Chapter 1
Introduction to Green Internet of Things Sensor Networks

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1.1 Background

It has been observed over the years that an escalating rate of deployments of real-life applications of wireless sensor networks (*WSNs*) is realized. The various applications include environmental monitoring, medicine, health care, surveillance, power monitoring, structural monitoring, disaster detection, home automation, smart building, rescue, smart agriculture, traffic control, and object tracking [1]. Research has identified *WSNs* as networks with more limited energy than other wireless networks. Power consumption has risen as a major setback that limits network lifetime in these networks [1, 2]. This is usually the power lost during transmission of information from a source to its destination. This loss is greatly experienced during the transmission of this information than during processing [2, 3]. Other limitations of the conventional sensor networks include restricted radio bandwidth, memory, processing capability, packet size, and high rates of packet loss. Various approaches that aim to reduce this loss of power as an effort to extend the network lifetime have been proposed. Communication between sensor networks cannot be achieved physically through sensor nodes. There is a need for an Internet-based network (Network to Networks communications).

Since wireless sensor networks are deployed in larger volumes through several tiny elements called sensor nodes that are powered by small rechargeable batteries, the networks are faced with a number of limitations that pose a threat to the network lifetime. The advancement of the traditional WSNs gave birth to the Internet of Things sensor networks. In general, the Green Internet of Things Sensor Networks (GIoTSNs)

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combined four critical components: “Energy Harvesting,” “Internet,” “Things,” and “Sensor Networks.” The simple explanation to this is, “Any device having the capability and is compatible to connect to the Internet will come under Things.” The term refers to a network that connects anything with the Internet, according to established protocols. The connection can be through equipment designed for information sensing that conducts an exchange of information for communication purposes. Besides communication devices, “Things” include physical objects such as computers, personal devices including cars, home appliances, or smart devices, medical instruments, and industrial systems that are controlled through wireless communication, sensors, and “Miscellaneous Objects.” The nodes in the network interact with one another and are able to access anything anytime and from anywhere in the system (Network) [4]. IoT involves collecting, processing, and use of data for communication. Processing big data requires a large capacity for storage and high power consumption. Internet of Things is an Internet of three things: (1) people-to-people, (2) People to machine/things, and (3) Machine/things to machine/things [5]. The increased energy demands across the globe already have adverse environmental effects on society. The development of technologies to meet the needs of the smart world and sustainability by implementing green IoT aims to reduce carbon emission and power consumption. In this, it makes it possible for a network to survive for a longer time as it is “Green,” meaning that it can self-harvest energy to sustain the nodes in the network. The “Green” IoT technologies make it environmentally friendly by focusing on optimization of data centers through techniques of sharing infrastructure, which leads to increased energy efficiency and lower cost of operation. The inexpensive, low powered sensors will expand the application of IoT to even smaller objects in any kind of environment at affordable prices.

1.2 Internet of Things Sensor Networks

Wireless sensor networks are recognized as vital enablers for the Internet of Things [6]. They form a network that senses and control an environment while enabling interaction between computers, persons, and the environment. The *Internet of Things sensor network* is a network of networks that can overcome most of the sensor networks’ limitations. This network is made up of smart devices that can be identified in the networks. They should also be able to collect and share data over the Internet as well as process it. For real-time applications to be realized, storage services are made available to cloud platforms where other services can be performed on the data for end-users. End usage of data includes modeling and data analysis of the data gathered from the different *IoT* elements for informed decision making [4]. Figure 1.1 illustrates an IoT sensor network, with numerous small-size sensor nodes spatially distributed over chosen fields of networks. This makes the networks suitable for large-scale deployments. The hardware of a sensor includes four parts: the power module (battery), sensing unit, processing unit (usually a microcontroller for analog to digital conversion), and the transceiver unit [7, 8].

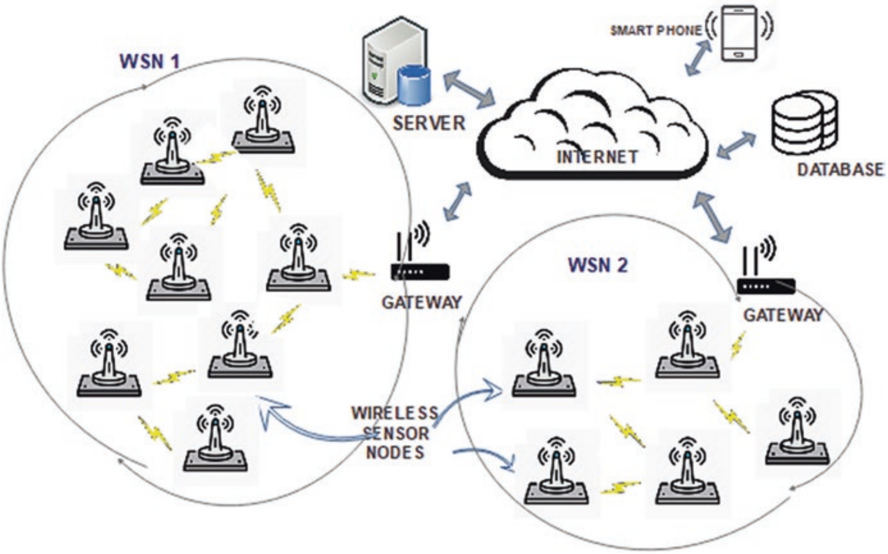

Fig. 1.1 An Internet of Things sensor network

They work collectively to monitor the sensor field and gather information about the environment. They are independent in their organization and communicate with each other wirelessly to achieve desired goals. The information that is gathered is propagated wirelessly from the source nodes to the sink node by multi-hop or single-hop communication [7].

The *WSNs* connect to the Internet through gateways and base stations. Wireless devices like smart phones, servers, and others can connect to the Internet to exchange information. Wireless sensor network technologies are advancing, making the cost of equipment affordable, thus expanding the market size of applications. The low-cost and low-power transceivers make it possible for WSN use in home automation and industrial monitoring applications. The goal for researchers and developers is to collect and analyze every piece of information around us to improve production efficiency and ensure optimal resource consumption.

1.2.1 Green Internet of Things Sensor Networks (GIoTSNs)

Due to the growing awareness of environmental issues around the world, green IoT technology initiatives should be taken into consideration. Environmental hazards like chemical emissions and energy dissipation normally accompany new inventions and innovations that are brought by new technologies that are needed by the world today. Sensors consume lots of power while performing tasks. In networking, green IoT aims to identify the location of the relay and the number of nodes that satisfy energy-saving and budget constraints [9]. There are three green IoT concepts, namely design, leverage, and enabling technologies. Design technologies are concerned with the energy efficiency of devices, communications protocols, network architectures, and interconnections, while leverage technologies deal with cutting carbon emissions and enhancing energy efficiency. The reduction of negative consequences that come with these technologies to save the environment is crucial and inevitable. This can be achieved by considering implementing green IoT technologies to achieve the development of energy-efficient products and services associated with *IoT Sensor Networks*. This action will result in preserving natural resources, minimizing the technology impact on the environment and human health, waste reduction, efficient utilization of energy, and lower cost of operation. Principles of *GIoTSNs* highlight conservation of energy, that is, switching on only facilities that are required while those that are not needed are switched off. Using natural energy supply sources like wind, solar, and many others that are freely available is another way of generating clean energy. Communication technologies that improvise on the overall spectral efficiency, modulation techniques, usage of power, and frequency operation can be implemented to save energy. Improving *IoT sensor networks* lifetime through the deployment of energy-efficient communication protocols is another option of saving energy as well as migrating to cloud-based processing and storage to reduce operation costs and overcome security, bandwidth, and latency problems. Technologies that are associated with *GIoTSNs* are Smart Home, Smart Cities, Smart Grid, and many other Smart technologies [4]. The green Internet of Things is expected to bring significant technological developments in the wireless sensor network and its applications. The technology will make it possible to have a massive amount of sensors, devices, and "things," which will enable the new smart objects to perform certain functions autonomously. In this, communication between people and things, and between things themselves enable lower power consumption, and bandwidth utilization is maximized [10].

This book intends to combine the strategies of Energy Harvesting, Communication Protocols, and Data Compression to improve the lifetime of the *Internet of Things sensor networks*. Energy Harvesting will help to support the networks' sensor nodes' energy. At the same time, Communication Protocols will allow the reduction of the amount of power consumed in the transmission of data in the networks. The reduction of this power consumption can also be achieved through the application of Data Compression.

1.3 Energy Harvesting

Sensor nodes have limited energy in their power storage unit, making it challenging for a sensor node to remain operational for long periods. The solution is for the sensor nodes to be able to harvest ambient energy from the surroundings to recharge the batteries, which can then directly power the sensor nodes. Energy Harvesting is a process whereby energy is extracted from the surroundings and stored to supply low-power wireless devices. This is a natural energy that is freely

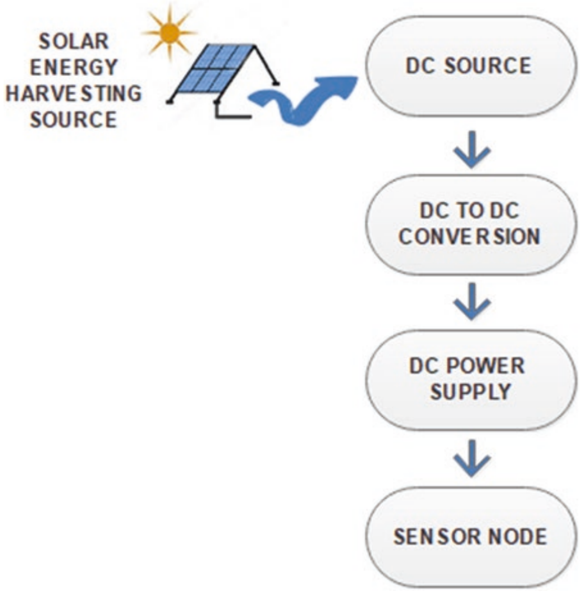

Fig. 1.2 Solar energy harvesting process

available in the environment. Sources of harvested energy can be radiation, e.g., solar, radio frequency (*RF*), thermal, e.g., heat, mechanical energy sources like blood or water flow, vibrations, wind, and many others [11]. Since this energy cannot directly power small devices like sensor nodes or batteries, they go through a process of signal conditioning, rectification, and power conversion. Figure 1.2 below illustrates a solar energy harvesting process. Optical energy from the sun is converted to direct current (dc) energy by the solar panel, and it is further converted by a *dc to dc* converter to a suitable dc power source, which is sufficient to power a sensor node. An energy harvesting system is, therefore, made up of an energy harvester, which collects energy from surrounding sources and transforms it into electric energy that can power the components of the sensor node like sensor unit, processor unit, and communications unit.

The energy management unit then receives the electric energy and processes it further. An energy storage unit also forms part of the harvesting system to store energy that can be used at a later stage, eliminating the dependency of sensor nodes battery power, thereby reducing costs. The reliance on batteries puts limitations on implementing WSNs for environmental monitoring applications. Due to the challenges with changing batteries of nodes regularly, nodes that have depleted their batteries are considered dead and cannot participate in the network operation. This challenge makes it even more critical to explore energy harvesting aware protocols [12]. The choice of a suitable energy harvesting system for a *WSN* should consider its application and area of deployment, where the energy source is abundant [13]. Over the past years, there has been a significant improvement in energy harvesting technologies, especially in their efficiencies. Energy harvesting devices that are capable of providing continuous power output from various energy sources such as light and temperature based energy for smart building lighting and air monitoring applications have entered the market. Other products, such as those capable of converting mechanical vibration into electrical energy use by wireless sensor nodes, are also available. The energy made by fingers knocking the desk can support the sensor node sending 2 kb data to 100 m away every 60 s [14].

1.4 Communication Protocols

Communication protocols are another effective technique that is used to save power in an *Internet of Things sensor network*. They assist in discovering optimal paths for information sharing under existing sets of constraints in the network [7]. Their key role is to provide an efficient exchange of information between sensor nodes with less or no interruption. A good communication protocol determines better performance, reliability, and service of a sensor network [15]. They should be energy efficient and adopt optimization methods to enhance sensor nodes' efficiency in routing [4]. Different classes of communication protocols exist depending on the various ways in which the data is sent from the source point to the destination and also on the sensor network application. Traditionally information can be sent from a source node directly to the destination node, a communication process known as a single hop, which usually requires high transmission power. Alternatively information can be routed through intermediate nodes, which further passes the information to the destination node. This is called multi-hop communication and requires less transmission power. The whole process of gathering, processing, and forwarding information is termed routing and is handled by communication protocols.

1.5 Data Compression

Data Compression reduces the amount of data to be transmitted in the network and consequently saves a significant amount of power used for transmission. It is a simple and effective power-saving technique that is also robust and without loss. This power saving is achieved by eliminating redundant data and, to some extent, at the expense of the quality of data [3]. A lossless Data Compression technique is generally used in order to prevent loss of data. With lossless Data Compression, the original data and reconstructed data after compression (decompressed data) are the same. A block diagram that illustrates a simple Data Compression model is shown in Fig. 1.3.

Considering a stream of data "*ABABCCC*" in Fig. 1.3, redundant data is removed during compression, so fewer bits of data, "*2AB3C,*" are transmitted along the communications line. During decompression, redundant data is added to reconstruct the original symbols. Different Data Compression techniques exist for different applications. The choice of a Data Compression technique depends on the type of data to be transmitted and its application. An energy-efficient Data Compression scheme

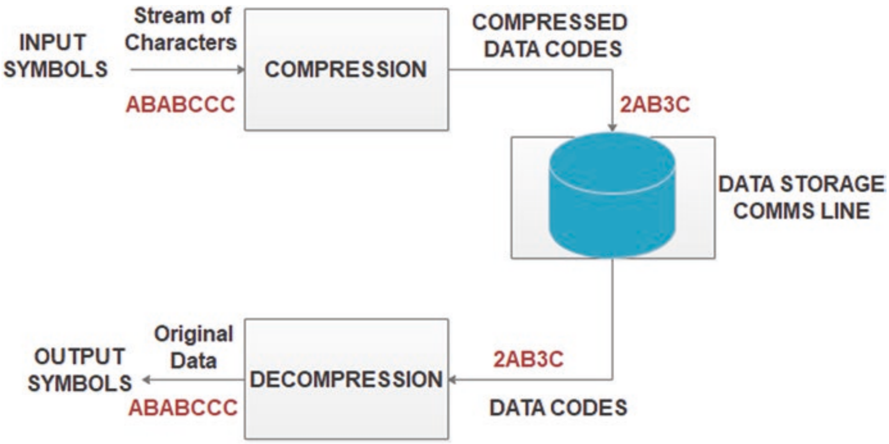

Fig. 1.3 A simple Data Compression model [16]

provides a desirable trade-off between energy used for transmission and energy used for processing information [2]. The technique must not be complicated and should require fewer resources for compression of data.

1.6 Summary

It is anticipated that combining Energy Harvesting, Communications Techniques, and Data Compression will yield high results that will help to improve the network lifetime of *Internet of Things sensor networks*. Since these networks are suitable for large-scale deployments, large quantities of data are handled during transmission from source to sink. This also includes data that is irrelevant and may add to the energy that is wasted during the transmission of data that eventually results in reducing the network lifetime. The need for a robust and energy-efficient technique to minimize data before transmission and transmit the reduced data along optimal transmission paths motivated this book. Since wireless sensor networks are deployed in larger volumes through several tiny elements called sensor nodes that are powered by small non-rechargeable batteries, the networks are faced with a number of limitations that pose a threat to the network lifetime. The advancement of the traditional *WSNs* gave birth to the *Internet of Things sensor networks*. In general, the *Green Internet of Things Sensor Networks (GIoTSNs)* combine four critical components: “Energy Harvesting,” “Internet,” “Things,” and “Sensor Networks.” The simple explanation to this is, “Any device having the capability and is compatible to connect to the Internet will come under Things.” Things can be referred to as “Smart Devices,” “Sensors,” and “Miscellaneous Objects.” The nodes in the network interact with one another and can access anything, anytime, and from anywhere in the system (Network) [4]. The network will survive for a longer time as it is “Green,” meaning that it can self-harvest energy to sustain the nodes in the network. Hence, the batteries carried by the nodes in the network will not deplete as they usually do.

References

1. J.G. Kolo, S.A. Shanmugam, D.W.G. Lim, L.M. Ang, Fast and efficient lossless adaptive compression scheme for wireless sensor networks. Comput. Electr. Eng. **41**(C), 275–287 (2015). https://doi.org/10.1016/j.compeleceng.2014.06.008
2. J.G. Kolo, S.A. Shanmugam, D.W.G. Lim, L.M. Ang, K.P. Seng, An adaptive lossless data compression scheme for wireless sensor networks. J. Sen. **2012** (2012). https://doi.org/10.1155/2012/539638
3. J. Uthayakumar, T. Vengattaraman, P. Dhavachelvan, A new lossless neighborhood indexing sequence (NIS) algorithm for data compression in wireless sensor networks. Ad Hoc Netw. **83**, 149–157 (2019). https://doi.org/10.1016/j.adhoc.2018.09.009
4. A. Solanki, A. Nayyar, Green Internet of Things (G-IoT): ICT technologies, principles, applications, projects, and challenges. Comput. Sci., 379–405 (2019). https://doi.org/10.4018/978-1-5225-7432-3.ch021
5. K.K. Patel, S.M. Patel, Internet of Things-IoT: Definitions, characteristics, architecture, enabling technologies, application & future challenges. Int. J. Eng. Sci. Comput. **6**(5), 6122–6123 (2016). https://doi.org/10.4010/2016.1482
6. M.T. Lazarescu, Wireless sensor networks for the Internet of Things: Barriers and synergies, in *Components and Services for IoT Platforms*, (2017). https://doi.org/10.1007/978-3-319-42304-3_9
7. L.K. Ketshabetswe, A.M. Zungeru, M. Mangwala, J.M. Chuma, B. Sigweni, Communication protocols for wireless sensor networks: A survey and comparison. Heliyon **5**(5), e01591 (2019). https://doi.org/10.1016/j.heliyon.2019.e01591
8. T. Nottingham, N.E. User, School of electrical and electronic engineering energy-efficient routing algorithms based on swarm intelligence for wireless sensor networks, Adamu Murtala Zungeru, B. Eng., M.Sc. Thesis submitted to the University of Nottingham for the degree of Doc, (2013).
9. F. Al-Turjman, A. Kamal, M.H. Rehmani, A. Radwan, A.-S. Pathan, The Green Internet of Things (G-IoT). Hindawi Wirel. Commun. Mobile Comput. **2019**, 1–2 (2019). https://doi.org/10.1155/2019/6059343
10. S.H. Alsamhi, O. Ma, S. Ansari and Q. Meng, Greening Internet of Things for smart everythings with a green environment life: A survey and future prospects. 1–3 (2018). [Online] Available: https://arxiv.org/ftp/arxiv/papers/1805/1805.00844.pdf
11. R.S. Lakshmi, RF energy harvesting for wireless devices. Int. J. Eng. Res. **11**(4), 39–52 (2015). [Online]. Available: www.ijerd.com.
12. International Electrotechnical Commission, Internet of Things: Wireless sensor networks. 20–21 (2014). [Online] Available: https://www.ipeea.org.
13. S.O. Olatinwo, T.H. Joubert, Energy efficient solutions in wireless sensor systems for water quality monitoring: A review. IEEE Sens. J. **19**(5), 1596–1625 (2019). https://doi.org/10.1109/JSEN.2018.2882424
14. K.S. Adu-Manu, N. Adam, C. Tapparello, H. Ayatollahi, W. Heinzelman, Energy-harvesting wireless sensor networks. ACM Trans. Sens. Netw. **14**(2), 2–3 (2018). https://doi.org/10.1145/3183338
15. N. Shabbir, S.R. Hassan, Routing protocols for wireless sensor networks (WSNs). Wirel. Sens. Netw. Insights Innov. (2017). https://doi.org/10.5772/intechopen.70208
16. T.A. Welch, Welch_1984_Technique_for.Pdf. IEEE Comp. **17**(6), 8–19 (1984)