Chapter

Energy Harvesting Technology for IoT Edge Applications

Amandeep Sharma and Pawandeep Sharma

Abstract

The integration of energy harvesting technologies with Internet of things (IoTs) leads to the automation of building and homes. The IoT edge devices, which include end user equipment connected to the networks and interact with other networks and devices, may be located in remote locations where the main power is not available or battery replacement is not feasible. The energy harvesting technologies can reduce or eliminate the need of batteries for edge devices by using super capacitors or rechargeable batteries to recharge them in the field. The proposed chapter provides a brief discussion about possible energy harvesting technologies and their potential power densities and techniques to minimize power requirements of edge devices, so that energy harvesting solutions will be sufficient to meet the power requirements.

Keywords: energy harvesting, edge devices, IoTs, standards

1. Introduction

The technological advancement in energy-efficient low-power hardware vanquished the need of AC current for IoT-based embedded systems, making them suitable for remote applications. The number of new applications including weather data estimation and real-time parameter monitoring is gaining ground with the evolution of different environmental sensors and telemetry applications. Energy harvesting technologies together with low-power platforms and energy-efficient storage technologies allow edge devices, IoTs and embedded systems to work in remote areas.

A report published on energy efficiency of the Internet of things (IoTs) focuses attention on the utilization of edge devices in various applications, and most of these applications are battery driven, which are having limited lifespan (**Figure 1**). The objective of the proposed chapter is to highlight the potential of energy harvesting technologies that can reduce the dependency on fixed charge batteries and lead to interrupted device operation. The chapter covers the discussion on basic elements of an energy harvesting system, enumerates possible energy resources and quantifies the potential of different harvesting technologies including photovoltaic cells, piezoelectric materials, thermoelectric and electromagnetic generators and electrostatic motors.

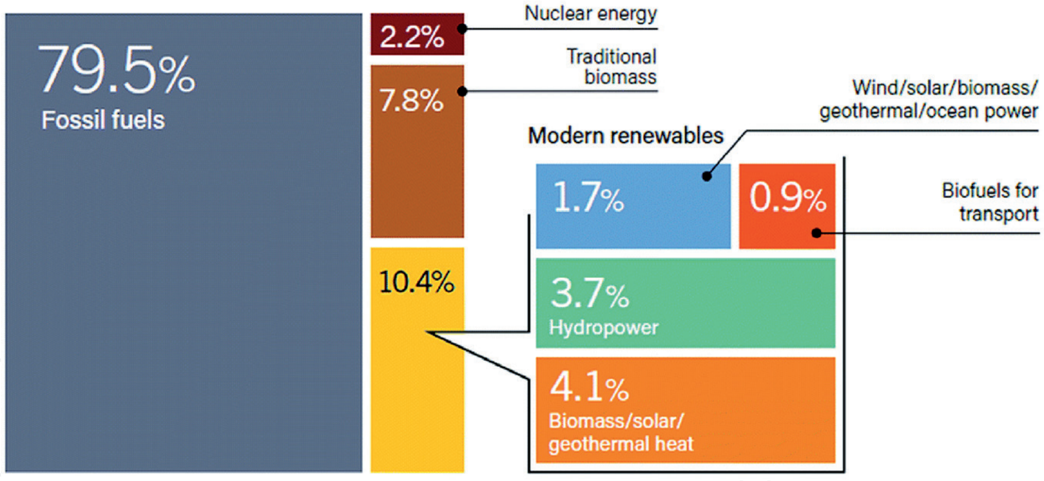

Figure 1.
Share of renewable energy resources in total energy consumption, 2016 [1].

2. IoT and IoT edge devices

Internet of things abbreviated as IoT leads to ambient intelligence that is based on the connectivity of people and things and utilizes the adaptive and sensitive electronic environment to address the need of the things around. Diab et al. [2] summarized six essential building blocks of IoT-based system, as shown in **Figure 2**.

Deployment of IoT-based systems in remote locations demands unattended operation over long time spans. In achieving this target, constant power supply and energy efficiency are the key challenges. Energy harvesting allows on-site charging of the storage devices and thus leads to an uninterrupted sensor node operation. In addition to it, edge devices control the flow of information between two network boundaries. Basically, the edge devices are utilized by service providers and act as entry and end points for a network. Their primary functions include processing, filtering, translation and storage of data and transmission and routing of data within the network [3].

In order to attain intelligence systems with advance features and to gain more computing power, IoT-based applications make use of edge devices. This process of using logical physical locations and decentralized processes is called edge computing [4].

Edge router is the most common type of edge devices and acts as the gateway between the different networks [5]. The primary function of the edge router is to connect a wide area network or a campus network with the Internet. Firewalls are the category of edge devices which are located on the margins of network and perform filtering of processed data during transmission between external and internal networks [6]. Further, different types of sensors/actuators and other types of end terminals also act as edge devices. The figure given below encapsulates the different types of end devices and their role in the network (**Figure 3**).

If the number of IoT devices is connected in a system, edge devices provide distributed operation among them using dynamic host configuration protocol and domain name systems [7].

2.1 Importance of edge technology

The conventional cloud computing network being a centralized network collects the data at the outermost layer and sends it to the server for further procedure. Limited hardware capabilities of the devices especially near the network edge

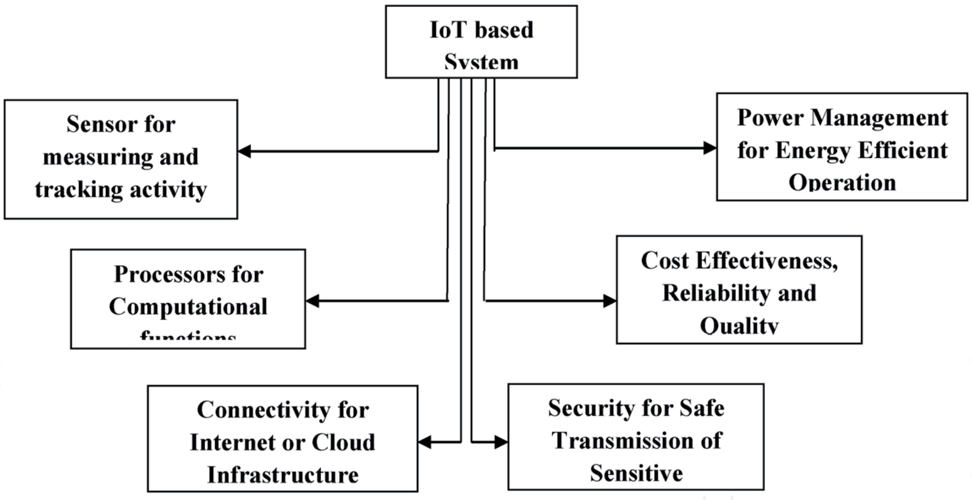

Figure 2.
Essential building blocks of an IoT-based system.

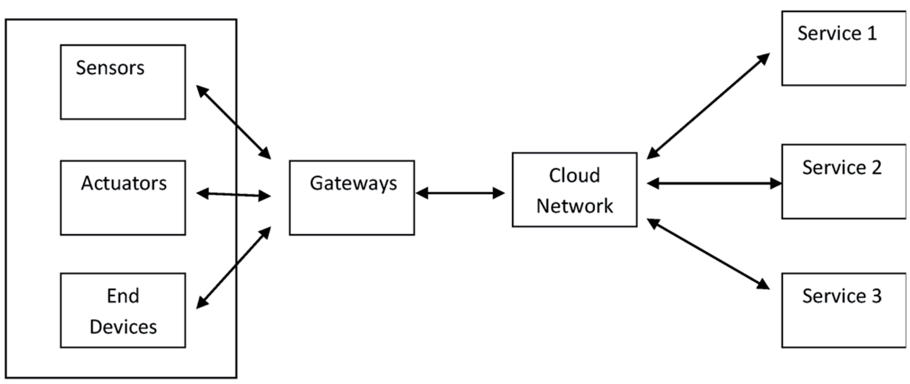

Figure 3.
Edge devices in IoT-based system.

are the main reasons behind this setup. These devices have limited functionality, limited power capabilities and limited storage capacity that restrict them to process or analyse the gathered data. With the advancement of miniaturization techniques in fabrication, present day IoT devices have capabilities of handling large data. This feature leads to optimized network operations by collecting data at edge terminals and relocating advance processing functions in real time [8].

Thus edge computing ensures processing of data where it is created rather than routing the data to data centres for processing. This feature leads to improved response time to milliseconds and optimum usage of network resources.

2.2 Advantages of enabling edge computing for IoTs

- **Reduced data exposure and reduced network load:** Real-time data handling by the edge devices with advance processing and storage capabilities prevent the data to route through the whole network and enhance the offline capabilities by making the apps independent from uninterrupted network connection.

- **Reduced delay:** IoT edge computing devices optimize the network performance by reducing delay or latency parameter. By storing and processing the data in edge data processing units, real-time computing is possible instead of communicating with the cloud server for each interaction.

- **Secure communication:** Since edge computing architecture deals with distributive nature of collecting, processing and storing the data among the large range of data centres and edge devices, it is not easy for an intruder to demolish the privacy and security of the network [9].

2.3 Industry benefits

- Efficient massive data processing
- Local data handling ensures security of sensitive data
- Quick response time with smart devices and applications

Cloud-based deployments of edge devices and data exchange features between edge and cloud is the next generation build out for 5G communication by telecommunication sector. High-speed network response with very low latency factor is the target where data compilation is carried out at the edge devices and reports are sent to the central cloud for storage. This feature eliminates the unnecessary data movement over the network [10].

3. Energy harvesting technology

Energy harvesting is a process through which energy is derived from external resources and captured energy is converted into electrical energy through energy harvesting device. The various resources are tabulated in **Table 1** that can be used for conversion.

Basically, an energy harvesting system comprised of three main components including application specific transducer, an interface circuit with or without storage device and receiver. The transducer or energy harvesting unit harvests the energy from the ambient sources and converts them in electrical form. The function of the interface unit is to extract maximum amount of energy from the harvesting unit and make the energy level compatible with the specific receiver or load. This has been accomplished with different power management approaches including voltage regulation or rectification [20], etc. The receiver may include different sensors, transducers or any other electronic circuit. The presence of storage unit avoids the start-up problem and energy depletion state in case of large interval in harvesting cycles. **Figure 4** shows the basic block diagram of an energy harvesting system:

S. No.	Form of energy	Source
1	Light energy	Solar energy from sun (outdoor/indoor) [11, 12]
2	Kinetic energy	Vibration, rotation, motion [13–16]
3	Thermal energy	Human body, industry [17, 18]
4	Atmospheric energy	Pressure, gravity
5	Radio frequency	Antennas, radio frequency spectrum [19]
6	Biological/chemical energy	Diffusion, radioisotopes
7	Hydro energy	Kinetic energy from water

Table 1.
List of various energy resources and their source.

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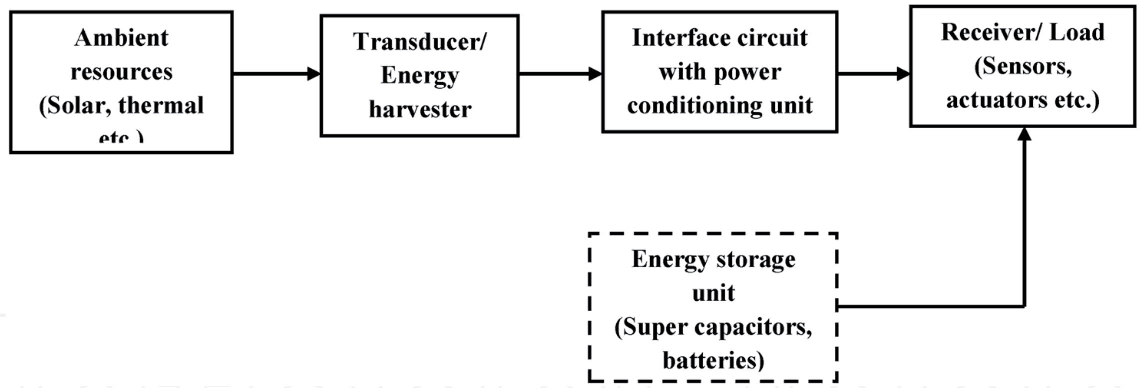

Figure 4.
Basic building blocks of an energy harvesting system.

4. Requirement for energy harvesting in IoT

Energy harvesting is a promising solution to power IoTs especially when they are installed in inaccessible areas and regular battery maintenance is not possible. Energy harvesting approach extends the life cycle of the device and eliminates the constraint of fixed charge batteries as an energy source. Some key factors are enlisted below that highlight the requirements for energy harvesting technology in IoT applications.

S. No.	Energy harvesting technology	Potential production	Industrialization
1	Thermoelectric	10 μW–1 kW	Widespread production
2	Photovoltaic	1 μW–1 MW	
3	Electrodynamic	0.1 μW–1 MW	
4	Piezoelectric	10 μW–100 W	
5	Capacitative electrets movement harvesting	0.1 μW–1 mW	Research
6	Pyroelectric		
7	Capacitive without electrets	0.1 μW–1 MW	
8	Triboelectric		
7	Radio frequency waves	0.1 μW–1 mW	Limited production
8	Magnetostrictive	10 μW–1 MW	Major trials

Table 2.
Different energy harvesting technologies and their potential production [21].

S. No.	Electronic module	Power range
1	Watch/calculator	1 μW
2	RFID tag	10 μW
3	Sensors/remotes	100 μW
4	Wireless sensors/hearing aid	1 mW
5	Bluetooth transceiver	10 mW
6	Global positioning system(GPS)	100 mW

Table 3.
Overview of power consumption by different IoT modules and sensors [22–24].

4.1 Power

The energy harvester should generate power at least of the order of milliwatts to sustain in IoT domain applications. **Table 2** shows the potential production of different energy harvesting technologies.

In conjunction to the survey given in **Table 2**, an overview of power consumption of different electronic modules has been depicted in **Table 3**. The survey reflects that the operating range of different IoT devices and sensors is in between 0.1 μW and 1 W, which can easily be handled by energy harvesting devices. Since ambient resources are stochastic in nature, energy demand and supply may not be time synchronized; the presence of backup storage devices and effective power management electronics is essential to deliver power from harvester to IoT devices in time.

4.2 Size scaling

With the advancement in integrated circuit technology, the size of the IoT devices is not an issue as number of features can be integrated on a single chip.

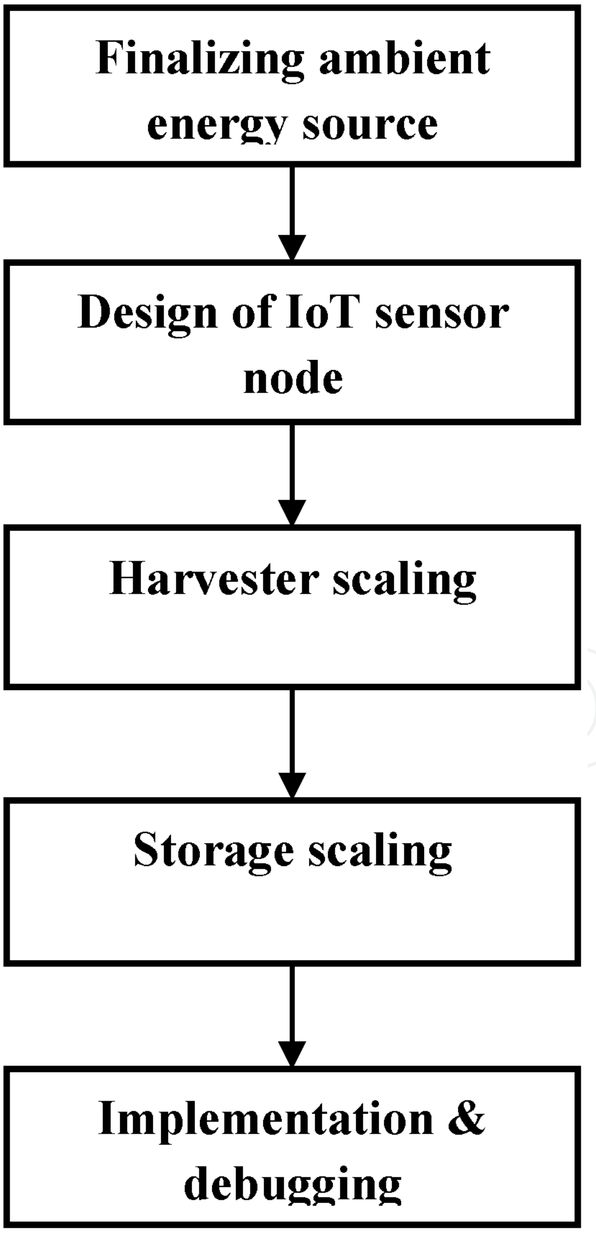

Figure 5.
Development procedure of rechargeable sensors.

The battery used in conventional module designs generally has a life cycle of 1 year and is the key factor in overall weight and size of the module. As an alternative to the fixed charge batteries, the size of the energy harvesting unit is application specific and should not be greater than the previous energy storage. The scalability of the energy harvesting unit with the size of IoT module should be ideal.

4.3 Cost factor

Conventional battery is an economical product because of the mass production, which leads to cost-sensitive production of battery-driven IoT devices. On the other hand, integrating energy harvesting technique into the module will increase the cost. This cost will include the component cost together with the redevelopment cost of the device because implanting an energy harvesting device on the top of the conventional module is not a practical solution and whole internal design gets modified. **Figure 5** shows the development process of rechargeable sensors and validates the above statement.

5. Constraints and potentials of energy harvesting technique

5.1 Constraints

The constraints in practical implementation of energy harvesting techniques in IoT domain are as follows:

1. High cost as compared to the conventional batteries is the most important constraint to be considered.

2. The second barrier is the size of the harvesting module, which increases as per the energy demands.

3. Energy storage unit is essential for uninterrupted sensor node operation.

5.2 Potentials

Although the additional cost is a barrier for mass production of harvesting modules and power requirements of some technologies may not be in the range of harvesting technologies, there are high possibilities in wide spread adaption of energy harvesting technology. Few of them are enlisted below:

1. The estimated life cycle of an energy harvesting module is above 5 years. In a survey, it has been observed that some energy harvesting units are working smoothly from the last 15 years without hardware degradation [25]. Thus, regular hardware servicing is not required in inaccessible locations.

2. The evolution of advance low-power electronic hardware together with the cloud computing for data processing further reduces the energy consumption in electronics and increases the feasibility of energy harvesting.

3. A high factor of energy saving can be in building automation where copper wires, materials, installation and maintenance cost can be reduced by energy harvesting approach.

4. With the growth of IoT industry, more energy harvesting modules will be implemented that will in turn reduce the cost.

6. Energy harvesting standards

Interoperability between different end systems is an important criterion for the successful adaption of energy harvesting techniques in different applications. To achieve this target, there are three standard policies, which are depicted in **Figure 6**. The EnOcean Alliance follows the standardization of communication profiles (EnOcean Equipment Profiles) to ensure that the entire product range including rechargeable sensors, wireless switches and controls can communicate with each other. The EnOcean wireless standard is geared to wireless sensors and wireless sensor networks with ultra-low-power consumption and also includes sensor networks with energy harvesting technology.

The EnOcean wireless standard became the standard ISO/IEC 14543-3-10:2012 in 2012. The standard is applicable to Information technology, Home electronic system, wireless short packet protocol and optimized for energy harvesting, its architecture and lower layer protocols. The proposed protocol supports energy harvested products for IoT sensors and switches designed without wires and batteries. The standard allows low-power consumption of sensors and switches by transmitting multiple short transmissions and appropriate frequency bands with adequate signal propagation and minimum interference.

6.1 Socio-economic applications

In this section socio-economic application of energy harvesting technology has been discussed, and their market share has been depicted in **Figure 7**.

- **Energy harvesting power sensors**

Renewal of battery-operated power sensors with energy harvesting-based rechargeable wireless sensors is the prime factor in the growth of energy harvesting market. Rechargeable sensors are becoming the first choice for the deployment

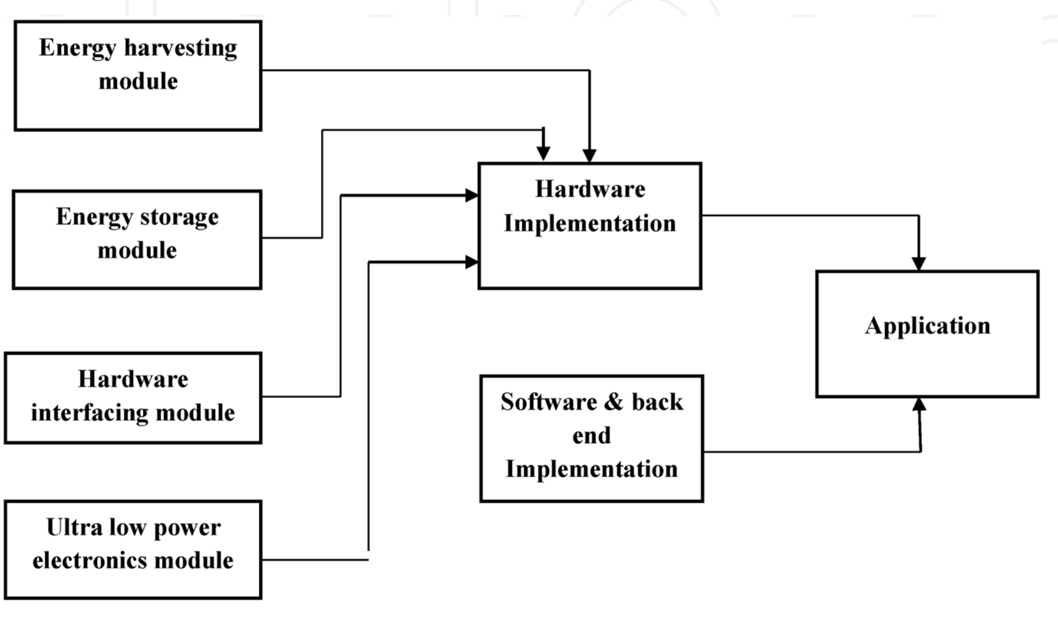

Figure 6.
Implementation of energy harvesting platform.

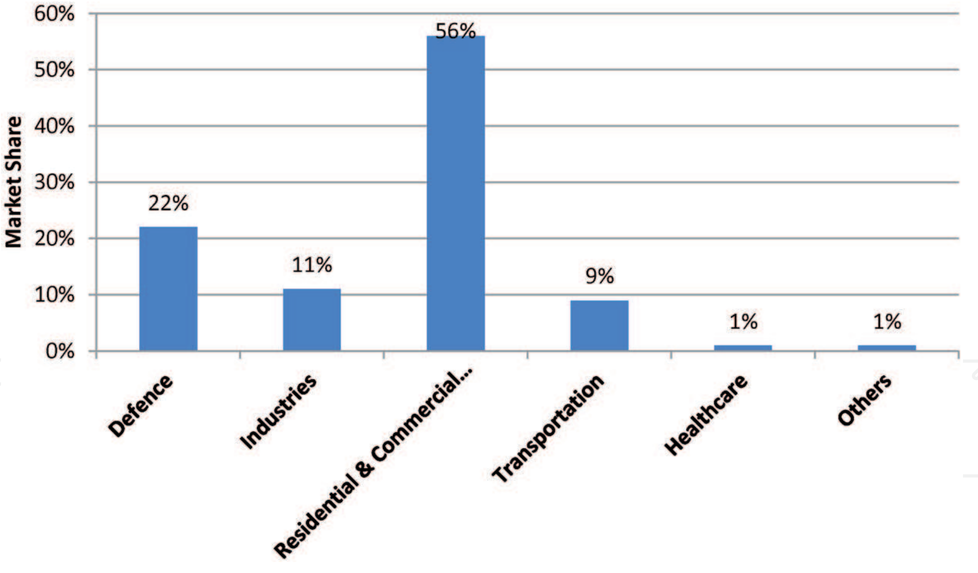

Figure 7.
Energy harvesting market share under different sectors.

in remote or inaccessible locations where it is not possible to replace the batteries frequently especially in offshore oil, gas systems or sensitive military areas [26]. Further, autonomous or rechargeable sensors are environment friendly as they do not contain any harmful metal or chemical for the environment.

- **Benefits for primary industry**

The energy harvesting market in primary industry sector was sized at EUR 130 million in 2014 and predicted to reach EUR 380 at the end of 2020 [27]. To enhance the reliability and availability of industrial processes, energy harvesting devices are employed in primary industry sector.

- **Benefits for defence industry**

Energy harvesting technology has been increasingly used in defence sector as it leads to the way where heavy battery packs are replaced by autonomous or rechargeable devices. Solar photovoltaic-based autonomous aerial unmanned vehicles called Drones are the great achievement for military applications. According to the latest survey, energy harvesting-based defence applications target EUR 730 million by 2020 [27] (**Table 4**).

- **Benefits for transport industry**

Different transportation media offer various forms of energy that can be harvested by different means. For instance, solar panels installed on the road collect the solar energy and convert it into electrical form through walking or driving. Similarly, vibration energy generated through various transportation means can be utilized for energy harvesting. It is estimated that transportation sector can target EUR 310 million by 2020 [27] (**Table 5**).

- **Benefits for residential and commercial sites**

Energy harvesting will be an essential feature for the upcoming trend of home automation and smart housing. This is because of the reason that energy

	Application	Edge devices	Energy source
Smart industry	Remote control of machines	Machines	Main power supply
	Real-time monitoring of machine wear	Appropriate sensors	Main power supply
	Diagnostics of machines	Appropriate sensors	Main power supply
	Surveillance of maintenance conditions	Appropriate sensors	Main power supply; energy harvested source
	Inventory management and asset tracking	RFID tag	Passive energy source; energy harvested source
	Smart pipeline management	Dedicated sensors, e.g. thermal, pressure, humidity, etc.	Energy harvested source

Table 4.
Application and energy sources of edge devices for smart industries.

Application area	Application	Edge devices	Energy source
Smart transportation	Smart roads	Energy collector roads	Pressure- or vibration-based energy harvesting technology
		Smart sensor in roads	Vibration, RF or thermal-based energy harvesting technology
		Smart lightening system for roads	Main power supply; solar- or vibration-based energy harvesting system
	Real-time monitoring of traffic congestion	GPS system in cars	On board or rechargeable battery
	Car-to-car communication system	Inbuilt devices in car	On board or rechargeable battery
	Car-to-infrastructure communication system	Inbuilt devices in car	On board or rechargeable battery; solar- or vibration-based energy harvesting system

Table 5.
Application and energy source of edge devices for smart transportation.

harvesting technology will reduce the large-size batteries for mobile devices. Rapid growth of IoT devices is also possible with energy harvesting as it facilitates rechargeable power supply with low installation and maintenance cost. The market value of this sector is expected to reach EUR 1750 million at the end of 2020 [27] (**Table 6**).

7. Communication protocols used in IoT systems

Various communication protocols with their different positive and negative attributes have been used to communicate with the network through IoT devices. **Table 7** enlists different communication protocols along with their properties.

8. Summary

Different levels of technical maturity are available with different types of ambient energy resources and corresponding energy harvesting techniques.

Target area	Application	Edge device	Energy source
Smart home	Home automation	Actuators	Main power supply
		Camera	Main power supply
		Gateway	Main power supply
		Smart sensors including humidity sensor, temperature sensor, fire sensor and door sensor	Energy harvesting source of light or thermal energy
		Sensors connected with mains	Main power supply
	Smart lightening system	LED bulbs	Main power supply
		Hub; gateway	Main power supply
		Smart light switches	Vibration- or pressure-based energy harvesting source
Smart workplace	Workspace automation	Main server	Main power supply
		Actuators	Main power supply
		Sensors	Energy harvesting source of light or thermal energy
		Gateways	Main power supply
	Control system	Reporting time, access control	Main power supply
		Badge	Passive source of energy
		Gas sensor, motion sensor, smoke sensor	Energy harvesting source of light or thermal energy
		Window/door sensor	Energy harvesting source of light or vibration energy

Table 6.
Application and energy source of edge devices for smart home and working area.

Communication protocol	Power	Data rate	Distance covered
ZigBee	50 mW	250 kb/s; for medium data rate applications	25 m; for medium distance communication
Wi-Fi	Greater than 500 mW	Greater than 100 Mb/s; for high data rate applications	10 m; for low distance communication
LoRa	100 mW	1 kb/s; for low data rate applications	500 m; for high distance communication
Bluetooth	10 mW	1 Mb/s; for high data rate applications	10 m; for low distance communication

Table 7.
Different communication protocols with their properties.

The magnitude of available power from different sources ranges from microwatts to milliwatts. This range is suitable for a variety of IoT devices and related applications. Some practical implementations of energy harvesters are surveyed in the literature that offers power to drive IoT devices. But there are various technical constraints that limit the worldwide implementation of energy harvesting technology. These issues need to be addressed to satisfy the future demands of the world.

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