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Energy Resources in Agriculture and Forestry: How to be Prepared for the Internet of Things (IoT) Revolution

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Abstract

The Internet of Things (IoT) revolution is getting attention of all kinds of enterprises and industries: from the big ones to the startups. From the energy point of view, deploying IoT devices in urban or industrial environments is not a dramatic problem since electrical outlets and chemical batteries are easily available almost everywhere. However, why not tap into natural resources first? The future may bring an Internet of Natural Things (IoNaT). If so, the agricultural and forestry industries will certainly take advantage of such technology. The question will then be how to power the IoNaT. Chemical batteries are not an environment-friendly option in an agricultural field or in a forest. In this chapter, we suggest different and innovative, natural and easily available energy sources and the main processes to harvest them. The use of these natural and revolutionary technologies may ensure that monitored data could be obtained in a sustainable way.

Keywords: internet of things, energy harvesting, environment-friendly energy sources, chemical batteries, internet of natural things, wireless sensor network

1. Introduction

Currently, the expression Internet of Things or simply IoT has been broadly used. However, the actual meaning of IoT, in the sense to help to understand how it could change the world, could be extracted as compared to the Internet revolution.

The Internet revolution was the development of a global network where data are originated by people (typing, pressing a record button, taking a digital picture or scanning a bar code)

using connected computers [1, 2]. For its turn, the IoT revolution has its premise that any object or thing (like a light lamp, a door, a refrigerator, a garment, etc.) can directly originate and send data to the Internet without any human interaction. For example, a sensor in a connected light lamp may automatically order a new one when it is near the end of life. In short, the Internet is based on human-entered data and the IoT on Thing-entered data.

As the world population is estimated to reach 8 billion by 2020 and supposing that each individual may be related to about five different connected Things¹, we can compute 40 billion of connected Things by this time. However, the IoT revolution does not relate only to people, but all kinds of enterprises and industries (e.g., all products of a given industry may be connected). In this sense, that number could reach trillions.

From the energy point of view, deploying IoT devices in urban or industrial environments is not a dramatic problem since chemical batteries are easily available and electrical outlets are almost everywhere to recharge them.

Nevertheless, it is important to highlight that this huge number of connected Things would need batteries to work and, more importantly, chemical batteries wear out, even the rechargeable ones, and, if not properly disposed, they can be harmful to the environment.

From the point of view of urban life, IoT is an extraordinary technology despite the chemical batteries issue where massive recycling campaigns worldwide or even recycling laws can minimize its damage to nature.

From the point of view of non-urban life, as rural, forest and other natural environments, the IoT will certainly be a very interesting technology. We have to be carefully prepared to take advantage of such technology because it could be hard or impossible to take back batteries for recycling from battery-powered IoT devices deployed directly into the environment.

From this perspective, the future may bring an Internet of Natural Things (IoNaT). For example, a Thing could be a tree, a fruit, a submerged stone in a river, etc. However, IoNaT presents some challenges as radio frequency (RF) communications in the presence of vegetation and powering the electronics of the Things using batteries. Considering the battery issue, deploying them directly into the nature is certainly not an environment-friendly option. The question is how to power the IoNaT using a non-battery approach.

In this chapter, we suggest different and innovative natural, easily available, energy sources and the main processes to harvest them. The use of these natural and revolutionary technologies may ensure that monitored data could be obtained in a sustainable way.

2. Batteries, problems, and solutions

Batteries have played an important role for decades both in small-scale energy storage and in high-scale energy storage. For small-scale (e.g., video/audio players, medical equipment,

¹Connected Things: an IoT-device connected to the Internet.

power tools, meters and data loggers and remote sensors), batteries enable portable use [3] and free the device from power cords and also from being near to an energy power socket. However, the batteries in these devices are discharged and then recharged periodically, meaning that the portability feature takes the fixed costs of replacement or of recharging as a disadvantage.

Nevertheless, batteries do not free the device users from power cords since they still need them to connect the battery charger to energy power socket. In this sense, charged batteries works as an invisible cable or, better, as an energy transportation system since the energy source is distant from the device. Ever the most modern wireless charging station based on Inductive Power Transfer [42] need its base to be plugged to an energy power socket.

Batteries are devices that convert the chemical energy contained in their active materials, immersed in an electrolyte solution, directly into electric energy by means of electrochemical oxidation–reduction (redox) reactions [4]. They come in two different forms, namely, disposable or primary batteries and secondary or rechargeable batteries [5]. The reactions are reversible in secondary batteries so that discharging the batteries returns the electrodes to their pre-charged states [5].

Many different battery chemicals are used as active materials, namely, lead, nickel, cadmium, lithium, zinc, manganese, mercury, and others and as electrolyte, namely, acid, potassium hydroxide, organic carbonates, and others [4, 5]. In addition, it is important to observe that electrolyte can be in liquid, gel (which means that it can leak) and solid form [4], and those batteries are packed in metal and plastic cases or containers.

All parts of a battery, as shown in **Figure 1**, are made of pure or compound chemical material where some can be toxic, environmentally unfriendly, or not sustainable. As a result, if batteries are not properly disposed, then their toxic material can leak and contaminate the soil and water, and some of the materials can accumulate into the surrounding environment. Some of these materials can also contaminate humans and the wildlife.

Researchers are continually inventing lower cost and longer life battery chemistries and as batteries become integral part of high-volume products, economies of scale will reduce costs [3]. However, splitting the battery market into small-battery and of large-battery relating it to the IoT industry and the electric vehicle (EV) industry, respectively, it is expected between 22 billion and 30 billion of connected devices (“Things”) by the year 2020 [7] and, for electric cars, it may achieve globally between 9 million and 20 million by the year 2020 [8]. That means that billions or trillions of small-batteries and millions of large-batteries will be manufactured, deployed and the wasted ones may be dumped on the nature if not properly recycled. The worst scenario may be one of the IoT worn-out batteries, since the electric vehicle’s wear-out battery regulations tend to be extremely rigorous with the carmakers holding responsibilities for them, which differs from the IoT scenario, where responsibility holds on individuals.

In order to show a fair comparison between the IoT and EV battery scenarios, we can normalize the expected number of batteries by the year 2020, using the standard 18,650 cells as normalization base. That is a standard type of Li-ion (LiMn_2O_4) battery where 18 indicates that the cell has a diameter of 18 mm, 65 indicates the height of the cell is 65 mm, and 0 indicates

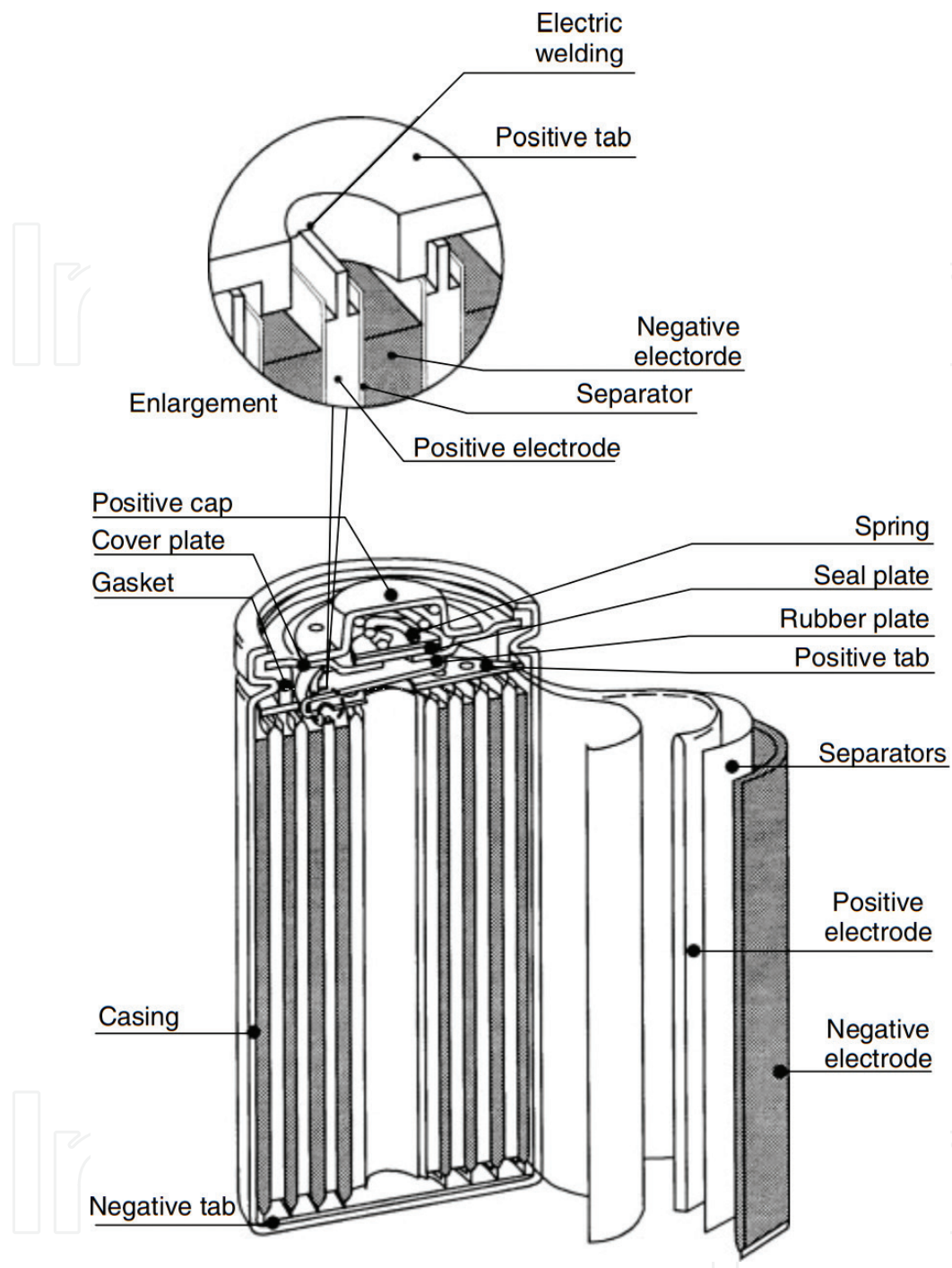


Figure 1. Internal structural design of a cylindrical Ni-cd battery [6]. Copyright Wiley-VCH Verlag GmbH & co. KGaA. Reproduced with permission.

the cell is a cylindrical battery [9]) and considering, as an EV default battery size, a battery formed by 6831 18,650 cells. That is also exactly the battery used in the luxury Roadster introduced by Tesla Motors [10].

In this way, it is expected between 3.2 million and 4.3 million of EV-battery-equivalent connected devices by 2020 at which means that IoT battery impact is about 25% of the EV battery

impact on the environment. As a result, we can consider that the IoT battery scenario has to be considered as harmful to the nature as well as the EV batteries.

An actual solution for this issue is to eliminate the need of batteries of IoT devices generating their energy on the spot where the devices are. Such a solution is theoretically simple, but in practice it needs lots of scientific and technological researches. For instance, how to power an IoT in the middle of an office or on a street? That is where the development of energy harvesting system takes place.

3. Energy harvesting

In general, to harness energy from the environment is not a novelty, for instance, solar and wind energies are harnessed for centuries. Despite harnessing energy to high-power applications like industries and cities, which wind and solar power plants are good examples, harnessing energy to low or ultra-low-power applications gave rise to the expression “Energy Harvesting.”

Energy harvesting is defined as the process of capturing very small amounts of energy from naturally occurring energy sources surrounding the low-power electronic device to be powered, accumulating, storing and converting them to electrical energy for powering the device [11–17].

The possibility to harvest energy from the environment to power electronic circuits became a reality due to the advanced in microelectronic technologies that occurred during the last decades. With this advance, the size of electronic devices has becoming so small, make possible the development of tiny portable devices integrated in objects like watches, glasses, clothes, etc., as well as the energy needed to power these devices has decreased drastically [16].

Some possible energy sources can be solar light, thermal, mechanical vibration, electromagnetic waves, and so on. For example, a wireless seismic sensor powered by solar cells was the first to be installed in a bridge in Corinth, Greece [17]. Another example, bridges vibrate when vehicles travel over them, and such vibrations have a kinetic energy that can be used to generate electricity [4].

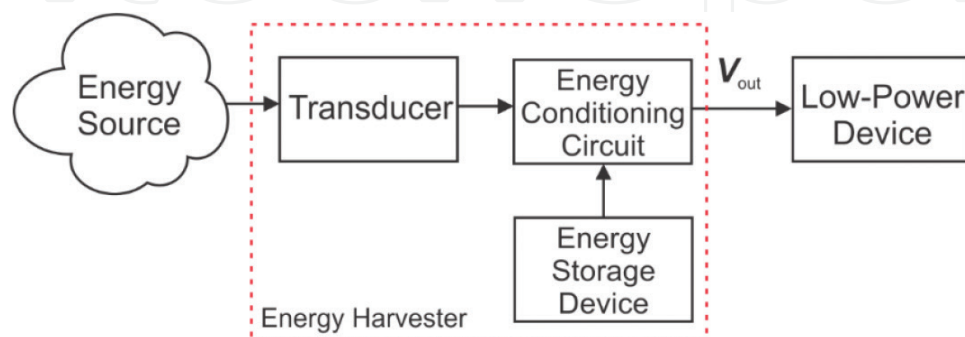


Figure 2. Basic structure of an energy harvesting system.

Naturally occurring energy sources can be roughly classified as **environment energy sources** and **human energy sources** [16]. Examples of human energy sources could be kinetic energy coming from arms and legs movements, and thermal energy used to power wearable sensor [18, 19].

Nevertheless, there are some energy sources for energy harvesting applications that occur not precisely naturally, like those originated by electrical, magnetic, and electromagnetic fields, but they can be available in the environment. For example, radio frequency (RF) signal are being harvested to power sensor at a distance [20]. RF energy harvesting is become a good option to power IoT devices.

Figure 2 shows a basic structure of an energy harvesting system. Its main blocks consist of:

- I. Energy transducer:** it performs the conversion of a primary energy source to electrical energy. Examples: solar photovoltaic cell, in which electrical energy is obtained from solar light energy, thermoelectric generator (also called Peltier module), in which electrical energy is obtained from the difference of temperature on its sides (thermal energy), and so on.
- II. Energy conditioning circuit:** a group of subcircuits, which is capable of adjusting the voltage from the transducer in an adequate voltage for powering the target low-power device. Some subcircuits are rectifiers, filters, DC/DC converters, and so on.
- III. Energy storage device:** it stores energy for two basics, namely: to accumulate energy which is enough to power the target device and to store the surplus energy. The main examples are batteries, capacitors and supercapacitors.
- IV. Low-power device:** the target low-power device.

Utilizing energy harvesting systems as main energy sources is turning to be one of the most promising systems for batteryless low-power electronic devices. However, energy harvesting systems can be combined to batteries (or other energy storages) as a solution to reduce the battery’s lifetime limitations or to decrease the dependency of battery performance [21, 22].

Energy harvester	Power density
Solar panel (outdoor conditions)	10,000 $\mu\text{W}/\text{cm}^2$
Thermoelectric generator (30° C)	3500 $\mu\text{W}/\text{cm}^2$
Shoe inserts	330 $\mu\text{W}/\text{cm}^2$
Mechanical vibrations	200 $\mu\text{W}/\text{cm}^3$
Batteries (non-rechargeable lithium)	45 $\mu\text{W}/\text{cm}^3$
Solar panel (indoor conditions)	10 $\mu\text{W}/\text{cm}^2$
Ambient Radio Frequency	1 $\mu\text{W}/\text{cm}^2$

Table 1. Power density of different energy harvesting propositions [15, 23].

In order to compare and to obtain a general view of different energy harvesting propositions, **Table 1** shows the power density achieved by them.

4. Internet of natural things

Even though IoT has gotten substantial attention recently and is a key factor in several paradigms like Smart City [24], Smart Building [25], Connected Cars [25] and Industry 4.0 (Smart Factory) [26], it does not have a standard or globally accepted definition.

Below are some of the concepts related to IoT, which are described taking into account considering:

- **The Thing itself:** A **Thing** (also called smart object) is any object with embedded electronics (microcontrollers, transceivers for digital communication, sensors, actuators, networking processing support circuits, etc.) that can transfer data over a network—without any human interaction [27]. Things can be home appliances, surveillance cameras, monitoring sensors, actuators, displays, vehicles, smart phones, tablets, digital cameras, doors, windows or literally any object that turned into a smart object.
- **The network of Things:** IoT is a communication paradigm that envisions that objects of everyday life, turned into a smart object, be able to communicate with one another and with the users, becoming an integral part of the Internet [24].
- **Service provider:** IoT is characterized by its pervasive nature, meaning that it can be everywhere, enabling nonhuman direct interaction with a wide variety of everyday things and fostering the development of a number of applications. Those applications can make use of the potentially enormous amount and variety of data generated by such Things to provide new services to citizens, companies and public administrations [24].
- **Human benefit:** IoT has as its ultimate goal to create benefits for human beings, where smart objects around people know what they like, what they want and what they need and act accordingly without explicit instructions [28] and to promote an enhanced level of awareness about the world [29].

Taking into consideration the abovementioned concepts, then the IoT can be defined as a network that links smart objects (Things) worldwide, which are capable of: processing, sensing, actuating and communicating with one another, originating directly data to the Internet without any human interaction and providing services to citizens, companies and public administrations.

As described at the beginning of this section, several paradigms related to “smartization” in a given context (e.g., Smart City, Smart Building and Smart Factory) is taking place in the word. In this perspective and considering that the current environmental issues of the planet, it is

very natural that the IoT revolution addresses these issues. Consequently, new paradigms as, for example, Smart Forest, Smart Plantation and Smart Farming arise and, as a result, Things can be trees, stones, submerged stones or floating logs in a river, fruits or their fruit trees, barns, cows or anything in a natural or rural environment.

In this context, an Internet of Natural Things (IoNaT) takes places for rising smart natural or rural environments.

IoNaT can be defined as a network of natural Things capable of communicating each other and directly originating data to the Internet and providing services to benefit their environments.

A very interesting example could be a Smart Forest where a Smart Tree communicates with other trees. For example, if its temperature is too high (indicating possibly a fire), these data are passed throughout the network to a nearby fire department or the surrounding neighborhoods.

Since 2000, on average, 18 firefighters have died each year fighting flames and the 2015 wildfire season was the costliest on record, with \$1.71 billion spent to fight the blazes, as said by the U.S. Forest Service. One of the worst problem battling wildfires is to not know rapid weather condition changing, as for example, wind direction, which can put fire towards firefighters giving no way they get away to a safe position. Therefore, having information about local weather and environmental conditions can save many lives.

The main challengers for an IoNaT are:

- I. Power supply to the Things without chemical batteries and
- II. Communications support in the presence of vegetation.

4.1. Energy harvesting as a solution for power supply in the IoNaT concept

Over the last decades, due to the advancement in microelectronic technology, electronic devices are progressively getting smaller and achieve extremely low-power consumption enabling the design of energy autonomous systems (EAS), which are low-power systems that run without being connected to any power grid and are powered by small batteries [30].

In its turn, energy harvesting system either increase the battery's life cycle toward perpetual EAS [14] or marking self-powered batteryless EAS.

Therefore, with the purpose to avoid deploying the battery directly into the nature, the development of batteryless energy harvesting devices is an ideal alternative since they can be designed considering natural energy sources around the natural Thing in the IoNaT context.

Potential candidates of natural energy sources for batteryless energy harvesting devices could be:

- **Solar light.** Everywhere in natural environments as fields, deserts, water's surface, mountains, etc., solar light is a good option with the usage of small photovoltaic cell. However, at daylight, it works well, but at night, it needs some energy storage device to work where capacitor or supercapacitor may be used.

- **Thermal sources.** In natural environments, this kind of energy is largely available since different materials or substances in these environments when near each other may produce different temperature levels providing a way to obtain heat. For example, under the soil, the temperature can be colder than above, so an energy harvesting solution may take place. Another example, under forest canopy, where solar light is not a good option, thermal sources exist in a variety of ways, for instance, it was proved that it is possible to obtain heat from tree trunk [13].
- **Mechanical movement or vibration.** Due to wind in a field or forest, or due to underwater currents in rivers or due to any natural movement, mechanical vibration of Things is an option where piezoelectricity can be used. For example, a small waterfall can be used to obtain rotational movement to rotate a dynamo. Another example, the tree leaf movement due to wind can be harnessing.

4.1.1. An example of IoNaT thing: a smart tree

As described in [13], it is possible to get temperature gradients² at different tree trunk depths and to take advantage of the natural temperature control of the trees, that maintains that gradient, and convert it into electric energy.

It was proved that, as a tree trunk is a living organism, the temperature gradient ΔT between any annual ring and the external temperature can be slightly constant or presents slow increment or decrement as the external temperature varies, as shown in **Figure 3**. The explanation to this is that trees try to remain in a comfort zone despite its external temperature regulating their temperature.

Figure 4 shows the experimental results when the temperature was measured in three different depths of a tree³: 100 mm, 75 mm and 50 mm and the external temperature. As can be noted, the deeper the depth, the bigger is the ΔT . This result indicates that the depth to install the energy harvesting transducer can be chosen accordingly to the voltage level that is required. An interesting point that worth to be highlight is that either at daylight or during the night, ΔT exists with an inversion at 18:00 (6 pm) and at 6:00 (6 am), the local twilight hours, showing to be possible to harvest thermal energy all day long.

A possible implementation of the tree trunk energy harvesting transducer is shown in **Figure 5**.

4.2. WSN as a solution for communication in the IoNaT concept

Wireless sensor networks (WSNs) are an important technology for large-scale monitoring, providing sensor measurements at high temporal and spatial resolution [31–33]. In general, WSNs are composed of a large number of low-cost and low-power sensor nodes communicating at distance and sink nodes. Routing nodes and cluster head nodes are also used in WSNs.

²Temperature gradients are the temperature difference between the two bodies over a specified distance between them.

³The tree is of the species *Adenanthera pavonina*, commonly called red lucky seed, located in the City of João Pessoa, PB in Brazil.

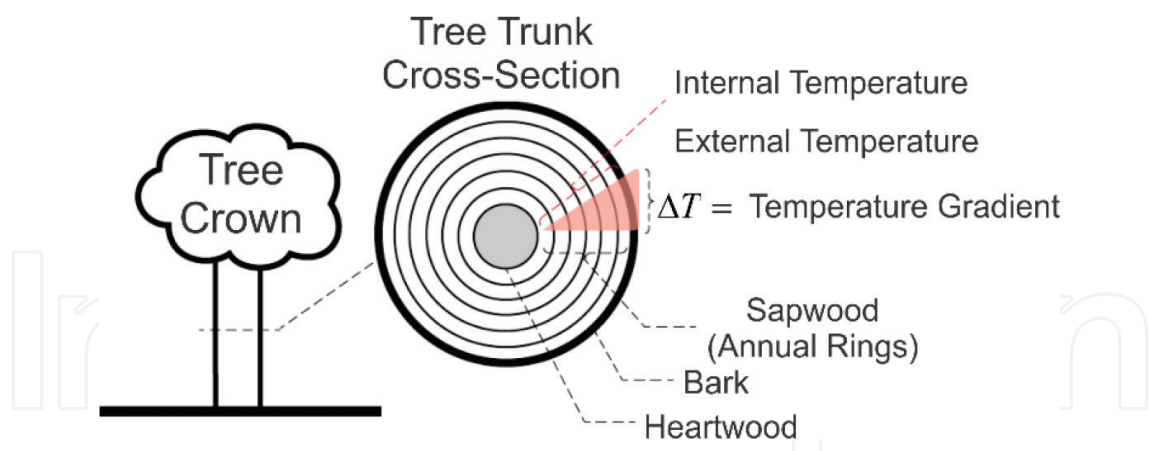


Figure 3. Temperature gradient comes from different annual rings related to external temperature [13].

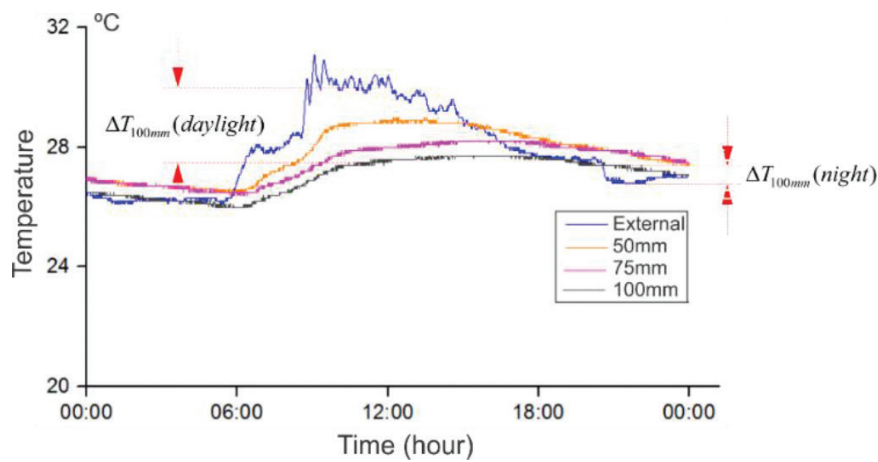


Figure 4. Temperature measurement in three depths of a tree: 100, 75 and 50 mm and the external temperature.

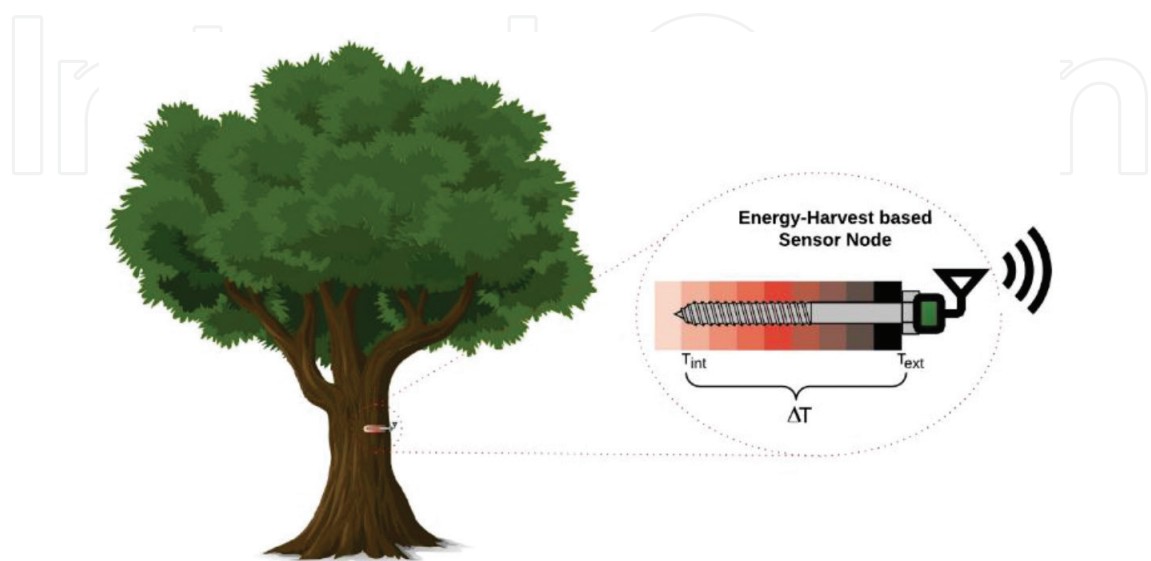


Figure 5. A possible implementation of the tree trunk energy harvesting transducer.

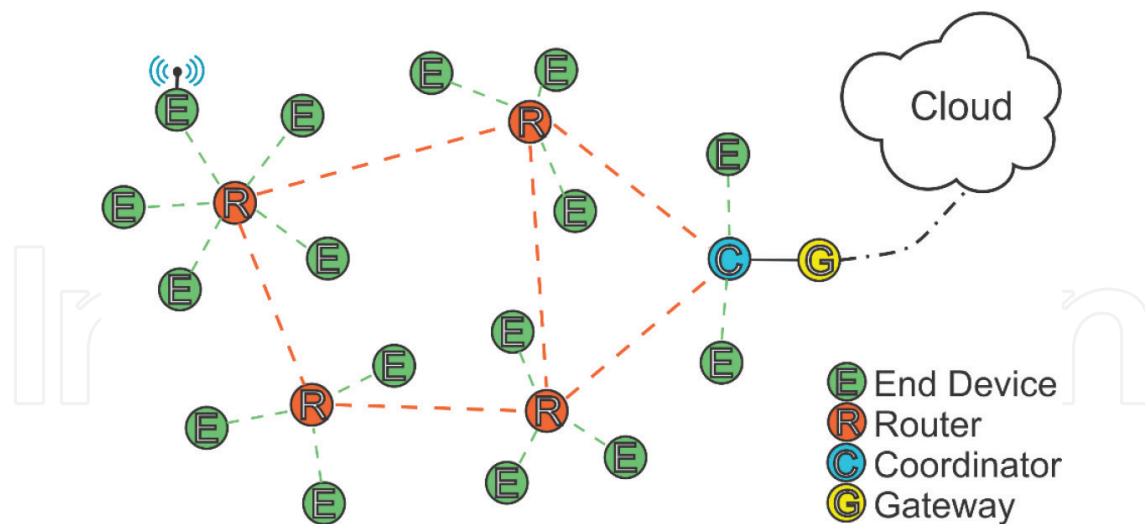


Figure 6. Typical wireless sensor networks.

WSN technology was triggered by the availability of low-cost low-power feature-rich micro-controllers and single-chip radio transceivers [31].

Figure 6 shows a general structure of a WSN in a very popular implementation, which comprises of the following three nodes [34, 35]:

- **End device** (also called sensor node): It contains functionality of sensing and communicating with its parent node (the coordinator or a router) and does not participate in routing.
- **Router**: It acts as an intermediate device, and its main function is to participate in multi-hop/mesh routing of network messages permitting them to propagate over long distances.
- **Coordinator** (also called sink node): It controls the entire WSN, initiates the network and is capable of bridging other networks, generally, using a **gateway**. In general, currently, the gateway is used to connect the WSN to some Cloud service as data storage, analytics, visualization, and so on.

An important application of WSN technology is in environment monitoring [called environmental sensor network (ESN)] that has attracted considerable research interests in recent years [36], and they can be applied in pollution monitoring, meteorological conditions measurement (e.g., temperature, wind velocity, solar radiation, atmospheric precipitation etc.), forest fire, seismic activity, etc. [37]. In addition, depending on the density of nodes distributed in a natural environment, WSN technology presents potential to support communications in the presence of vegetation due to the short distances involved.

The environmental sensor network is directly related with IoNaT paradigm because currently, it is possible to utilize low-power System-on-Chip (SoC⁴), which integrates micro-controller, some peripherals and RF radio, to design nodes for the network capable of running with extreme low energy [38]. In addition, modern SoCs with RF communication

⁴An SoC is an integrated circuit that integrates some components in the same chip like processor, digital, analog, mixed-signal peripherals and RF transceiver—all on a single chip.

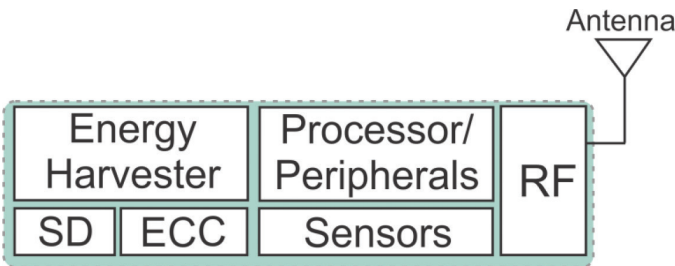


Figure 7. IoNaT node. SD: Energy storage device. ECC: Energy conditioning circuit. RF: RF transceiver.

capability have different low-power or sleep modes to save energy during times of inactivity. The management of these modes is very important in relation with an energy harvesting strategy allowing to refill the energy storage device during these periods of low activity [16].

Considering the environmental sensor network, energy harvesting and low-power RF SoC, a possible structure for an IoNaT node is shown in **Figure 7**.

It is important to observe that as the data coming from IoNaT nodes would be sporadic and with an extremely low data rate, potential technologies to implement an IoNaT-node network may be those based on the IEEE 802.15.4 physical radio specification [39], particularly, for example, ZigBee [40] that features low-power and low-bandwidth capabilities. Another potential technology for the same purpose would be LoRaWAN [41] that is a low-power wide-area network (LPWAN) that features low-power and low-bandwidth capabilities, but is still capable to sustain long-range wireless connections. However, LoRaWAN only implements star topology.

5. Conclusion

An Internet of Natural Things (IoNaT) approach has the potential to be fully developed and gain the same attention as the IoT in a near future. However, to obtain such a development and at the same time, to be an environment-friendly option, it is mandatory to avoid using chemical batteries and to use technologies based on energy harvesting along with wireless sensor networks. In the context of IoNaT, it will be possible to take advantages of modern technology and, as a consequence, to incorporate services as environmental monitoring for impact assessments of human activities, animal surveillance, plantation monitoring and other services related to natural environments.

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Conflict of interest

There is no conflict of interest to report.

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