Green Computing and Internet of Things for Smart Cities: Technologies, Challenges, and Implementation

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Abstract Green computing as well as Internet of Things (IoT) are becoming attractive technologies for building smart cities. Statistics has shown that the use of Information and Communication (ICT) devices will increase 41.6 billion by the year 2023(2019). While there are numerous applications and benefits of using IoT enable devices, studies have shown that the potential number and intensity of serious environmental issues including high consumption of energy, emission of carbon and other electronic waste. To deal with the adverse effects of such huge usage of ICT devices, the research community has started exploring the area of Green IoT and Networking much more exhaustedly. Fortunately, technologies like IoT can be used with green networking to reduce electronic waste and relatively use of less power/energy for future applications and in return help in achieving better results for our ecosystem. This chapter provides a survey of green computing and IoT for smart cities highlighting the importance and real-world implementation challenges.

1 Introduction

In recent years, the development of IoT has experienced a dramatic and rapid growth along with increasingly extensive use of smart devices and applications. There have been many billion devices or things already connected via the Internet and will be increasing in future as well [23]. Moreover, as per latest studies of International Data Corporation (IDC) this number has increased to 41.6 billion IoT connected devices in 2023(2019). Therefore, from the aspect of the environment, to generate enough electricity to support this increasing number of devices or other infrastructure of network may also lead to a great emission of Carbon Dioxide. Muhammad Ismail [10] provided a data which showed that the industry of telecommunication provides

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two percent Carbon Dioxide emissions of the global emissions in 2016. Ha-Vu Tran [29] predicted the overall Carbon Dioxide footprint of Information and communication Technology (ICT), such as, IoT devices, Cell phones and wireless networking) in 2020 is three times more than that of 2018. The power consumption is also a big challenge for wireless network. The wireless networks consumes much higher amount of power than that of wired networks; this results in the dissipation of heat and discharge of pollution from the electronic devices and power plants. From the aspect of finance and economy, some researchers have already present that the cost of energy of the whole OPEX (Operation Expenditure) ranges from approximately 18% in developed European market to thirty two percent in Indian market and for those operations which are off-the-grid may cost fifty percent of the whole OPEX in energy [10]. Finally, from the aspect of the quality of users' experience, researchers [10] indicated that more than sixty percent of mobile phones users are not pleased with the current capacity of cell phones' batteries, because the gap between the modern mobile devices batteries capacity and the user demand for power is still increasing, and the life time of the rechargeable batteries of the mobile devices is expected to be two to three years, but every year the disposition of batteries are 25000 tons which are a big waste and causes a big burden to the environment.

Therefore, to deal with these problems and issues in power using and wasting, firstly scientists and researchers tried aiming towards how to maximize the usage of existing communications system, but now they have changed the direction of their research/studies of how to produce maximum performance of a device and make that device use the minimum energy. In current industry, overproviding and redundancy are two good characteristics which can be used to boost the quality if the network and these two characteristics are widely used among the traditional network design. However, these two traits have some innate issues, or rather problems to the term used as green networking [19]. The standard station and control methods are ready for the energy saving and green communication technology to be applied to in the future. In report [19], it indicated that in Europe, this topic has already become a conspicuous with much attention on. There were some projects in FP7 (7th Framework Programs, 2007–2013) including EARTH, OPERA-Net, ECONET and TREND (a network of excellence). Those projects are used for energy-saving communications and networking. Also, EIT ICT Lab (European institute of Innovation and Technology) has created a concept which is called Smart Energy Systems and Green ICT (Information and Communication Technology) (2015).

Keeping in view the above stated energy and Carbon dioxide estimates, the fast development and increasing expansion of IoT technology is expected to provide a lot of benefits but also a series of serious environmental problems. These problems may include but not limited to excessive energy consumption, electronic waste produce, carbon emission and climatic variation. In order to keep the equilibrium between environmental issues and IoT advancements, the concept of green computing or green IT is necessary to be presented and considered. Researchers has now changed the direction of their studies towards how do we make the development of IoT greener and more environment-friendly? The goal of this chapter is to identify some directions to answer this question. For this let us start with some base knowledge about IoT.

2 Internet of Things

The term "Internet of Things" (IoT) refers to a worldwide network of uniquely identifiable interconnected smart objects or things that transmit data automatically without any human interaction [3, 28]. The motivation of IoT is to create an interconnected world where intelligent devices, objects and web-based systems are automatically linked and communicate with each other through the Internet, so that users' quality of lives can be improved by technology. In the IoT paradigm, a collection of intelligent devices, appliances, vehicles and other smart objects are embedded with sensing and actuation capabilities. These things are connected to a global networked infrastructure. They communicate and interact with each other, acquire and exchange data, in order to realize automation and intelligence [21]. Hence, the main characteristics of IoT are sensing, actuation and communication.

2.1 IoT Architecture

There have been a large number of researches and studies on the architecture of IoT, and so far IoT architecture has not been reached an agreement [18]. The paper written by Zhong, Zhu, and Huang [9] has presented a very typical three-layer architecture of IoT which is widely acknowledged. Figure 1 shows IoT architecture containing three layers namely, perception layer, network layer and application layer.

(i) Perception layer
Perception layer is the bottom layer in this three-layer IoT architecture. In the perception layer, data and information is collected from physical objects, environments, human, biology, etc. by using different types of perception devices and tools, involving various sensors and transmitters. After the data collection process, the collected data is processed and packaged preliminary in perception layer and gets ready to go to the upper layer.

(ii) Network layer
Network layer is also called transmission layer and it is placed in the middle of the IoT architecture. The task and responsibility of network layer is to transfer the data which is collected by the perception layer to the upper layer (application layer) through various networks. Enabling networking technologies are such as Bluetooth, Radio-frequency identification (RFID), Near-field communication (NFC), Wi-Fi, Zigbee, Ethernet, mobile communication, satellite communication.

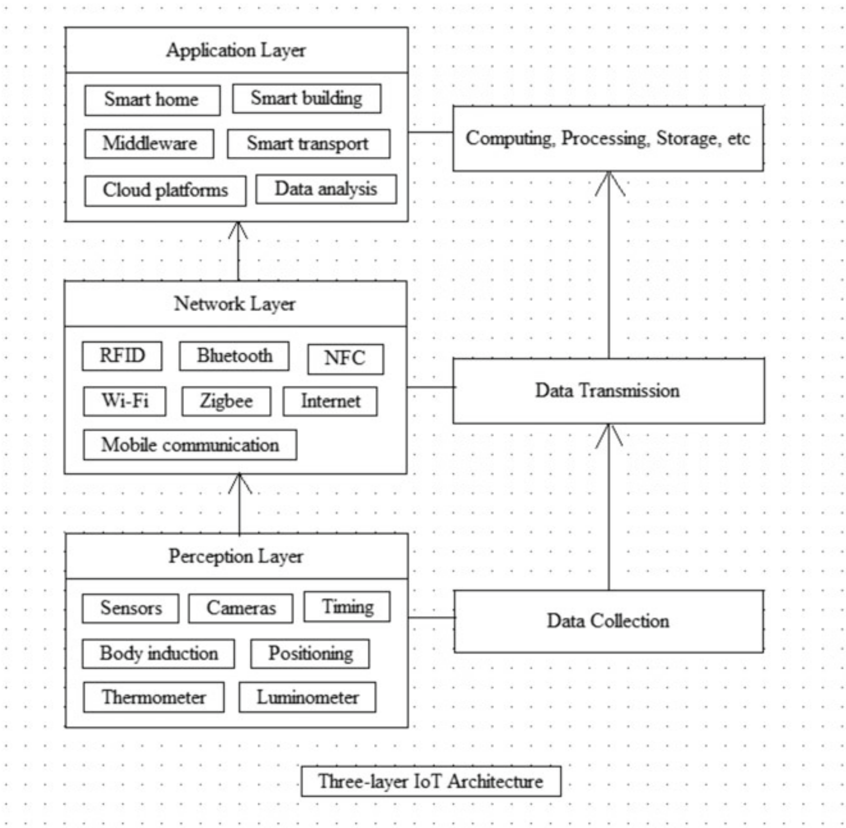

Fig. 1 Architecture of a typical IoT

(iii) Application layer
Application layer is placed in the top of three-layer architecture of IoT and it processes and computes data from lower two layer (perception layer and network layer) in order to realize the various IoT applications. Application layer can be regarded as the interface between IoT technology and clients.

3 Environmental Challenges in IoT Usage

The increasingly accelerated development of the Internet of Things (IoT) has also led to some tough issues and challenges, such as real-time requirements, redundancy, reliability and security issues [5]. But one of the chief problems is about the environment and sustainability during using IoT technologies. Environment issues mainly include three major parts: energy consumption, carbon emission and electronic waste.

3.1 Energy Consumption

There are a lot of reasons for energy consumption of the IoT. For example, the intelligent devices need power and energy to perform sensing, processing, computing, monitoring and communication in IoT tasks. The data centres behind IoT applications also need to consume a lot of energy. However, an extensive number of researches have already shown that the communications among devices for data transmission tasks result in the most energy consumption. In particular, the wireless connection technologies consume much more energy than wired connections [7]. In Decker's article, he has presented that 3G networks consume 15 times more energy than wired networks, and 4G networks use 23 times more energy than wired networks. However, wireless access networks are very indispensable and essential for the IoT, there is no doubt about it.

3.2 Carbon Emission

The rapid development and wide use of IoT technologies and intelligent devices has led to the increasingly massive energy consumption, simultaneously, is producing large amounts of carbon emissions. According to the statistics from the SMARTer2030 website [26], by the year 2015, there are 20% of the totally global carbon emissions influenced by the ICT industry. The carbon footprint of ICT industry has experienced a dramatic increase from 6 megatons of CO_2 in 2012 to 30 megatons of CO_2 in 2015. The increasing carbon emission leads to serious climatic variation issues. Hence, how to deal with carbon emission caused by IT field is another environmental challenge.

3.3 Electronic Waste

There are more and more ICT devices to be manufactured and used, in which case, large amounts electronic waste is produced. According to the Fig. 2, the Statista website has done the statistics, and it shows that the amount of electronic waste generated all over the world has rapidly and sharply increased from 33.8 million tons in 2010 to 49.8 million tons in 2018.

4 Green Computing

In this section we discuss the concept of Green Computing as a solution to our above environmental hazards. Then we present approaches to implement Green Computing firstly from the Green IoT perspective i.e., realizing green computing into three

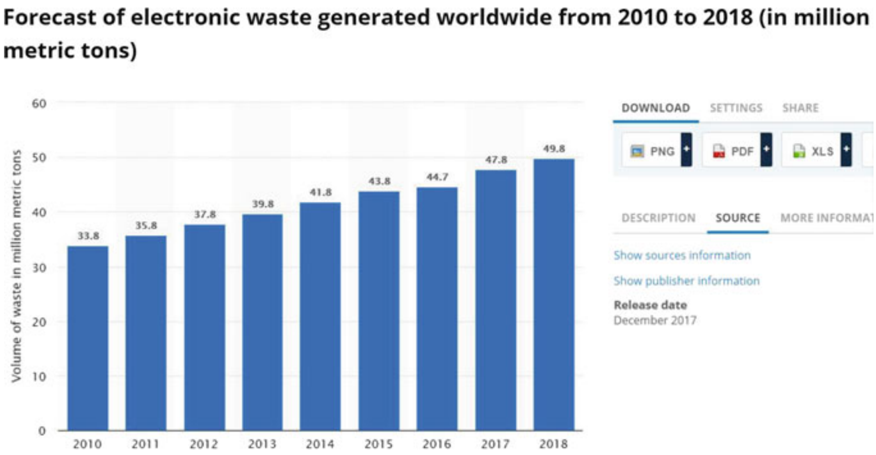

Fig. 2 Forecast of electronic waste—from Statista website [27]

categories according to IoT architecture i.e., physical devices, network connectivity and application design. Secondly we discuss the Green Computing implementation from system point of view.

4.1 *The Concept of Green Computing*

In order to deal with the above tough and serious environment issues, the concept of green computing has been presented and spread. Murugesan and Gangadharan [17] has defined that green computing or green IT means the sustainable, environment-aware and environment-friendly computing or IT. It is the study and practice of designing, manufacturing, using, and disposing of computers, servers, monitors, printers, storage devices, and networking and communications systems efficiently and energy-savingly with the minimal influence or no influence on the environment [1, 17].

The concept of green computing can be applied to the development of Internet of things, so that these environment issues which are caused by technology can be solved by technology as well. Malviya and Singh [16] have presented some current technologies and approaches to realize green computing in their article, such as green data center, green algorithms, virtualization and cloud computing [16]. Bianzino et al. [4] have also given four efficient solutions in their paper, including resource consolidation, resource virtualization, selective connectedness and proportional computing.

The number of wireless devices (including smart devices or IoT devices) has already increased significantly in recent years and the number is actually still increasing and technologies are developing either. Some of those applications are currently

Table 1 The comparison of power consumption of different wireless device types

Devices type	Scope of connection	Power consumption (watt)
Base stations	WMAN	300–3000
Points of access	WLAN	10
Screen-on cell phones	WMAN and WLAN	1.5
Screen-off cell phones	WMAN and WLAN	1 (approximately)
Computers	PAN and WLAN	1.78

and widely being using in our daily life, like: smart home, smart health care [13] and video streaming. In 2012 the predication [24] said that the traffic of data could increase 18 times in 5 years. And in 2016 [9] predicated that the in 2020 each person may own 6–7 internet of things devices. Thus, it is obvious that power or energy consumption can be very high in the future. It is a major challenge and concern for telecommunication, industries and scientists.

In [24], authors mentioned that the relative energy consumption of the wireless devices greatly varies depending on the type of overall network devices used in the network. The differences of the consumption of the power range from the case of screen-off mobile phones which results in extremely low values of power consumption to the base stations which gives the highest values of power consumption and more than half of the consumption is caused by machine cooling and operation of power amplifiers.

These great differences in the relative power consumption which are caused by the wireless devices and machines require different methods to reduce the power expenditure of different kinds of devices or machines. The paper [24] provided two reasons for the inefficient and unnecessary power consumption despite of the different demands of power of current devices (Table 1).

First, it gave a point of view that it is very common for infrastructure of network which is unnecessarily powered on, and even the number of users and load of traffic which is caused by them are low. Although, this practice is very commonly being used and it can guarantee high degrees of coverage and availability of service, but this practice is responsible for a great amount of power consumption which is unnecessary. The second cause of unnecessary power consumption which is also critical and intrinsic in current design of hardware. Especially in processors of hardware which is power hungry, bad design of the amplifiers of power, inefficient and poor heat dissipation which results in relying on intense cooling. Although those problems are easy to identify, but it is somehow pretty difficult to cope with them. Because it involves totally redesigning over the equipment of wireless network that requires a great time, endeavour and also the coast is huge, those problems make the redesigning work is not easy or even not practical to do. In [31] it summarized and introduced some different definitions which have already been proposed in the previous literature to estimate the efficiency of energy consumption of wireless networks from the aspects of network operators and mobile devices users. As an indispensable component of the definition of efficiency of power consumption, researchers provided many kinds of models of throughput and power consumption for base stations and mobile terminals and gave some green solutions to both high and low traffic load.

Keeping in view the huge usage of IoT devices; In future the IoT devices can be a major portion of the wireless devices and contribute the most traffic load to the whole load of traffic of wireless network. Thus, the power that those IoT devices can consume can also be very high which results in high Carbon Dioxides emissions. Therefore, it is important to make the IoT greener. In [2] it indicated that since the green ICT technologies has been developed, thus, green IoT can be much more efficient in power consumption through using less power, emitting less hazardous substances, taking and using less resources and reducing pollution. As a consequence, it is natural that green IoT turns to preserving and protecting natural resources, keeping the technology impact on the environment to and health of human at a minimum level and reducing the cost in using power and restoring the environment of nature significantly. Thus, green IoT is a technology which basically focuses on green manufacturing, green design, green utilization and disposal [2]. In details:

1. Green use: Try to make the consumption of power computers and other information systems to the minimum level and make sure the damage to the natural environment are reduced to the minimum level either.
2. Green disposal: We should reuse the old computers and get the parts from unwanted computers and other electronic devices and machines (we can recycle them).
3. Green design: We can redesign system to make it more energy efficient for IoT components, computers, base station, servers and cooling system equipment.
4. Green use:
5. Green manufacturing: The adverse impact towards the natural environment should be controlled and restricted to a minimum level when producing electronic equipment. Also, in [2], it introduced some methods which are currently not been widely used but have potential possibility to make the natural environment become greener or rather healthier and provide very high quality of service of IoT in an environmentally sustainable manner.

4.2 Implementation of Green Computing—IoT Perspective

(i) Physical Devices

Smart objects or things mainly rely on two devices: they are sensors and actuators. Sensors include security cameras, environmental monitoring sensors, healthcare sensors, thermometers, and so on. Examples of actuators are all kinds of intelligent home appliances, such as floor sweeping robot. These sensors and actuators are equipped with different types electronic components, such as microcontrollers, CPUs, GPUs, transceivers, batteries, memories, and protocols [6]. All of these components require energy consumption.

One of the chief approaches to achieve the goal of IoT devices with energy-saving is using sleeping models on devices. Majority of modern microcontrollers can provide two different sleeping modes: shallow sleeping model and deep sleeping model [11]. Shallow sleeping model allows a quick wake-up and memory retention, while deep sleeping model takes a long period of time in sleep state and does not maintain cache. Switching IoT devices to sleeping model is much energy-saving than maintain in an active mode when devices are idle.

Another possible approach to address energy consumption issues of physical IoT devices is to reduce the weight of hardware in system-on-chip (SoC). Lim et al. [14] have presented a reduced hardware architecture of IoT healthcare sensor nodes in their research. This architecture reduces the numbers of general-purpose I/Os (GPIOs) and peripherals in a system-on-chip (SoC), but this process must be very careful in order to have no impacts on devices' performance. This design has not only reduced 20% energy consumption approximately but also saved more excessive space, so that the volume of SoC and devices could also be diminished.

(ii) Network Connectivity

Although IoT physical devices lead to a bit of energy dissipation, the major reason of for energy consumption of IoT is the transmission process. In which case, most of efforts and researches focus on the network layer of IoT, to achieve the aim of green and energy-efficient IoT. In this section, I mainly explain three valid approaches to green network connectivity: Selective Connectedness, Data Compression and various Low-power required Communication Protocols for IoT.

Selective Connectedness

Selective Connectedness mechanism is similar with sleeping model. It allows some of network equipment to go to idle or some unused edge nodes of the network to be turned off when network infrastructure is not busy. In which case, unnecessary workloads can be reduced even avoided, and much energy will be saved in the network layer [4].

Data Compression

In some situations of IoT services and applications, data are not required in real time. Hence data compression is an alternative approach to shrink the size of data, in order to reduce the network traffic [28]. In which case, not only network layer but also application layer will both reduce storage, workloads and consume lower energy.

Low-power Required Communication Protocols

As I have mentioned before in this paper, wireless connection technologies consume much more energy than wired connections. To address this problem, there are various wireless communication protocols in the IoT area with requiring low energy and low cost have been provided. ZigBee is one of the low-power protocols for short-range wireless connection. ZigBee is based on IEEE 802.15.4 standard and it provides low energy consumption, low cost, low data rate and high throughput [20]. ZigBee can be applied in all kinds of IoT systems with short distances (10–100 m), such as home or building automation.

Another similar wireless communication protocol for short-range IoT is Thread. Thread protocol is also based on IEEE 802.15.4 standard and it provides ipv6 addressing. Thread uses 6LoWPAN. In this protocol, border routers do not maintain the application layer states, so that the energy consumption of border routers can be reduced.

Wi-Fi HaLow (IEEE 802.11ah) is a new wireless networking protocol with low-power requirement and it is published in 2017. Wi-Fi HaLow can send packets under a high speed while consume low power, because it allows to predefine wake/doze periods. Comparing ZigBee and Threat, Wi-Fi HaLow protocol provides an extended range (1 km radius), so it can be applied in smart metering.

(iii) Application Design
There are some types of enabling technologies and approaches can be used in IoT application design. For example, virtualization technology allows a set of software replaces different kinds of hardware and devices. Cloud provides public resource and pay-for-use model for IoT applications. In these cases, the goal of green IoT applications can be achieved. On the other hand, IoT technology itself can be applied and utilized to implement green computing and to address environmental issues. For example, some IoT devices and sensors are used in smart home or buildings to monitor and manage energy consumption. IoT technology can also be applied in environmental monitoring area, such as temperature measurement, air quality monitoring and so on. In addition, IoT technologies can be applied in ICT products manufacture industry and e-waste disposal industry, to improve working efficiency and reduce manual labour, cost, time and energy consumption.

4.3 Implementation of Green Computing—General Perspective

Many studies have been conducted which explores and suggests Green Computing Implementation from general perspective i.e., not binding them tightly with IoT architecture layers.

In [22] researchers suggested a technique for greener IoT which uses sensor nodes. And those nodes play important role which can be described in two different parts: 1. the nodes which work as collectors and 2. the normal types of nodes. The node which is called data-forwarding node is the neighbour node of sensors and it is chosen by the collectors of mobile data while they are running in the predesigned and predefined elliptical path. Also, the rest of the sensors in the area of sensing act as sensor nodes with standard source, except the node of data-forwarding. After the deployment of the sensor nodes, a path of the network can be revealed for the collectors of mobile data which is based on the concept of conversion of a maximum area of the wireless sensor network. In this suggested technique for greener IoT, the data collectors run

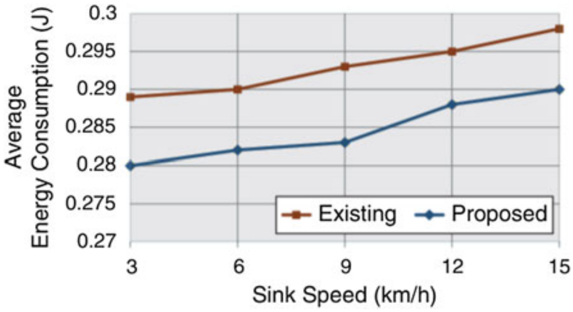

Fig. 3 The variation of the average power consumption and the data collector speed over collection of the data

in an elliptical path which is predefined and do the collection of the data from the nodes of source from nodes which is called collector nodes and make a delivery of the data to the base station of the whole network (Fig. 3).

The experiment which was carried out of this technique gave a good result over the average consumption of power of a node which is the power that is consumed averagely during the transition and reception of packets of data and control packets in a network. The consumption of power of protocols which are used for routing could be reduced the effectiveness of network could also be improved. In the experiment, the consumption of power was recorded averagely by the processes of varying the collector speed of the data which ranges from three to fifteen km per hour with increments of 3 km per hour at a constant time of simulation of 600 s. This result showed that average consumption of power of the suggested technique is less than the current data-routing technique of mobile with standard sink protocol. Also, the average consumption of power showed this technique can bring improvement over the lifetime of network.

Also, [22] provided the researchers suggested future direction of researches, the paper indicated that in the IoT, tiny sensors which are deployed to the sensing networks under the scenarios that the sensors have limited capacity of battery and replacement of battery needs effort. In such situation, the main challenge or we can the issue is how to make a better use of the limited power of the node of sensor to achieve a longer lifetime of the network. In this paper, the sensor of power constraint was the main design which was focused. Also, in this suggested routing, there were two collectors of mobile data that were utilized to collect the data from the field of sensor that was divided into two parts and they were mentioned in the previous paragraphs. Collectors of mobile data running in a rotating way on the predefined and predesign elliptical path, and their jobs were to carry out the collection of data from each sensors, send a message of signal to the forwarding neighbour nodes, make collection of the sensed data from the previous nodes, and make delivery of the data to the base station that was situated at the centre of the field of sensor. The results of the performance of the suggested technique of routing was much better with respect to the average power consumption of the control packet, the total average consumption of power, the latency of the delivery of data, and also, the relatively

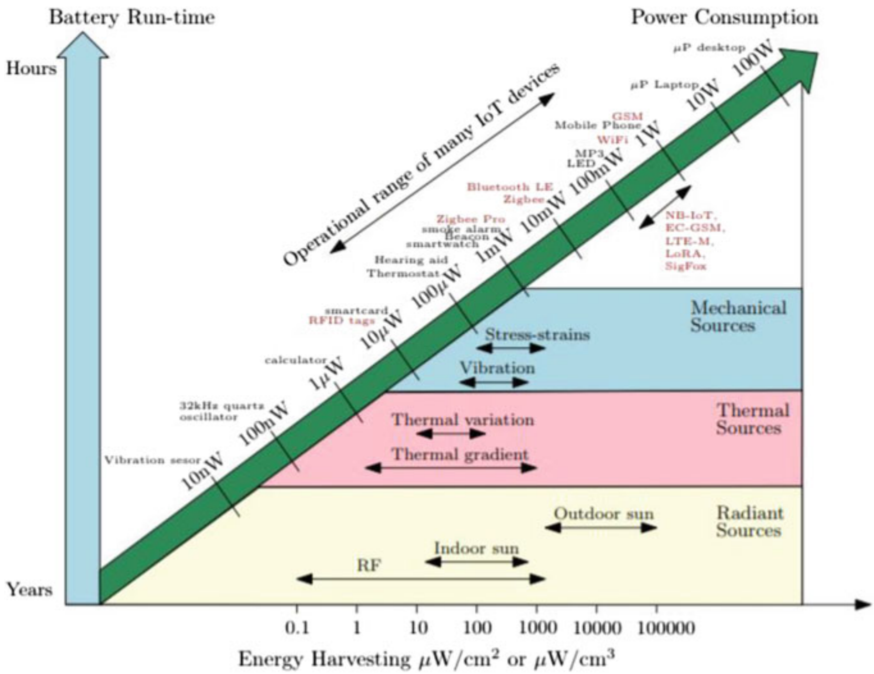

Fig. 4 The consumption of the power of different kinds of wireless devices and the different kinds of wireless techniques based on various types of sources of power

low latency of end to end. Thus, this proposed technique of routing is a good and practical solution to the problem and issue of energy-hole and it is very promising with a great potential for IoT applications (Fig. 4).

Shirvanimoghaddam et al. [25] introduced a concept of a type of IoT which is called self-powered Internet of Things. This suggested plan for the IoT uses energy harvest. The techniques of EH (energy harvest) can utilize different kinds of sources of power within the environment that surround devices in order to do a process which is called harvest to get enough power and the power will be used later by the equipment or devices of IoT for sensing, activation, and communication with the server. The paper also indicated that some traditional sources of energy like: radio frequency (RF), solar energy, energy of heat, vibration, wind, and even the body of human are only few instances of the sources of power which are available within the environment and they are used for energy harvest commonly. Also, this paper introduced that there are several different kinds of scenarios in which technologies of the EH can greatly provide enhancement over the wide performance of a system, with respect to the consumption of the power, life time of network, cost of the power and maintenance of machines or devices. Those different kinds of scenarios can be discussed by dividing them into three different categories.

1. The technologies of energy harvest is very promising and useful in some situations where machines or devices are situated or the deployment of them was made in some areas where are hard to reach. Thus, in those kinds of areas, making a massive replacement of the batteries of the nodes of sensor is nearly impossible. Also, the technology of WSN (Wireless sensor networks) have been studied and researched widely for the health monitoring of network structure. Sometimes the damage of the network may occur in space, normal buildings, bridges, and public infrastructures and they can be detected by nodes of sensor. The aim of it is to make a massive replacement over visual inspection with qualitative analysis and maintenance procedures which are based on time with a more automatic process of assessment over damage which is based on condition. The system of health monitoring of network for aeroplanes can get benefits by using techniques of WSNs and energy harvest, including the natural sources and devices like thermoelectric generators and vibration. To use piezoelectric effect and wireless charging devices as EH was also suggested by researchers to monitor and check the health and condition of tracks of railroad.
2. The technologies of energy harvest can be applied to circumstances that normal has a big requirement over a great number of devices which makes the massive and total replacement of their batteries is literally impossible or the cost can be very high. There are many examples, like: electronic shelf labelling, networks of sensor for body, massive IoT and its applications.
3. In many places there might be not enough steady or available supply of power. For example, the technology of energy harvest can be used in a farm which situates in a hard to reach area by using the technology of the energy harvest, it can support a DTN (delay tolerant network) which is combined with wireless sensors.

From the aspect of data centre. In [12] researchers suggested some future directions of researchers of green data base (due the huge amount of data may be transmitted in the near future and the rise of the cloud computing and IoT devices) which including the use of VM (virtual machines) and better control of temperature.

Another study [2] suggests that we can deploy more UAVs in order to make replacement over a significant number of IoT devices in the following areas, like: agriculture, traffic and monitoring. By those UAVs which can help people in reducing in power consumption and emission or discharge of pollution. The use and technology of UAV are environmentally beneficial which will make the green IoTs with low cost in power consumption and result in a higher efficiency.

The transmission of data from the sensor to the cloud of mobile devices can be more useful in the future. Basically, the Sensor-cloud is an integration of the wireless network between the mobile cloud and the sensors. This technology and its applications of greening IoT are very popular and promised, especially, it can save the cost of the consumption of power. An investigation and investment can be carried in green SNaaS (green social network as a service) which may enhance the efficiency the use of the power of the systems, wireless sensor network (WSN), cloud management and cloud service.

Also, in order to enhance and keep balance of power for supporting green communication between different and massive number of IoT devices, the energy harvest of radio frequency can be considered as a good solution. More researches are still needed to make the development over the design of IoT devices and equipment which can help many factories and manufacturers to make reduction of emission of Carbon Dioxides and the energy usage. Therefore, the most essential task for smart and green environmental life is to lower the consumption of power and decrease the emission of the Carbon Dioxide and discharge of other kinds of pollution.

5 Conclusion

The green computing and IoT is really important and promising technology not only towards people's normal lives but also it is very helpful to restore the health of the natural environment including the green housing effect, global warming and the rise of the sea level. In the future, the IoT devices and applications can definite be the one of the major consumers of the power, thus, by using green networking and integrate them with the IoT technology we can greatly avoid the unnecessary waste of power and enhance the performance and lifetime of the network.

In this chapter we have highlighted today' environmental issues, summarized the researcher in the areas of Internet of Things and Green Computing, and discuss various approaches to implement green IoT. Different types of methods can be applied in different layers of IoT (device, network and application). Technology is rapidly developing and leads to challenges and issues, and these problems would be fixed by technology as well. Of course, the "green" awareness is always important and should be maintained and improved.

So far how to achieve a greater equilibrium between environmental issues and IoT advancements has still a big challenge. Although there have been a lot of efforts to provide methodologies in this area, the problem remains serious. The foreseeable future trend of greening Internet of Things would focus much on creating new networking and communication protocols for wireless connection, because network layer and transmission tasks have the major influence on IoT energy consumption.

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