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Energy harvesting for devices in wireless sensor networks: A Review

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Abstract

Recent years have witnessed several technological breakthroughs in wireless sensor networks (WSNs), yet energy continues to be an indispensable resource despite these advancements. The amount of energy that is available in WSNs has a direct bearing on how well it functions, how well it performs, and how long it will continue to operate. Because of the limitations imposed on them by cost and size, sensor nodes almost always come outfitted with a constrained amount of energy. As a direct consequence of this, their batteries will need to be replaced at regular intervals. However, the replacement is only sometimes a viable alternative; in fact, there are some situations in which it is unlikely to be achievable and entirely improbable. Because of this, there is an urgent need for more feasible solutions, which include energy harvesting or wireless energy transfer, as well as the creation of power at the sensor nodes themselves or their delivery of power to them. These options are among the options that are now available. This study intends to accomplish the following three primary goals: In the first step of this process, we will investigate prospective renewable energy resources and information on their qualities and uses in WSNs. Second, this study examines various methods for charging batteries and the various ways each of these methods might be applied to the networks.

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Keywords: Wireless sensor network (WSN), Wireless recharging, energy harvesting, sensor nodes

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1. Introduction

Wireless sensor networks (WSNs) have been used widely for many applications in different fields [1, 2]. The networks often include a certain number of sensor nodes deploying in sensing are to collect data or to provide warnings or detection purposes [3, 4]. In order to measure and to collect data for application-specific analysis such as civil and military applications, a sensor network is deployed. The network of cooperating embedded devices is known as a big group of sensor nodes [5, 6]. Sensor nodes are equipped with sensing, computation, and communication capabilities. In addition, the nodes include computation, communication, storage, control elements that can support the networks for different activities [7, 8]. Their tasks such as monitoring of habitats [9], supporting vehicles [10] structure monitoring [11, 12], and early warning of volcano activities [13] are common examples of the networks. Working in a harsh condition or in places where people may not reach easily, the networks are powered by pre-charged batteries that can deplete quickly [14]. The networks always need energy-efficient manners to improve their lifetime [15, 16].

The fact that sensor nodes have a limited battery capacity is one of their most significant drawbacks [17]. This means that nodes can only function for a specific time before their power supply runs out. A finite node lifetime either means that the applications have a finite lifetime or that additional costs and complexity will be associated with regularly changing the batteries. Nodes may use large batteries to achieve longer lifetimes. However, this will result in the nodes having to deal with increased size, weight, and expense. There is also the option for nodes to use low-power hardware, such as a low-power processor and radio, but this comes at the expense of a reduced capacity for computation and shorter transmission ranges [18].

Many different technical solutions have been suggested to lengthen the amount of time that battery-powered sensor nodes can remain operational [19, 20]. These include paper energy-aware MAC protocols (BMAC) [21], SMAC [22] and XMAC [23]). Using UAVs-(unmanned aerial vehicle) or mobile robots to assist in data collection and powering sensor nodes is one method to prolong network device lifetime [24, 25]. In paper [26], the authors focus on implementing graph-based deep learning methods in communication networks involving both wired and wireless situations to tackle issues such as energy consumption and network communication. Although all of the aforementioned strategies optimize and adjust power consumption to extend the lifetime of a sensor node, lifetimes continue to be limited and finite. When working with a limited power supply, it is challenging to optimize all performance parameters at the same time. For example, increasing the battery capacity results in an increase in cost, and increasing the transmission range can lead to a rise in the amount of energy required.

Using energy harvesting is a different approach that has been used to solve the issue of limited node lifetime [27]. The energy sources mentioned are renewable energy sources from the environment [28], or other energy sources such as body heat [29]. The paper [30] is a comprehensive survey and solar energy harvesting process, but the authors have not mentioned other energy sources' technologies and potential. The sensor nodes are provided with power by the electrical energy that has been collected. If the energy source that is harvested is substantial and continuously available, then a sensor node may be powered indefinitely [31]. Furthermore, the system parameters of a node can be adjusted to improve node and network performance based on the periodicity and magnitude of harvestable energy by using Reinforcement Learning. A device can maximize its power use to achieve peak performance during the period that it has remaining because it is limited by the next harvesting chance (recharge cycle) [32].

Energy harvesting offers several advantages to the end user, and some of the most important advantages of EH applicable to WSNs are listed and expanded below. Energy harvesting technologies may:

-Reduce the reliance on the power provided by the battery. The amount of power that the sensor nodes require is steadily decreasing due to developments in microelectronics technology. Therefore, the energy captured from the ambient environment might be sufficient to do away with the need for a battery.

-Decrease installation expenses. Self-sufficient wireless sensor nodes require no power cables, wiring, or pipes. In addition to being incredibly simple to install, they also lower the hefty installation expense.

-Reduce the expense of maintenance. Once implemented, energy harvesting enables sensor nodes to operate autonomously and eliminates battery replacement service calls.

- Maintain continuous sensing and actuation capabilities in potentially dangerous environments that are difficult to reach.

- Reduce environmental effects. Harvesting energy has the potential to eradicate the need for millions of batteries as well as the energy expenses associated with replacing batteries.

The rest of the paper is organized as follows. Section 2 describes the architecture of the energy harvesting system. Section 3 presents the types of renewable energy sources. Section 4 provides energy storage techniques. Section 5 describes wireless power transmission techniques. Section 6 discusses challenges and future directions for research. Finally, Section 7 provides conclusions and future work.

2. Architecture of the energy harvesting system

The original sensor nodes were big devices, but today's embedded sensor nodes are much smaller. They consist of a single processor unit, one or more radio transceivers, a power unit, and a sensing unit, as shown in Figure 1. Recent years have seen the introduction of sensor nodes equipped with energy harvesters, resulting in the creation of EH-WSNs. The design of the sensor node in these networks is made up of one or more than one sensing unit(s), a radio transceiver, a processing unit, an energy harvester, one or more than one energy storage unit(s), a power management system, and optionally an energy predictor [33].

2.1. Structure of energy consuming device

Small energy-consuming devices have many different constructions in practice[34]. However, their standard structure usually has the same essential components, as shown in Fig2. There is no storage component in the structure for devices that use energy collected by the direct method. Each functional block in the device's structure holds important and distinct tasks—for example, the power block stores and supply power to all energy-consuming components. The computing block holds the functions of processing, storing data, and managing resources. Sensing is a sensor block to collect data and then put the data into the computing block. Communication is the unit that transmits data

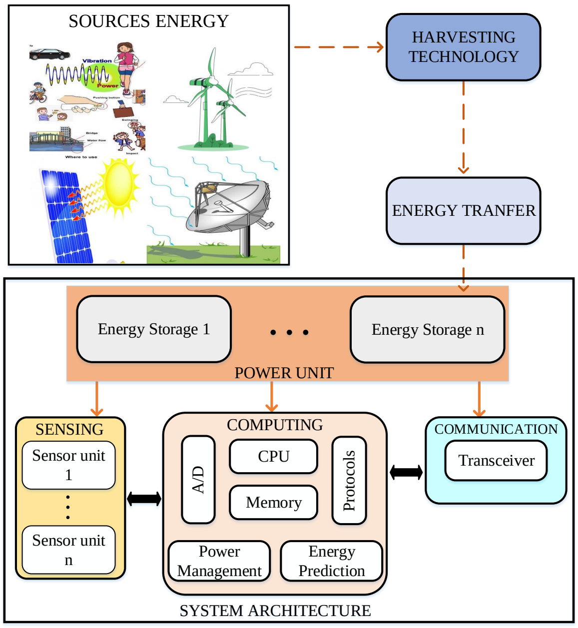

Figure 1. The architecture of the system harvest energy for devices in the sensor network.

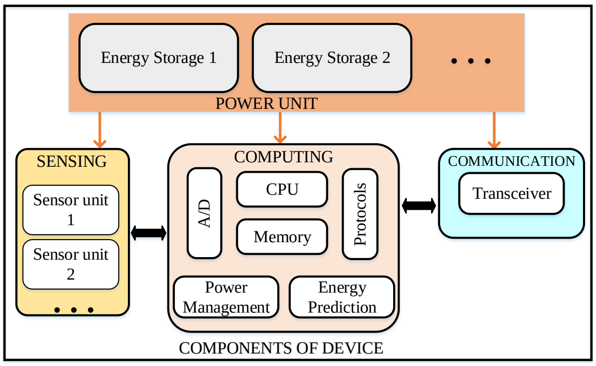

Figure 2. The general structure for small power consumption equipment

between components in a device or between one device and another.

2.2. Types of use of harvesting energy

The energy-harvesting system transforms the collected energy into electrical energy that can be used for the sensor node. This can happen directly, as shown in Figure 3a, or indirectly, as shown in Figure 3b. The capacity for energy storage is an essential feature of sensor nodes. It stores the collected energy and supplies the sensor nodes with the power they need to function correctly. In addition, energy predictors are utilized to estimate the amount of energy that has been harvested and will be made available to a sensor node at any particular point in time.

By utilizing strategies such as the adaptive duty cycle and other power management techniques, it is possible to achieve energy-neutral operations, as presented in the paper.

In general, energy-collecting architectures can be classified into two categories- 1) Harvest-Use: Just in time for consumption, the energy is harvested, and 2) Harvest-Store-Use: Whenever there is the opportunity, sources of energy are collected and stored for later use. A classification analogous to this one can be found in the paper [35, 36].

Figure 3a depicts the architecture known as the Harvest-Use model. The power harvesting system supplies direct power to the devices in this scenario [37]. Consequently, for the sensor node to function correctly, the power harvesting system's power output must be maintained at a consistently higher level than the minimum operating point. The node will be rendered inoperable if there is an insufficient energy supply. Sensor nodes will switch from the On state to the Off state when there is a sudden change in energy that the energy harvesting system produces is less than the power consumed by the sensor nodes.

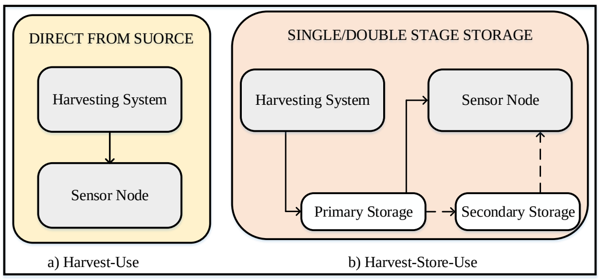

Figure 3. Energy harvesting architecture with and without storage devices.

The Harvest-Store-Use structure is represented by Figure 3b. The structure features a storage component that stores the collected energy and provides power to the devices [38]. Energy storage is helpful in situations where the amount of energy that can be harvested is greater than the amount of energy being used at the moment. In addition, energy can also be stored in storage until large enough to help the system extend operating time. Energy storage will be used later, either if a harvesting opportunity is unavailable or in the event that the energy consumption of the sensor nodes increases to improve capability and performance metrics. The storage component itself can have either a single stage or two stages. Secondary storage is an additional storage option that can be utilized if primary storage runs out of energy or fails.

3. Energy- harvesting sources

The energy source is an essential part of any energy harvesting architecture because it determines the total amount of energy used and the rate at which it can be used. Each potential energy source possesses unique characteristics, the magnitude of which can be predicted and controlled by us [39, 40]. It is optional to make an accurate prediction of the amount of energy available before harvesting when using a controllable energy source to supply harvestable energy at any time required.

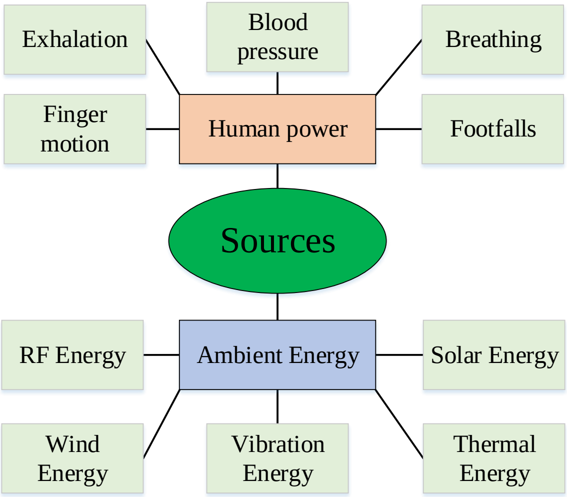

Figure 4. Energy harvesting sources

With uncontrollable energy sources, it is necessary to collect power whenever available. In this scenario, if the source of energy can be predicted, then a prediction model that predicts the source's availability can be utilized to determine when the next recharging cycle will take place. In addition, two main categories can be used to classify the many types of energy sources [41], 1) Ambient Energy Sources: Renewable forms of energy that are derived from the natural environment, such as solar energy, wind energy, and radio frequency (RF) energy, 2) Human energy sources: Movements made by people are converted into usable energy as shown in Figure 4. Energy sources collected from the human movement are energies the system user cannot control. Several instances include the body's blood pressure, temperature, and breath. The energy sources generated from human activities are those under human control when man generates a specific activity to generate energy for harvesting, such as movement of the fingers, rowing, or walking.

4. Energy storage techniques in low-power consumption devices

The capacity for energy storage in portable devices, such as sensor nodes, is of the utmost importance. A node's size, cost, and lifespan of operation can all be significantly influenced by its storage technique. In practice, the storage of electrical energy in sensor nodes can be divided into two distinct types of technologies: super-capacitors and rechargeable batteries [18, 42]. These techniques differ concerning charge storage density, lifetime, discharging capability, leakage, and size. Utilizing the two techniques in one of three different ways is possible for sensor nodes. The first is using super-capacitors in a device that doesn't need batteries and is suitable for small and low-power implementations. The second is that charging the battery is beneficial for prolonged use and jobs that necessitate a lot of power. Finally, the choice is a hybrid system that combines super-capacitors and rechargeable batteries. It is essential to have a thorough understanding of the differences between the various energy storage technologies to choose the most appropriate storage method for any given application.

4.1. Super-capacitors

The term "super-capacitor" refers to a device with a high energy density compared to a battery and a conventional capacitor, the unit of measurement for which is the Farads. These capacitors have a few different names, including electric double-layer capacitors (EDLC), ultra-capacitors, and electrochemical capacitors. In paper [42], the super-capacitors, unlike regular capacitors, the charge does not build up in the two plates of the device. Instead, these devices allow an electrical charge to build up between electrodes with a larger surface area and a thinner electrolyte. This configuration also shortens the distance separating the electrodes, which results in an increase in capacitance and energy density. Compared to chemical batteries, super-capacitors have several benefits, the most significant of which is their ability to withstand an extremely high number of charge and discharge cycles. It can undergo this process without significantly reducing performance or storage capacity. The electrochemical energy storage mechanism used in these devices is the cause of this phenomenon. Because these devices use a highly irreversible storage method, they can be quickly charged, which boosts the charge/discharge efficiency of these devices to as high as 98 %. Because of this, they are an excellent option for use as a reservoir in compact energy harvesting devices. Consequently, this enables sensor nodes to function in harsh environments, particularly in scenarios where a plentiful supply of energy is available for a sustained period of time. In addition, the memory effect in these devices is practically nonexistent, and they can function in an extensive range of voltages and temperatures. Since super-capacitors can be drip charged, in most cases, complex charging circuitry is unnecessary. This makes it much simpler to integrate super-capacitors into compact sensor nodes.

The fact that super-capacitors suffer from a severe leakage problem makes the rate at which they self-discharge significantly faster than that of standard batteries. Whereby a super-capacitor can release as much as 11 % of the energy, it has stored in a single day. If it continues like this, it will only last about ten days. The good news is that this disadvantage is recompensed for by rapid recharging. When combined with periodically available ambient energy and effectively exploited, it can allow an approximate 20-year working life with no need for upkeep.

4.2. Rechargeable battery

Rechargeable batteries are yet another technology that can be utilized in WSN applications as an alternative source of power reserve. This method has a higher energy density, more significant development, and more widespread application than super-capacitors. According to its chemical makeup, a rechargeable battery must go through an electrochemical reaction in the opposite direction to regain its previous power level. This device can be categorized into several technology categories, such as sealed lead acid (SLA), nickel-cadmium (Ni-Cd), nickel metal hydride (Ni-MH), and lithium-ion (Li-ion). Lithium-ion polymers and (Li-Po). Less often employed energy reservoirs in the WSN are Ni-Cd and SLA. This is due to the fact that Ni-Cd batteries have a memory effect, which means that when they are frequently charged after only a partial discharge, their capacity will be lost. This phenomenon is quite undesirable, particularly in applications that involve energy collecting. The SLA batteries are cumbersome, need a significantly larger space, and have a poor energy density. The two Ni-MH and lithium-based batteries that are left have a much higher capacity for storing energy, are much more affordable, take up significantly less space, and can be trickle charged. Ni-MH also suffers from the memory effect, but in contrast to it, it can be undone by carrying out a full discharge after it has been charged. On the other hand, Li-based batteries have a higher operating voltage, are capable of providing more energy, and weigh less than their Ni-based counterparts. For battery-powered sensor nodes to last as long as possible, batteries must be discharged in a manner that extracts the maximum amount of charge possible. In order to accomplish this, the sensor node must be designed with robust energy-aware functioning and self-monitoring capabilities. This means that all of the integrated modules in a node should make efficient use of the available power. In addition, the system should be able to quantify various aspects of the battery, such as the type of battery, the current state of the battery, the amount of time remaining until the battery is completely discharged, and other parameters. Utilizing an algorithm, design, processing, routing, and transmission range that are all aware of energy consumption can result in a power-efficient functioning system.

In order to efficiently discharge a battery, in-depth knowledge of the energy distribution of a node is necessary, especially in simulations or in deployments that take place in the real world. Some parts of batteries are not taken into account. This reduces the charge that can be taken from the battery and makes it hard to predict how long the node will last.

5. Energy transfer methods

Another option would be to send the power to the sensor node rather than generate it at the node itself, which would mean not harvesting the energy from the surrounding environment. The transfer of power in WSN can be broken down into two categories: 1) direct-contact charging and 2) charging that is performed wirelessly. Direct contact charging entails physically touching a node in order to recharge its batteries. Other techniques, such as using wires, are also possible; however, using wires to connect sensor nodes is incompatible with the idea of a wireless network. This section's primary emphasis is going to be placed on wireless charging. A comprehensive overview is going to be offered in the following paragraphs.

5.1. Transferring energy with wireless recharging

The transfer of electrical energy from the power source to the deployed sensor nodes without the requirement of a wired media is the process that we refer to as wireless recharging [43, 44]. The idea of transmitting power without wires or cables has been kicking around for over a century. Nikola Tesla was the first to suggest and show the apparatus required for such a wireless transmission in the paper [45]. Since the invention of wireless power transfer, scientists have been working to improve its fundamental concepts to extend its range, make it more portable, and improve its overall efficiency. Wireless power transmission techniques are presented and discussed below.

Inductive coupling-based energy transfer: The use of inductive coupling to accomplish wireless power transfer has seen significant development in recent years. It operates according to the theory of electromagnetic induction, which states that a time-varying voltage in a coil generates a fluctuating electromagnetic field. If we were to put another coil within this field, the voltage from the primary coil would be induced across the terminals of the secondary coil, as shown in Figure 5. Inductive coupling allows for the transmission of power in a way that is uncomplicated, long-lasting, secure, and effective. Equipment adopting inductive charging does not demand a wired electrical connection and is typically insulated or enclosed in a compact shape, such as an electric toothbrush [46, 47] consisting of a charging base and brush unit, each with a coil. When the brush unit comes into contact with the magnetic field produced by the stand, power is transmitted to the brush unit and utilized to recharge the battery. Because of its small size and portability, inductive power transfer is simple to incorporate into WSN to lengthen the sensor node lifetime.

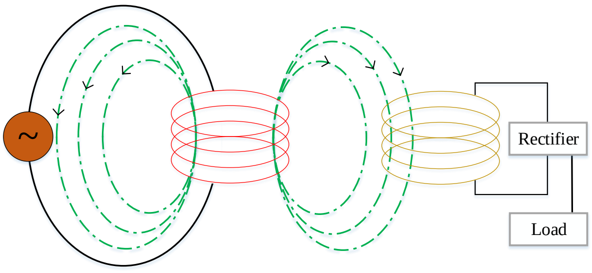

Figure 5. Inductive power transfer

Magnetic resonance-based energy transfer: This method is quite close to inductive coupling in its execution. The fundamental idea is that if a variable electric current is passed through a coil tuned to a specific resonant frequency, a fluctuating magnetic field will be produced around the coil. If another coil tuned to the same frequency is placed in this field, it will couple with the field created by the first coil, creating a robust resonant coupling.

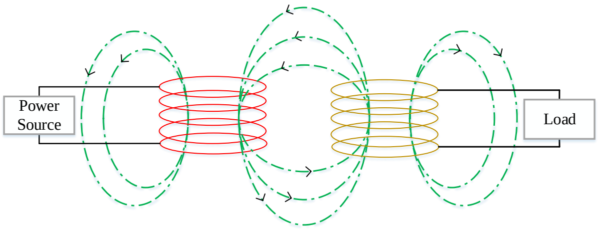

Figure 6. Resonant coupling

This notion also referred to as resonant coupling, states that two coils can exchange energy at a distance, provided that both coils resonate at the same frequency. This procedure is depicted in Figure 6. Compared to inductive coupling, this method does not generate any interference with nearby environments. Additionally, the energy source does not need to be in close touch with the receiving device to transfer power over a medium-range distance effectively. According to this plan, the distance over which power can be sent is directly related to the dimensions of both the receiver and the transmitter.

Radio frequency (RF): The portion of the electromagnetic spectrum that is covered by radio waves ranges from 3 kHz to 300 GHz. By making use of the far-field radiative waves, it is possible to use a portion of this range to facilitate the transmission of energy from a transmitting antenna to a receiving antenna. This Omni-directional transmission system has low efficiency, and because the radiation may pose potential human health risks, government regulations limit the amount of power that can be output; as a result, it can only be used for low-power applications, such as those in the mW and uW range [48]. Because electricity is emitted from the transmitting antenna in all directions, this approach does not require a straight line of sight to be established between the transmitter and the receiver. Additionally, this indicates that power can be delivered to several devices simultaneously. It is important to note that switching antennas also requires a certain amount of energy [49]. Figure 7 illustrates the power transmission across numerous devices using RF waves.

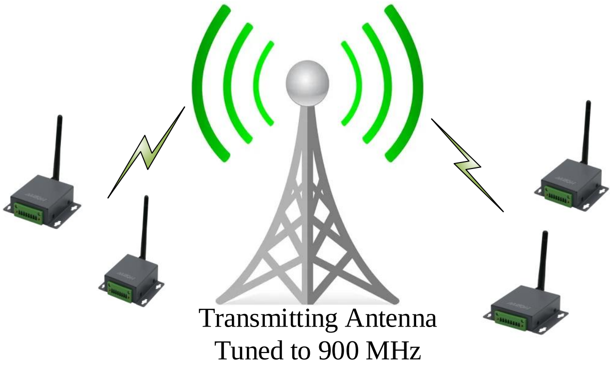

Figure 7. RF energy transfer

Laser-based system: The frequency range of lasers is approximately 30 THz to 3 PHz, which places them in the visible or near-infrared region of the electromagnetic spectrum. Like radio frequency, lasers can transfer power by first transforming the power source into an intense laser beam and then concentrating that beam on a panel of photovoltaic cells situated at the receiver, as shown in Figure 8. At the receiver, photovoltaic (PV) cells can convert the light from the laser into usable electric energy by employing the same methodology as solar harvesting. The laser beam is significantly more intense when compared to other light sources, and it can achieve a transfer efficiency of 98 % over a distance of 50 meters [50]. Despite this, the conversion efficiency

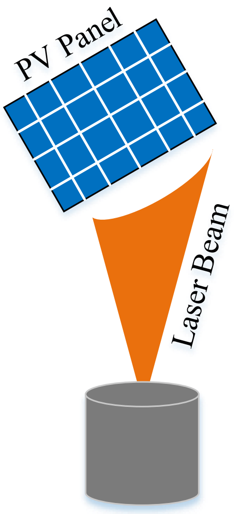

Figure 8. Laser beam energy transfer

is restricted because it depends on the type of PV cell. Transmitters and receivers for electromagnetic waves with shorter wavelengths can be made much smaller than those for other types of electromagnetic waves. For a laser beam to function correctly, it is necessary for there to be no break in the line of sight between the sending and receiving devices. This limitation can be overcome by employing either mirrors or a Corner Cube Retroreflector (CCR) [51], which can offer the beam a path that is free of interruptions. The second method involves the utilization of large capacitors that perform the function of energy buffers [52]. Using a laser beam to transfer power has several disadvantages, one being that an intense beam can be extremely hazardous to humans.

Acoustic energy: This undetermined method makes use of the energy that is emitted from various types of mechanical waves, such as vibrations, sound, ultrasonic, etc., with the waves having the ability to pass through gases, liquids, and solids [53, 54]. Acoustic energy is a form of radiative energy, but it is not electromagnetic; it can be reclaimed from the surrounding environment or wirelessly transmitted to the receiver. As shown in Figure 9, the structure of wireless power transmission is dependent on acoustic pressure waves.

These waves travel at a slow speed, which results in shorter wavelengths. Since shorter wavelengths mean smaller antenna sizes, these waves can be transmitted over greater distances. The authors in [55] evaluated by comparing the power delivery of inductive coupling with ultrasonic acoustic energy. A variety of

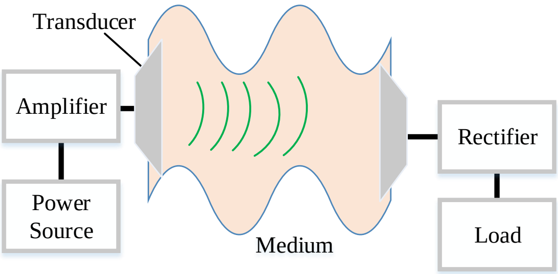

Figure 9. Acoustic energy transfer

experiments were carried out to measure the efficiency of energy transmission as the length increases. The authors concluded that inductive coupling was less efficient than ultrasonic transmission when applied over a more extended range.

5.2. Methods of distribution

The purpose of this section is to provide an overview of the various power distribution methods available for recharging sensor nodes in a network through the use of power transmitted wirelessly. These methods are interchangeable, which means that they can be utilized with any charging system.

Individually: In a WSN with a relatively low density of nodes, this is one of the fundamental and most frequently employed approaches. It includes a mobile host moving to each sensor node and wirelessly charging its battery. Once the host's battery has been charged to a certain percentage or completely, it continues to the next node.

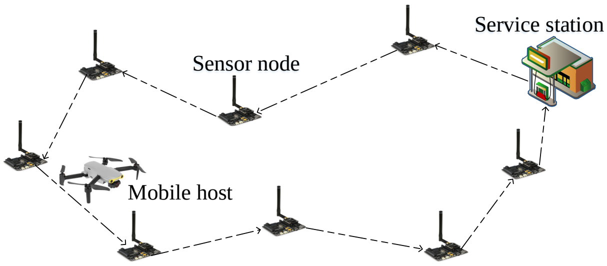

Figure 10. An example mobile charging host travels to each node individually

In Figure 10, once the host has finished charging the last node, they will head back to the service station to prepare for the next journey. This strategy works reasonably well in relatively small networks. Still, it is not practical for use in large networks due to the possibility that individual nodes will become inoperable before being approached by mobile hosts.

In addition, the mobile host is typically fitted with a single source that serves the dual purpose of powering the host and charging the nodes; this further restricts the application of this strategy in dense network environments. The authors of the paper [56] suggested using a wireless charging vehicle to perform periodic charging of the nodes. The vehicle's power output is sufficient to charge all of the nodes in a single journey. In addition, the solution is presented in order to optimize the amount of time that the vehicle spends at the service station. This solution includes calculating the optimal traveling route for the vehicle as the minor Hamiltonian cycle that passes through all the nodes.

Multiple: This strategy utilizes either a stationary charger stationed at a predetermined location within the network or a mobile host that moves to a predetermined location within the network to power multiple nodes in that area. The location of the charger can be either static or dynamic. This strategy is frequently utilized in dense node deployment and typically uses several different mobile chargers. In [57], it was looked into how many energy-constrained mobile hosts are needed in a two-dimensional WSN. The authors devised algorithms to ensure each node keeps working as usual while retaining the number of mobile chargers to a minimum. Within an intelligent grid monitoring network that the authors in paper [58] consider locations to be landmarks, the authors utilized multiple approaches. The landmarks are organized into clusters, and then, through RF energy transmission, each cluster is serviced by a mobile service that chooses to follow the optimal route that takes the least amount of time. This is referred to as the shortest Hamilton period.

On-demand: Sensor nodes can keep track of the amount of energy they have left, and if it falls below a certain threshold, the sensor nodes will send out individual requests to be recharged. The request could be sent to the sink, the energy station, or the mobile charger. Additionally, the requirement could be transmitted either straight or through multiple nodes. The energy information from the nodes with the shortest lifetimes is sent to the power station through multiple intermediate nodes in paper [59]. The power station intends to install a charging line that will be connected to the mobile charger. The portable charger utilizing this information will begin charging a selected set of sensor nodes in sequential order. This method is also utilized in biomedical sensor networks and can accommodate scenarios involving mobile sensor nodes and static chargers. A sample of a charging request that a node might send to a mobile host is presented in Figure 11.

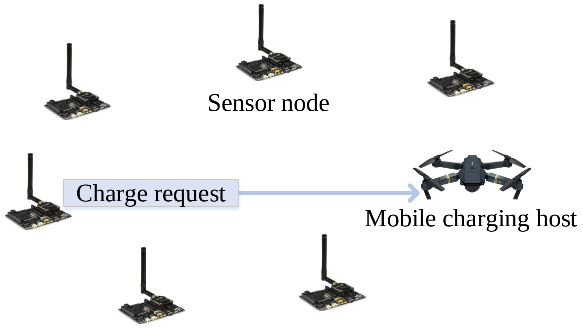

Figure 11. An example a charging request is sent to mobile host by a node

6. Challenges and future directions for research

Besides the benefits that harvesting energy to improve the performance of devices in the network, they still present some challenges.

Energy storage: Devices must have suitable energy storage methods to ensure effective operation and a long lifetime of service. Super-capacitors and rechargeable batteries are the two primary storage technologies that can be included in devices. These technologies were covered in the prior sections. Choosing an acceptable approach is only the first step in this process. Because these technologies have particular challenges, which prevent them from realizing their full potential and necessitate research; as a result, these technologies are currently in need of investigation. Compared to rechargeable batteries, super-capacitors are a relatively new technology still in its developmental stages. Self-discharge rates significantly high enough to prevent its use in routine applications pose a significant obstacle to the technology's implementation in wireless sensor network (WSN) applications. These devices have a relatively low energy density, which is another problematic factor that limits the applications for which they can be used. These problems can be fixed by devoting significant research effort to developing methods that increase energy density and charge holding duration. In addition to fixing these challenges, research has the potential to lower costs per unit, which is an objectively good thing.

Renewable energy: The idea of using renewable energy is not brand-new; nonetheless, implementing such a notion in micro devices such as sensor nodes is still in its infancy and faces challenges that call for a significant amount of research. Light scavenging, regarded as mature energy for harvesting, is directly reliant on the surface area of PV cells, which also restricts the amount of energy gathered, particularly in a region where direct sunlight is not readily available. In addition, the panel's size needs to be compact because an increase in size is incompatible with microsensor nodes. PV cells convert power efficiently but cost much money. Therefore using them in sensor nodes that don't cost much is another complex problem. In addition, the research effort required to determine a cell's conversion efficiency is substantial. Because the starting voltage required in the electrostatic technique is a critical difficulty that restricts the usage of an electrostatic energy harvesting system, there is a need for a large amount of research into this topic. Utilizing the heat that would otherwise be squandered from various sources while simultaneously improving system efficiency is a problem for researchers working on thermoelectric harvesting devices. Developing new materials that can function in environments with more significant temperature gradients and efficiently carry electricity without transferring heat calls for further research. Wind energy harvesters on a smaller scale require further investigation.

Wireless recharging: Even though there have been significant advancements made to the method of inductive coupling, there are still challenges in the form of alignment and transmission range. Besides, as the transmission distance grows, the effectiveness of this method decreases. Assume we have a mobile charging station that employs this technique. In this case, it will use up a significant amount of energy while traveling to the device that needs to be charged. As a result, to ensure that the mobile charging station has enough power left over to charge the device, it is best to reduce the amount of energy used up while traveling or equip a mobile charging station with two independent power sources. The method of collecting energy from radio frequency sources can only be used with low-power devices. Utilizing this method in a common node calls for a significant amount of research. The utilization of lasers as a source of electricity for devices is still in the infant stages of development. The power conversion depends on PV cells, which can only produce a maximum conversion efficiency of 20%. In addition, utilizing it is expensive and potentially harmful to one's health. The requirement for line-of-sight makes it difficult to provide power to dispersed nodes. Despite this, it is a workable strategy that has the potential to significantly improve research while simultaneously reducing the cost of hardware that is employed. Along the same lines as laser-based energy transfer, acoustic-based energy transfer is still in its infancy. The primary problems include misalignment losses between the receiver and the source, transducer losses, medium losses, and spreading losses. These problems can be alleviated by developing a more effective transducer. This difficult task depends on several elements like wave reflections, the power level, and the material's effectiveness. In addition to its applications in biomedicine, the utilization of the acoustic energy transfer method calls for significant study.

7. Conclusions

The development of wireless sensor networks has led to the abundance and ubiquity of these systems, which has given rise to a diverse range of applications. Inadequate battery life in buttons is one of the most significant obstacles hindering their operation. To extend the network's life, we have briefly reviewed different methods for charging batteries and harnessing renewable forms of energy. In this paper, we have discussed different characteristics of renewable. We have covered many aspects of renewable energy and potential renewable energy sources that can potentially be used in wireless sensor networks. In addition, we discussed various problems of battery recharging and the latest energy storage technologies, which were also covered.

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