energy harvester is in charge of converting energy and giving the gadget the controlled voltage. Since there currently is no storage system, the Internet of Things sensors will only be operated in either sleep or active mode. The Internet of Things sensor will be in either an active or sleeping mode depending on whether the energy available is smaller than the verge limit. Once the sensor are turned in the active mode, it collects data, process it, and transfer it to the cloud server. The power converters and management unit are in charge of organizing, controlling, and supplying power for the operations (PCMU). There are two types of energy harvesters available: discrete-time systems and continuous-time. Systems with solar and piezoelectric components are considered discrete-time harvesters, whereas thermoelectric generation (TEG) as well as microbial fuel cells (MFC) are classified as continuous-time harvesting tools [39].

Regarding the Harvest-Store-Usage arrangement shown in Figure 4(B), The energy is first extracted and put away in super-capacitors or rechargeable battery packs, after which it is used in accordance with the sensor node's needs. To charge the storage devices, MPPT algorithm and a DC-DC converter is needed. Certain applications utilize both primary as well as secondary storage devices, contributing to the system's overall bulk and cost. Additionally, it gives the IoT sensor greater autonomy. Thus, it follows that the application itself must serve as the foundation for the configuration. A comparative analysis of solar energy harvesting is given in Table 1.

Table 1. Comparative study of SHE and wireless technologies used for IoT applications.

References	Energy harvesting technique	Wireless technologies used in IoT	Energy consumption	Data rate	Advantages	Disadvantages	Applications	Range
[23]	Solar energy	Sigfox	High	High	Solar energy is abundant, long-range transmission, High data rate	Depending on the Sigfox subscription the maximum limit of message transmission is 140 messages/day	Autonomous Sigfox sensor node with the ability to send data gathered from various sensors straight to the cloud	10 to 40 Km in rural regions and less than 10 Km in densely populated areas
[19][40]	Solar energy	LoRaWAN	Low	0.3 Kbps and 27 Kbps	Long range transmission with low power consumption	Low data rate	Large area monitoring of IoT sensor network in Smart agriculture	10-50 Km line of sight
[41]	Solar energy	Wi-Fi	40% efficient	Up to 54Mbps	Inclusion of power management algorithm energy efficiency has increased to 40%	Suitable for short range communication	Health monitoring system	Up to 100m
[9]	Solar energy	Bluetooth low energy (BLE)	Low	1 to 2 Mbps	Both one-way and two-way communication, data latency improvements of up to 75%, and restarting prevention	Short range communication	Developed a prototype powering the BLE LPN with a bulb or a tiny solar panel for collecting indoor light	Up to 10 m

[42]	Solar	ZigBee	Low	Up to 250Kbps	Enhance performance and energy consumption, highly secured communication	Short range communication	In order to record energy usage and network properties under various weather and time conditions, the solar energy harvesting wireless sensor network described in this study was constructed.	1-100m
[29]	Solar energy	NB-IoT	Low but comparatively higher than LoRa WAN	250Kbps	Using the Lyapunov optimization technique, LOTEC stands for Lyapunov optimization on time improves average response time of IoT node	Long range communication	a thorough analytical methodology for adding renewable energy sources to enable the operation of fog computing and Internet of Things systems	35 Km

3.3 Challenges of Communication Technologies for IoT Applications

The goal of IoT communication technologies is to enable connection for IoT applications. With a billion of IoT devices connected to a single network, these advances have a lot of major challenges ahead of them.

Our belief is that energy efficiency and security awareness are the two most important factors. Next, we outline the difficulties with communication technology for IoT applications and suggest future lines of inquiry.

Privacy and security in IoT applications: With everything being linked to the Internet, the rise of the Internet of Things creates a genuinely open globe. As a result, items are susceptible to online attacks with ease. Therefore, amongst the more important criteria encouraging the creation of IoT applications which will become widespread are privacy and security, according to [43]. Threats can be carried out in several stages in IoT applications, notably as

IoT security: large numbers of less computationally capable IoT devices are not suited for implementing strong security algorithms. As a result, hackers concentrate on taking advantage of IoT device weaknesses.

Safety for gateway units: gateways are crucial for interaction among upper levels and objects layer devices. It is hence the core of Internet of Things applications. The gateway of Internet of Things applications frequently becomes the target of denial of services attacks or information spoofing.

Safety in edge devices: Newly suggested solutions lower service response times for real-time Internet of Things applications by utilizing edge computing technologies. Therefore, one of the main issues is ensuring the security of the edge servers.

Safety of cloud servers: Given the vast amounts of data generated by Internet of Things devices, cloud services may offer a way to store and handle large amounts of data. Thus, among the biggest obstacles will be ensuring the safety of cloud servers.

Efficiency in Energy Use: Assuming thousands of billions of IoT gadgets would run and send data constantly throughout the day and night once IoT applications get traction. It will therefore use a significant quantity of energy, depleting the energy supply day by day. It is not possible to do this. Energy-efficient methods of communication thus pose a significant challenge.

Popli et al. (2019) provided a thorough analysis of NB-IoT-based energy-saving strategies for Internet of Things (IoT) devices in [44]. According to the survey's findings, NB-IoT technology will be necessary in the future to implement green IoT networks. For IoT networks looking to preserve energy, authors in [45]proposed an optimum schedule approach based upon the multi-objective fuzzy algorithm.Authors in[46]offered a dependable and energy-efficient data transfer solutions for cloud-based Internet of Things systems in. In comparison to the conventional method, the suggested alternative increased reliability by 60% and decreased energy usage by 57%, as shown by the numbers.

In our view, the following approaches can serve as a basis for considering energy efficiency:

1. Based on communication technology: NB-IoT and ZigBee are two examples of intelligent, adaptable, low-power communication technologies. The authors of [47] provided an overview of energy harvesting communication methods for Internet of Things devices that can run on their own. Green energy is what this sort of technology claims to be in the future.
2. Based on trade-offs: Productivity and energy conservation are mutually exclusive in reality. As such, a clever, adaptable trade-off strategy must to be taken into account. For IoT-based smart grid applications, researchers in [48]suggested a trade-off approach for inverters that balances energy savings and efficiency.
3. Internet of Things networks built on the cloud: Because of the cloud's powerful processing, computation, and storage capabilities, IoT applications are going to continue to use it as their backbone infrastructure. However, because of the suggested edge computing technologies, cloud services have a slow reaction time. As a result, a smart offloading schema to allocate resources among mobile computing with wireless communications in the best possible way.

4 Conclusions

In this paper, a review on solar energy harvesting and the wireless technologies used for IoT applications is presented. Further, the motivation for using energy harvesting technology for the IoT node is discussed along with the wireless technologies used for the IoT nodes in detail. Solar energy harvesting is the main focus of the paper among other energy harvesting technologies and it is discussed in detail. Lastly, the paper is concluded by presenting a comparative analysis of solar energy harvesting and wireless technologies in Table 1. From Table 1 it can be concluded that if an application is battery driven and deployed in remote places where cellular network is not present but it is present within a range of 10 to 50 Kms then LoRaWAN is the best communication technology. If it is a grid connected application and the application require more data rate with low latency then cellular network is best communication technology. We believe that the energy-saving and security issues associated with communication technologies will remain fascinating research subjects in the future, drawing interest from academia as well as industry.

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