Application of IoT in Green Computing

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Abstract The Internet of things (IoT) enables global connectivity over the worldwide physical objects. The world is made smart with the development of science and technology, by people collaborating automatically with heterogeneous devices. The exchange of massive information between the devices gives rise to enormous energy requirements. The IoT is interconnected to big data analytics and cloud computing to predict the behavior of smart devices, provide useful business insights, and act as a feedback control. In addition, most of the organizations would adapt to the growing interest of smart world which in turn energy demand increases more rapidly. Moreover, there is a never-ending increase in number of vendors and users of various technologies. Green IoT prominently focuses on reducing the environmental problems and creating a sustainable environment related to IoT. It has been emphasized that the utilization of energy-efficient technologies in IoT either reduces the impact of greenhouse gases or inhibit greenhouse effect in various IoT applications. Green IoT assists in maintaining the climatic condition by introducing low energy consumption devices or electrical appliances, minimizing greenhouse gas emissions, utilizing carbon-free materials, and promoting reusability. In order to achieve sustainable environment, an outline of Green IoT and its applications are described in the perspective of minimizing the energy utilization in IoT. The designing of green data centers, sensor network, and cloud computing is discussed with certain policies in order to save energy. In addition, the different Green IoT strategies are analyzed

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and the principles that can be adapted to attain Green IoT also discussed. Finally, various applications of IoT are described such as smart home which allows the user to control the smart devices like automated doors, smart locks, security cameras, electrical appliances with the application on a smart phone or any other connected devices. Smart e-health is useful in monitoring and tracking patients, and smart city assists people by interconnecting systems, thereby offers required services in order to provide a smarter view for the present scenario and which in turn makes the IoT greener.

Keywords Green IoT · Sensor objects · Cloud computing · Smart world · RFID · Data center

1 Introduction

The Internet of things (IoT) aims to connect the physical world with the digital world with the help of sensors and actuators that sense, collect, and transmit information from the environment through the Internet. The world is become smart with the development of science and technology, by collaborating people automatically with various devices. It provides an opportunity for devices to be seamlessly connected and provide intelligent insights into human beings [1–5]. In particular, all the devices will be equipped with secondary sensors and additionally, so that they can respond to each other, thereby requiring more energy. Most of the devices have embedded radio-frequency identifier (RFID) tags through which the data is transmitted. In recent years, there is an increase in the sales of RFID and they seem to grow exponentially. The exchange of massive information between the devices gives rise to enormous energy requirements [6, 7]. The Internet of things is interlinked to big data analytics, cloud computing to predict and analyze the behavior of smart devices which provide useful business insights and acts as a feedback control. Cloud computing enables the interaction and integration of data in the cloud. In addition, most of the organization would adapt to the growing interest of smart world and the energy demand increases more rapidly. It is predicted by 2025, the IoT nodes may reside in everything like food packages, furniture, paper documents, and so on. However, for a smart world as such to be sustainable, energy efficiency should be considered.

In the recent years, the utilization of ICT has grown up rapidly and several areas getting better life with numerous benefits. The widespread adoption and advances in ICT have contributed to environmental problems where most of the people are unaware of it. All IoT devices consume significant amount of energy placing a great burden on electric grids and greenhouse gases. The constant increase in the accumulation of greenhouse gases has changed weather patterns and the world's climate causing drought in some regions and floods in others. The global temperatures are slowly pushed higher, posing serious problems to the world. Global data depicts the weather-related disasters—storms and droughts occur more frequently and have increased in magnitude. To inhibit the collection of greenhouse gases in the earth zone, global emissions should be prevented in further increasing. Furthermore, energy is also a major cause in the environmental change, as coal or oil that helps to produce power releases such as carbon dioxide, pollutants, and harmful chemicals into the environment. Thereby, reducing electric power consumption would pave a way for the reduction of CO_2 emissions that have an acute impact on global warming and the environment. Nevertheless, CO_2 emissions cause respiratory diseases and acid rain. Hence, on the roadmap of moving toward Green IoT, state-of-the-art technologies and practices that satisfy the energy hunger and billions of devices have to be evolved more.

Moreover, there is a never-ending increase in number of vendors and users of various IoT technologies. Green IoT can be assisted by formulating green policies and regulations, which stimulate the interest in users to use green products. Nevertheless, to build a green environment, the old way of doing things has to be eradicated and new adaptable methodologies have to be defined. Furthermore, Green IoT comprises the dimension of environmental inter-dependability, cost-effectiveness of energy efficiency, and the total cost of ownership which includes the cost of removal and recycling.

1.1 Internet of Things

Internet of things is a computing device that connects physical objects to the Internet, and it is capable to convey the identity to other devices. It includes sensor technologies, RFID, and wireless technologies. Moreover, it carries an immense amount of information that is helpful to make intelligent decision making and it enables security, resilient, convergent, efficient, and transparent in operations.

According to Cisco report, the number of interconnected devices will reach 50 billion by 2020 and the Gartner IoT estimates that IoT will have 26 billion units by 2020. The general view of IoT key elements is given in Table 1 where data is collected from the target, processed, and analyzed to offer intelligence services to the users. The hardware segment refers to the interconnection of sensors, actuators, or any embedded hardware that is used for communication such as RFID [8–10].

Sensors are devices that convert physical parameter to electrical output, whereas actuators are the devices that convert electrical signal to physical output. Wireless

Table 1 General view of IoT key elements

Elements	Description
Hardware	Embedded hardware, sensors, actuators, tags
Middleware	Data storage, computing, and context awareness
Internet	Provide communication anytime, anywhere between everything
Presentation	Processing, interpretation, and visualization of data

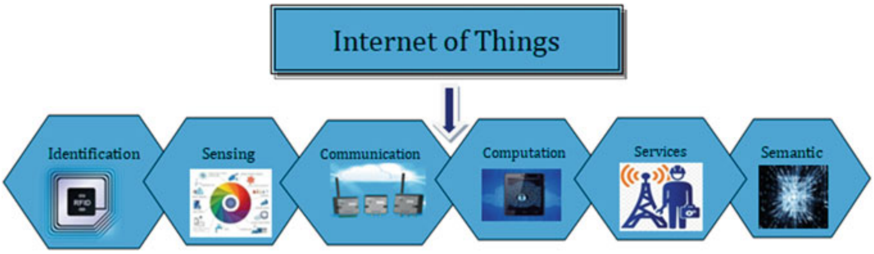


Fig. 1 Elements of Internet of things

sensor networks play a key role in the hardware layer. Middleware refers to the cloud environment, where data is being stored, processed, and various analyses are performed on the data to gain useful insights. Nevertheless, recent advancements in technology have brought forth fog computing and edge computing, where data can be processed locally to avoid latency and fast processing. On the other hand, the presentation segment interprets and visualizes the data in a form that is understandable by the user. The Internet segment is responsible for communication and cooperation between various segments anytime, anywhere, and between everything that is connected to the Internet of things. The six common elements in IoT are described, and it is shown in Fig. 1.

Identification: IoT provides an interaction among users and things where devices have to be uniquely identified to enable the interaction within a specific context, for instance, ubiquitous code (ucode), Electronic Product Code (EPC), radio-frequency identifier (RFID), automatic identification and data capture (AIDC), Host Identity Protocol (HIP), etc.

Sensing: The sensors collect data and share it with the connected devices in the network. It makes devices to function automatically, and the entire ecosystem becomes "smarter." The sensing devices can sense the temperature, humidity, proximity, pressure, water quality, chemical, gas, physical movement, acceleration, angular velocity, light rays, etc.

Communication: Communication technologies interrelate heterogeneous objects together to provide the various set of services. The protocols for communication in IoT can be Bluetooth, IEEE 802.15.4, LTE-Advanced, Wi-Fi, ultra-wide bandwidth (UWB), near-field communication (NFC), etc.

Computation: The software applications and hardware processing units (microprocessor, microcontroller, system on a chip (SoC), and field-programmable gate arrays (FPGAs)) perform the computational task. Various hardware platforms such as UDOO, Raspberry Pi, Arduino, Gadgeteer, and software platforms, such as RIOT OS, LiteOS, TinyOS, are used.

Services: IoT services are categorized into four types: information aggregation services, identity-related services, collaborative-aware services, and ubiquitous services. Identity-related services provide the base for other types of services, which help in relating the real-world objects to the virtual world.

Semantics: It is essential to extract the knowledge meaningfully so that the desired services can be offered. The steps involved in semantics are to discover and utilize resources, model and analyze the data. Some of the commonly used semantic technologies are Efficient XML Interchange (EXI), Resource Description Framework (RDF), Web Ontology Language (WOL), etc.

IoT offers a framework for interconnecting devices to permit the communication seamlessly. Most of the IoT applications are highly focused on the middleware layer of IoT architecture for information processing. Initially, IoT architecture is basically designed as a three-layered architecture which comprises of perception, network, and application layers. Further, it has been extended to five-layered architecture, where the basic architecture is not ample to face challenges of various IoT applications. The five-layered IoT architecture is shown in Fig. 2 which includes perception, network, middleware, application, and business layer.

1. Perception layer: The perception layer also known as device layer consists of different physical objects and sensor devices. The sensor devices can be the 2D barcode, RFID, or infrared sensor depends on object identification method. Such sensor device in this layer identifies the object, senses the environment, and collects information about the identified object. Any other smart objects can also be identified by sensing some physical parameters in the same environment. The gathered information is about location, vibration, motion, orientation, temperature, chemical changes, acceleration, humid level in the air, etc., depending on the type of sensors, and it is sent to the network layer for transmission.
2. Network layer: The network layer is also called as "transmission layer." The main functionality of this layer is to interconnect different network devices,

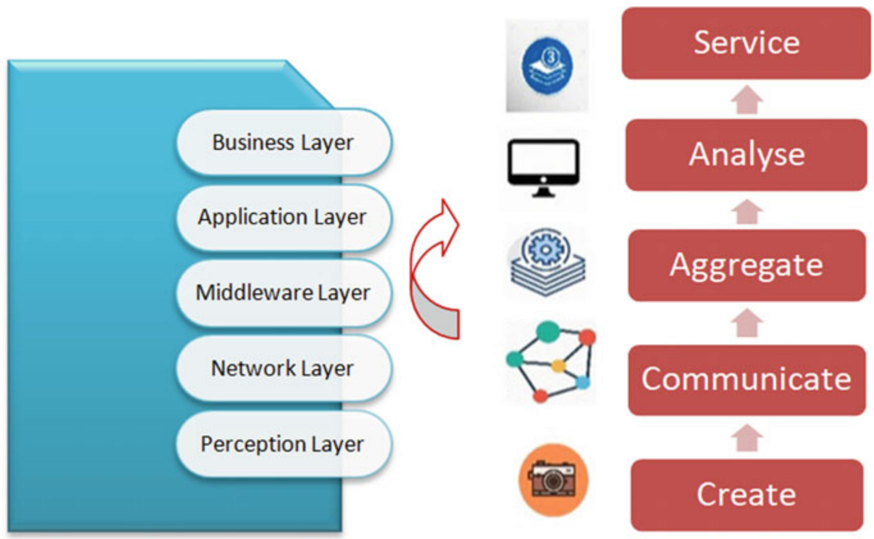


Fig. 2 IoT architecture

smart objects, and servers. It transmits and processes the data which is gathered already from sensor devices. The transmission medium can be either wired or wireless, and the technology can be infrared, Wi-Fi, Bluetooth, ZigBee, 3G, etc. Further, the information is transmitted to the processing layer.

3. Middleware layer: It is the main "processing layer." The middleware layer stores, analyzes, and processes a large amount of data which is received from the network layer. The responsibility of this layer also lies in the service management and sustaining the connection with the database. Since it is behaving as the middle layer, the devices in IoT provide various services to the lower layers. The devices can be connected and communicated easily with the devices that are designed to provide the same type of services. It may be interlinked with various technologies like big data, cloud computing, and databases for processing the huge volume of information. It plays a major role in automatic decision making, ubiquitous computation, and information processing. Processing layer gathers and stores the information received from the network layer.
4. Application layer: The main responsibility of the application layer is to deliver application-oriented services to the IoT end users. This layer directly communicates with the end-user application with its application layer protocols.
5. Business layer: Finally, the business layer has a control over the entire IoT system including business models, user's privacy, and applications. Based on the information received from the previous layer, it deals with the formation of different business models, graphs, flowcharts. Moreover, for IoT technology the real achievement lies in well-constructed business models. After analyzing data, the business layer helps in decision making about upcoming activities and business strategies.

The key technologies involved in IoT are RFID, M2M, WSN, addressing schemes, data storage, and visualization. In general, IoT has various application domains such as data analytics, data management, visualization, network management, application development, and research as shown in Fig. 3. Application development refers to the launch of IoT-enabled products by the industry. With the hype around IoT, many applications that ease the day-to-day life of humans, namely smart home, wearables, smart grids, connected cars, smart health, smart retail, smart supply chain, smart agriculture, smart city, have been introduced and developed. With the advent of many useful IoT products, frequent communication happens between the things or devices are the key elements of application design and development.

The network management domain plays a vital role in establishing the mode of communication that has to be deployed between various entities involved. The network could be wireless or wired, and in most of the scenarios, a hybrid model of both wired and wireless communication is used. The key technologies used are Bluetooth Low Energy (BLE), ZigBee, Z-Wave, Wi-Fi, near-field communication (NFC), LoRaWAN, and cellular communications—GSM, 4G, 5G. Initially, data transmission was event-driven but today data is transmitted periodically. Thereby, there is a constant increase in the quantity of data that is being generated every second. Data management refers to the adaptation of state-of-the-art technologies on

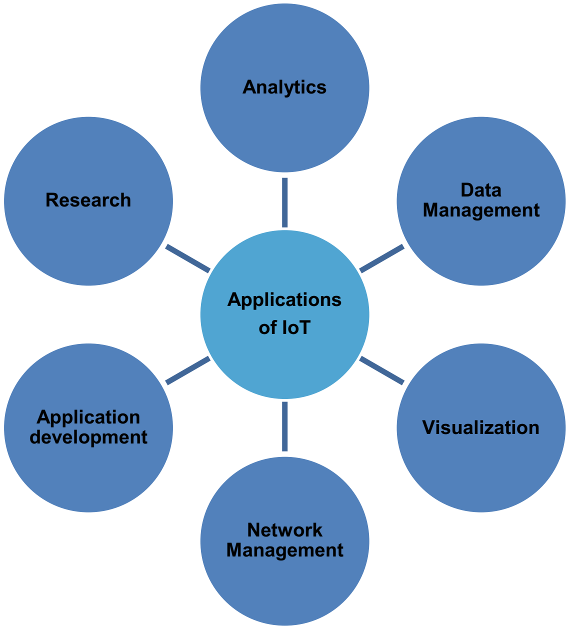


Fig. 3 Application domains of IoT

handling data. Many cloud vendors provide infrastructure and storage capabilities. Nevertheless, the major concern is on how the data is to be stored as the information transmitted from IoT devices come in various formats and varying sizes. Managing the immense amount of data is still a challenge that needs to be addressed. Data analytics is a domain that has attracted interest toward many academicians. The primary element in apprehending data analytics includes the datasets that are generated by sensors. Clustering, classification, and predictive analytics can be performed on data depending on the application use cases. Visualization deals with presenting the analyzed data in a format that is understandable and convenient to the user in the form of graphs or tables. All the above-mentioned application domains of IoT have involved significant research attraction in the past decades. Current research and development are focused on transforming IoT to Green IoT for sustainability and providing an eco-friendly environment [11, 12].

1.2 Green Computing

With the increase in number of devices, subscribers and digital content, the rise in energy utilization level is also obvious. It is expected that the number of connected devices will be around 50 billion by 2020 and 100 billion by 2030. There is an exponential increase in the amount of data generated, thereby increases the levels of carbon dioxide as well. The literature reveals that 345 million tons of CO_2 will be emitted by cellular devices in 2020 and the same will increase in the decades to come. Tremendous emissions of CO_2 are a threat to the environment and poses health hazards. Therefore, to ensure the sustainability of the environment and make the world a better place to live in all computing capabilities have to be made green. Green computing also focuses on various domains such as energy-efficient computing and power management, design and layout out of data center with server virtualization, responsible removal and recycling, green metrics assessment tools and methodology, usage of renewable sources of energy, environmental-related risk mitigation, and regulatory compliance [13].

2 Green IoT

To create a sustainable environment, IT sector and in fact every computer user should green their devices and the way the devices are used. Green IoT uses energy-efficient technologies either to reduce the impact of greenhouse gases or to inhibit the greenhouse effect in IoT applications. In the former case, the effect of greenhouse gases will be reduced [14–18].

On the other hand, the later would optimize IoT. Thereby, from the design to implementation of IoT everything should be green. Framework for Green IoT is discussed and may be implemented with Green RFID tags, data centers, sensor network, cloud computing. Using Green IoT, the greenhouse gas emission is lowered, and energy efficiency is improved by the utilization of less harmful materials and encouraging reuse and recycling. The large-scale consumption of energy resources consumed by IoT to make our lives easy and sustainable on this planet has to be efficiently handled. It is predicted to change the human's life in the future and would definitely lead to a green and smart environment which is shown in Fig. 4. Green IoT provides low carbon solutions and sustainability.

Green IoT is gaining more attention as the usage of energy is increasing and the available energy resources are decreasing rapidly. Different strategies are used to conserve energy in smart buildings, and the data is gathered with IoT devices [19]. It is inferred that an enormous amount of energy can be saved if the air-conditioning and ventilation strategies are efficiently implemented in the described systems. Wireless sensor network (WSN) plays a significant role in the deployment of IoT devices. In [20], the list of techniques with various environmental resources is described to conserve energy in WSN. Yet, instead of batteries if the different medium is used for storage it could improve energy efficiency. Data center is a vital component in energy-efficient IoT-based WSN. In the proposed system [21], orchestration agent (OA) in a client–server model is designed for context evaluation of servers in terms of resource consumption and the designated server manages data centers. The chosen server transmits the processed information to client systems. OA is installed on each device of client and server sides to ensure reliability, which automatically leads to high energy consumption.

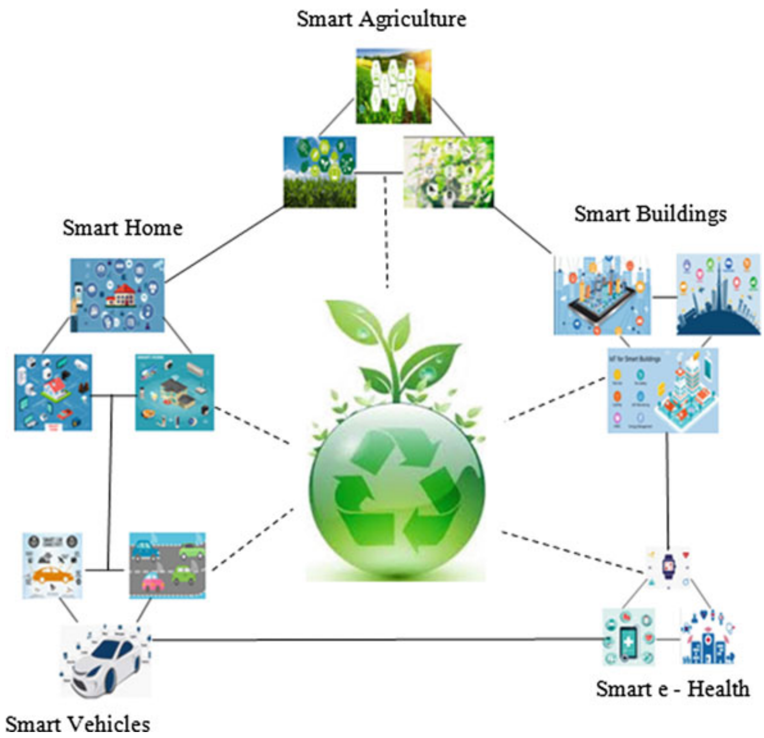


Fig. 4 Green Internet of things

In [22], C-MOSDEN is proposed as a context-aware sensing platform which implements selective sensing to obtain energy efficiency. However, it reduces the energy consumption but creates overhead and the model can be efficient if the overhead is minimized. An efficient scheduling algorithm is proposed to conserve energy in sensors if they are idle but are switched on. Reconfiguring virtual objects (VO) during run-time on three different operating modes, such kind of energy-efficient model is proposed. To estimate the energy consumption of the operating modes, analytical model was introduced and the outcome of one mode is resulted in 47.9% less energy consumption than the other. A green and scalable IoT is proposed to deploy IoT on a very larger scale, minimal consumption algorithm, and an optimized model supports the model to operate an energy-efficient way. The system works well with heterogeneous networking environment and achieves better level of energy efficiency [21]. Nowadays, medical industry prefers IoT devices to store real-time data of patient's due to its scalability and robustness [23]. In [24], dynamic packet downloading algorithm with cloud storage and access point (AP) is proposed for energy-efficient data communication. If APs are equipped with passive RFIDs for generating its own energy instead of battery-powered, the consumption of energy can be considerably reduced. In case of smart phones, sensing power is a major driving force in the emerging IoT sector even though the energy efficiency in mobile devices is a challenging issue. A novel solution is proposed in [7], uses prediction models, resource behavior analysis, and data logging records data in various aspects such as contexts, applications, time, and location to predict the consumption of energy in smart phones.

2.1 Green IoT Principles

Green IoT is an emerging technology in ICT research as the energy requirement raises exponentially and the traditional sources of energy are depleting. The following principles are suggested to achieve the benefits in Green IoT:

1. Reduced network size: Nodes have to be efficiently placed in the network and efficient routing mechanisms have to be used to save energy.
2. Selective sensing: It collects only required relevant data, thereby eliminates unwanted or irrelevant data energy loss.
3. Hybrid architecture: Deploy passive and active sensors depending on the application can reduce energy.
4. Policy making: Effective policies have to be framed to reduce energy consumption in various IoT application areas such as smart buildings.
5. Intelligent trade-off: Trade-off must be chosen based on the scenario. Cost, communication, and processing have to be intelligently prioritized.

2.2 Green IoT Architecture

Green IoT focuses on the three main concepts, namely design, leverage, and enabling technologies. In the design phase, the technologies such as energy-efficient devices, network architectures, communication protocols, and interconnection are considered. In the leveraging phase, it refers to how to enhance the energy efficiency and minimize carbon emissions. By enabling green ICT technologies, Green IoT preserves natural resources by reducing hazardous emissions, energy, pollution, and resource consumption. Hence, Green IoT focuses on green design, green construction, green operation and maintenance, and green disposal.

To effectively notify the environmental impact of IoT, a holistic approach that addresses all issues must be formulated. In general, with the moving pace of technology and adaptation to the latest improvements in the field of ICT, the number of connected devices increases gradually. Nevertheless, energy consumption needs to be reduced for the reliability of Green IoT. By focusing on the above principles, total environmental sustainability can be achieved. Figure 5 shows the lifecycle of Green IoT, which has four phases—green design, green construction, green operation and

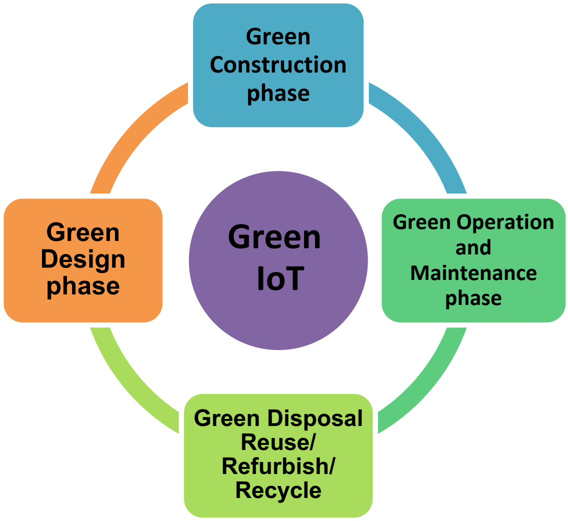


Fig. 5 Life cycle of Green IoT

maintenance, and green disposal such that the impact of environmental hazards could be minimized and the phases are described below in detail.

1. Green design: Component design should focus on the use of environment-friendly materials to be implemented in design. Hardware and software characteristics of the key components of an IoT system such as RFIDS, devices, sensors, and actuators that are the key role players of an IoT system should be designed to minimize resource utilization and produce less heat without reducing the performance. Hardware components could be reduced in size while the software characteristics ensure environment sustainability.
2. Green construction: IoT devices and sensors that are manufactured should be environment-friendly and the components must be made of biodegradable materials. As the number of devices grows rapidly, the construction sector ensures the compliance of green products. Standards and policies have to be framed for assessing the durability and quality of the components. All manufacturing firms should use only biodegradable materials and follow the efficient design.
3. Green operation and maintenance: Energy consumption of all devices should be reduced. Devices can be programmed to automatically power down, when they are not being used. Moreover, power saving mode can be established as the default mode must be enabled to reduce the emission of greenhouse gases. Utilization of IoT components can be significantly enhanced by making simple changes in the way it is used. Sensors can work on the principle of “awake and sleep” to prolong its lifetime. Moreover, energy consumption of the devices has to be reduced to minimize the impact of hazardous gases in the environment. The energy cost savings as per component may not seem much, whereas the cost of collective components within an enterprise would not be considered in determining the cost.

4. Green disposal: Recycling is the method of applying some technology to the existing devices or materials in order to remake the same device or some other devices. Old devices and equipment should be recycled and refurbished to reduce the amount of electronic wastes. In China, the rate of recycling of mobile phones is very less, since most of the devices are reused in the secondhand market which does not affect the environment. Around 15% of mobile phones are recycled in industrialized countries.

Green recycling refers to the use of recyclable materials in the manufacture of IoT devices. For instance, let us consider a mobile phone which is a commonly used device, and it contains copper, plastic, and some non-biodegradable elements. As per the survey conducted in Australia, it is found that 23 million mobile phones are no longer usable. Moreover, 90% of materials used in the manufacture of mobile phones are recyclable. The need for recycling increases and automatically reduces the energy consumption and the effect of greenhouse gases. Electric and Electronic Equipment (EEE) recently introduced the recovery and collection of metals that come under EEE-type. Furthermore, the use of solar energy for charging has been proposed by authors in that around 20% of the consumed energy is reduced [25].

2.3 Green IoT Technologies

The technologies that are pushing Green IoT forward are shown in Fig. 6. These are the major enablers and begin right from design to recycling as discussed in the Green IoT lifecycle.

Fig. 6 Green IoT technologies

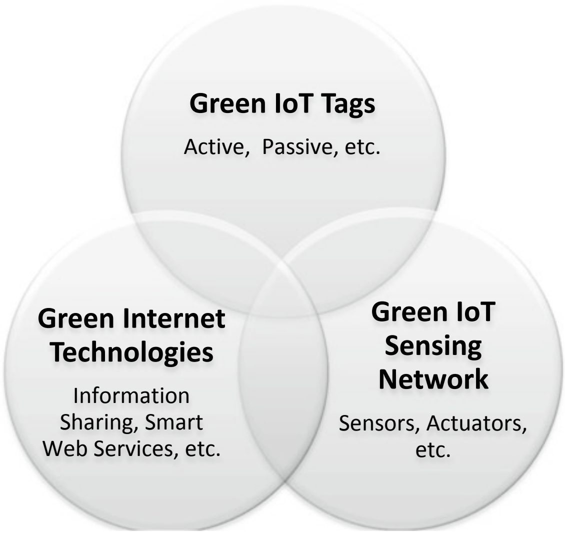


Table 2 Functionalities of sensing network

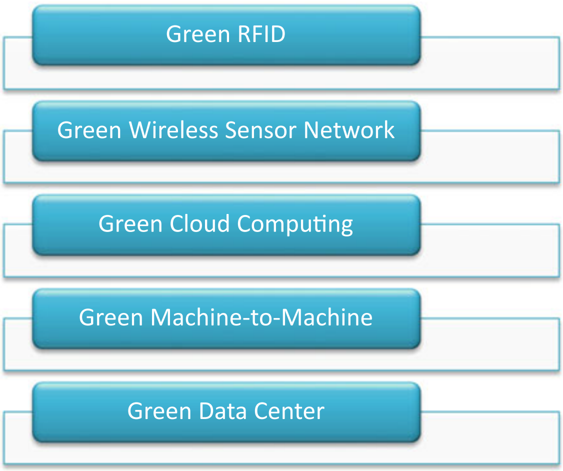
Sensing network	Functionalities
WPAN	Low range wireless network for connecting devices within the workspace of an individual
WBAN	Wearable or portables sensors and actuators are placed inside the body
HAN	A local area network that connects the devices in the vicinity of a home
NAN	Wi-Fi hotspots and wireless local area networks that allow users to connect to the Internet with low cost

1. Green tags: These are biodegradable RFID tags that are reduced in size to minimize the amount of non-biodegradable materials. In addition, there are various protocols which are designed to achieve energy efficiency. The RFID could be active, where the tags are powered by a battery, and they transmit data automatically, where passive RFID tags do not require to be powered by a battery; they transmit data only when they receive energy from an RFID Reader and work on the principle of induction.
2. Green sensing network: Sensing networks include WSN, wireless personal area network (WPAN), wireless body area network (WBAN), home area network (HAN), neighborhood area network (NAN). The functionalities of different sensing network are described in Table 2. The sensing network should employ energy management techniques by enabling power saving mode. Moreover, the size of the data may be reduced for efficient storage mechanism and conservation of electric power. Moreover, it is expected that 5G will appear in 2020 and handle mobile data 1000 times faster than the present cellular systems. It would link fixed and mobile devices at affordable rates with reliability leading to an economic industrial revolution. However, there are emerging challenges that need to be resolved in the horizon of 5G with Green IoT [26].
3. Green Internet technologies: Current scenario demands the manufacture of devices that consume less energy without compromising the performances in both hardware and software. In addition to that, software solutions should minimize the resource utilization to reduce energy consumption. Also, IoT devices transmit small packets with the connection between the devices; hence, the communication needs to be delay tolerant [27].

3 Green ICT to Enable Green IoT

The growth of ICT increases the rate of energy consumption and the rise in the number of environmental issues that need to be addressed. The green technologies that enable Green IoT are called as Green Information and Communication Technologies (Green ICTs). These technologies refer to the facilities and storage that allows devices and users to collect, store, access, and manage information with the new resources that

Fig. 7 Green ICT



do not affect the health of humans and environment. The core green technologies that construct a smart green world are shown in Fig. 7.

3.1 Green Radio-Frequency Identification (RFID)

RFID is a small electronic device with a unique identifier consisting of a microchip and antenna. The microchip is used to transmit and receive signals. It automatically identifies and tracks object that has the RFID tag. Collectively, they include numerous RFID tags and a small number of RFID Readers. The RFID tags come in various forms such as printable, paper-based and biodegradable RFID tags. Information flow is triggered when the RFID Reader transmits a query signal for which the RFID tags in the region respond. The transmission range of RFID signals is a few meters, and they have various frequency bands ranging from 124–135 kHz to 860–960 MHz. RFID plays a significant role in making the world greener by saving energy, improving the waste management process, and minimizing the emissions of the vehicle. In [26], Green RFID antennas provide solution for embedded sensors. The flexible design in antenna affords the sufficient calibration of the humidity sensor. RFID components include tag, reader, antenna, and station. RFID usage impacts directly and positively on both operational performance and logistics [28]. In [29], the lifetime of unmanned aerial vehicle (UAV) battery is enhanced and RFID Reader detection range also improvised. To achieve more benefits, RFID and UAV can be combined together and implemented in supply chain management systems. In an environmental monitoring operation, the recharging process of multipurpose RFID tag using UAV is examined [30]. In [31], UAV indoor localization technique using passive RFID is discussed and tracking, and localization activities are considered to reduce cost and provide more simplicity.

On the contrary, Green RFID emphasizes the following:

1. Reduction in size: Reduction in size would directly reduce the amount of non-biodegradable materials used in the manufacture, as it is difficult to recycle RFID tags.
2. Design of energy-efficient algorithms: Energy-efficient algorithms dynamically adjust to transmission power, optimize tag estimation, avoid tag collision, and overhearing should be designed and implemented.

3.2 Green Wireless Sensor Network

A wireless sensor network (WSN) consists of autonomous sensors that are spatially distributed and collaboratively monitor the various environmental conditions such as temperature, pressure, motion, and sound from the surroundings. The sensor nodes are incorporated only with limited power and storage capacity. They cooperatively work with the other sensors and collectively transmit sensory data to the base station, which is also called as a sink node in an ad hoc manner. IEEE 802.15.4 is a commercial WSN solution for low transmission and bit rate communications in the physical and MAC layer.

On the other hand, Green WSN should focus on the following techniques:

1. Power saving mode: Sensor nodes should transmit information only when it is required. The sensor nodes should be in sleep mode if they are idle, thereby saving energy consumption.
2. Energy depletion: Energy harvesting mechanisms that harvest the natural renewable sources of energy (Sun, kinetic energy, etc.) should be deployed. Traditional approaches such as wireless charging would deplete energy.
3. Radio optimization techniques: Energy-efficient cognitive radio, directional antennas, cooperative communication, and transmission power optimization techniques should be used for information transmission to the base station.
4. Data reduction mechanisms: The sampling rate of IoT sensors would be high, and the depletion of energy is very fast. Hence, data reduction techniques such as adaptive sampling, aggregation, compression, and network sampling have to be adapted.
5. Energy-efficient routing techniques: Routing algorithms with energy as a metric, multipath routing to have information transmitted in multiple paths with relay node placement and mobility should be deployed.

3.3 Green Cloud Computing

It provides on-demand network access in a shared pool of resources such as networks, storage, applications, and services that can be configured and customized based on the user requirement—infrastructure as a service (IaaS), platform as a service (PaaS), software as a service (SaaS), and with the latest improvement of everything as a service (XaaS). Elasticity is offered as resources are managed in a large pool with convenient access times. With the growing number of applications that require to be hosted in the cloud as private, public or community based, more resources are deployed and power is consumed causes environmental issues with the increase of CO_2 emission. On offloading data processing and storage tasks in mobile devices such as tablets and smart phones, cloud computing is integrated in the mobile environment introducing Mobile Cloud Computing (MCC). Nevertheless, on migrating to green cloud computing, the following would be the potential solutions:

1. Promoting reduced energy consumption in both hardware and software: Manufacturing units must design hardware that consumes less energy. Moreover, software solution should utilize minimum resources which consume less amount of energy with efficient design.
2. Power saving virtual machine techniques: Green initiative includes power saving VM consolidation, migration, placement, and allocation to reduce energy consumption in data centers.
3. Energy-efficient resource allocation: Various resource allocations such as auction-based resource allocation, gossip-based resource allocation and scheduling mechanisms should be implemented for energy efficiency.
4. Energy-saving policy: By drafting effective accurate models and evaluation approaches regarding energy-saving policies for cloud computing.

Recent advancement in cloud computing has led to the inception of sensor cloud, which is a powerful unique data storage platform that influences cloud computing technologies to provide rapid elasticity, excellent visualization, and user programmable analysis. It is capable of ever existing data sensing and gathering with powerful data storage and processing facilities. Sensor cloud model as shown in Fig. 8 and the sensor network provider (SNP) have a ubiquitous variety of sensors that could be static or mobile and to collect data from the environmental surroundings. The role of cloud service provider (CSP) is to store and process the transmitted sensor data with the data centers. The processed data is provided to the cloud service user (CSU) on demand. With the integration of cloud and sensor networks, there are many advantages. Users can access their sensor data from the cloud with a network connection in a pervasive manner. The utility of WSN is enriched as it can serve multiple applications such as healthcare monitoring and environmental monitoring. The services provided by cloud are enhanced with respect to speed, processing speed, and performance. Statistics reveal that sensor cloud outperforms than traditional WSN and cloud data centers with prolonged sensor life by 3.25% and reduction in energy consumption by 36.68%. These are seen as required characteristics for a smart world

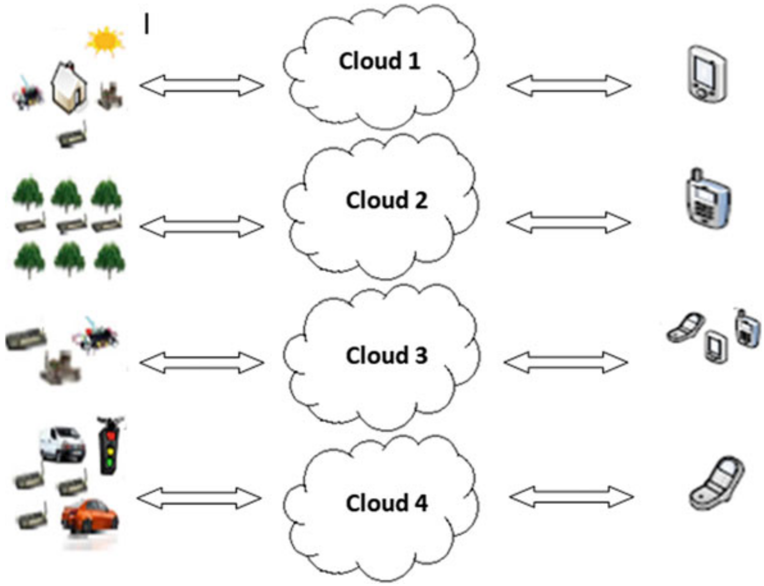


Fig. 8 Sensor cloud model

with green cloud. Nevertheless, security of sensor cloud continues to be a threat due to lack of trust and reputation between the CSP and SNP; as a result, any CSU may choose a fake CSP.

3.4 Green Machine-to-Machine

It allows both the wired or wireless devices of the same type to communicate with one other. Large number of M2M devices that are deployed in M2M domain collect the monitored data in IoT. The wired or wireless networks relay gathered data to the base station. As many devices are deployed in the M2M domain and the enormous growth of device to device communication and automation, energy usage has rapidly increased. Furthermore, the following mechanisms have to be implemented for Green M2M to reduce the consumption of energy:

1. Intelligent adjustment of transmission power: A threshold needs to be determined to ensure that the minimal range of transmission power is ensured for communication.
2. Design efficient communication protocols: Routing algorithms that focus on distributed computing techniques should be designed for M2M communication.
3. Activity scheduling: Switching devices to the low power operation mode called as sleeping mode should be scheduled. It implies that only a small subset of the

nodes will be active during the data-gathering phase. Thereby, around 40% of power can be saved and the negative impact of greenhouse gases is minimized.

4. Joint energy-saving mechanisms: Energy can be saved among the devices by following resource allocation and energy harvesting mechanisms such as spectrum sensing and management with interference mitigation and power optimization.

3.5 Green Data Center

Data center is physical or virtual repository for storage, management, and dissemination of data and applications that are created by various users or things. By continuing the development of Web services, many organizations are installing more servers for storage capacity and policy expansion. Besides cost, the availability of electric power is a critical aspect to be tackled by companies. Data centers consume enormous of energy with high operational costs and increased emissions of CO_2. With the increase in demand for IoT applications, massive amount of data is being generated by ubiquitous applications. Thereby, a vital requirement for efficient data centers and the urge for energy efficiency become much more significant. Data efficiency in data centers has to be improved by deploying energy-efficient equipment with proper airflow management for cooling purposes. Moreover, environment-friendly energy management software may be deployed in the data centers.

Green data center can become a reality by following the below-listed mechanisms:

1. Use of renewable or green energy sources such as water, wind, and solar.
2. Utilization of efficient power management technologies like vSphere, Turbo Boost.
3. Modeling of energy-efficient hardware by making use of the advantages of dynamically varying voltage and frequency. Server virtualization has saved energy consumption by 50%. Moreover, power down feature of servers should be enabled when not in use.
4. Design and implement energy-efficient data center architecture such as nano-data centers that achieve power conservation.
5. Design energy-aware routing algorithms and protocols that consider the traffic flow, network power, and state of sleeping nodes.
6. Draw support for sensing and analytical techniques such as optical communication and virtual machine migration.

3.6 Green ICT Principles

The Green ICT principles are described below in the objective of providing a sustainable environment for smart living [32–34].

1. Turn off devices/facilities when not in use: Devices or facilities are turned ON only when required. If these devices are always working (in ON mode always) enormous energy is consumed. Sleep scheduling is implemented in WSN, where sensor nodes dynamically turn awake (ON) and sleep (OFF).
2. Transmission of data only when required: Large-sized data consumes a lot of energy. Intelligent algorithms have to be deployed that send data only when required. For example, predictive data delivery sends data based upon the behavior of the user.
3. Minimize the length of data path: Routing algorithms that take the path size as a metric is a straightforward mechanism to reduce energy consumption. In addition to it, algorithms that consider the traffic flow in a path and effectively route paths in multiple paths have to be designed. Nevertheless, cooperative relaying in wireless networks has achieved significant gains with respect to energy consumption.
4. Advanced communication techniques: Data fusion with compressive sensing enhances energy efficiency by combining data from multiple sources and transmitting accurate data. Spectrum usage and efficiency can be improved with the use of cognitive radio which sense the environment and dynamically changes its modes of operation [35].
5. Renewable green power sources: Traditional sources of energy such as solar, wind, water, and biomass can be used as they can be renewed naturally and repetitively utilized. Renewable sources of energy have a vital role in energy efficiency and minimization of CO_2 [36].

4 Applications of Green IoT

Green IoT significantly makes remarkable changes in the surroundings due to the development of IoT devices and potentially reduces the cost of managing hazardous emissions, e-waste, and energy utilization. Green IoT is a good practice of designing, producing, using and disposing of servers, computers and some subsystems such as monitors, communication equipments, and storage devices more frequently and efficiently but with less impact on the environment and society. Optimizing the available resources and designing new IoT devices reduce the negative effect on human health and without perturbing the environment drives the force toward Green IoT. The main goal of Green IoT is to utilize environmental conservation, minimize the harmful effect of pollution and CO_2 emission, and reduce the cost of power consumption of IoT devices. Green IoT has a high potential with green ICT technologies to support environmental sustainability and economic growth which makes the world smarter and greener [13, 14]. In [37], industrial emission influence environmental changes for varying time and region is described and analyzed in detail. IoT devices with minimum energy consumption are required in order to form a healthier environment.

Many sensors, machines, devices, and drones are involved to communicate with each other for completing the task intelligently in the green environment. Moreover,

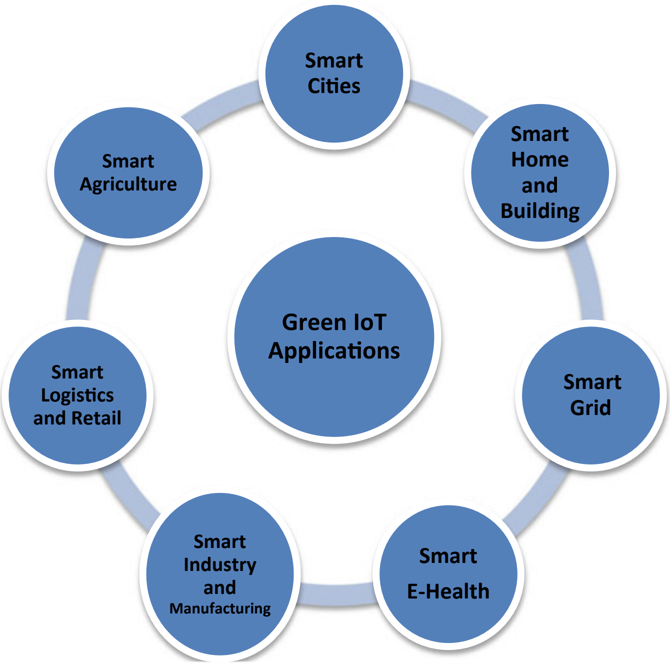


Fig. 9 Applications of Green IoT

Green IoT makes IoT to be benefitted in minimizing the harm, forming eco-friendly environment an exploring various energy sources. Therefore, many applications of Green IoT are economically, environmentally meaningful, and sustainable which preserves natural resources and reduces the harmful impact on human health. The various applications of Green IoT such as smart cities, smart home and buildings, smart grid, smart e-health, smart industry and manufacturing, smart logistics and retail, smart agriculture are shown in Fig. 9.

4.1 Smart Cities

Smart city market is predicted to reach 100 billion dollars by 2020, based on the annual report reaching nearly 16 billions every year. The interconnected systems provide the required services in regard to various needs of the users. The applications of Green IoT are smart transportation, smart security, and smart energy-saving mechanisms. Interconnected systems offer the required services to the users, and it is more convenient, easier to obtain the information according to their interest. The most upcoming applications for Green IoT are smart cities which have gained more attention in the last few years. It is a prominent and promising IoT application, where

Green IoT is characterized by efficient energy utilization to make the world smarter. Green ICT technologies should be enabled with sensors and communication add-ons to form a sustainable smart world. The devices can sense the environment, and data can be communicated with other devices as well. The smart city includes smart light lamp, smart parking, high-quality air, smart traffic management, smart vehicle, and so on [38, 39]. The quality of human life would be enriched by employing various applications of smart cities and introducing novel technologies for smart connected communities [40, 41]. Internet of things consists of Internet-connected devices where human uses it to make their life more comfortable and convenient. IoT plays a vital role in forming smart cities too eco-friendly.

1. Traffic management: It is an annoying experience for the persons who are being stuck in heavy traffic, and it creates too much emissions lead to global warming. For instance, IoT sensors fixed on traffic lights can alert if the traffic jam is heavy. After analysis, the big data platform could suggest the alternative routes to handle the situation. The person can be directed to find out the nearby parking places. The entering and leaving the parking places are monitored by IoT sensor, and the updated information will reach the person who is using application and connected to smart city. The application directs the user to the parking area nearer to their destination; thus, the person who caught in traffic jam gets assistance and could reach the destination earlier.
2. Waste management: Everyday 3.5 million tons of waste are generated and that too increasing continuously. Hence, the ways should be found to limit the waste production with recycling process to maintain the environmental sustainability for smart cities. The IoT sensors can track the level of recycling bins and give alarm to empty the container. The process should be tracked continuously by the relevant representative to check the waste level either increasing or decreasing. Waste management officials should take proper measures to prevent the illegal dumping of waste.
3. Evaluating the sustainability level of smart city: The factors which are affecting the planet negatively should be identified clearly to make the smart city more sustainable. Initially, the city officials can start the process with commercial off-the-shelf (COTS) sensor equipment and proceed with the customized sensors for rapid technological implementation. It is recommended to use IoT data along with big data to determine the city's present sustainability level, and how it is updated over time. The utilization of IoT technology in green computing will surely have a positive impact on smart cities [38].
4. Minimize resource consumption: The smart meter gauge typically tracks the consumed energy level in home and regarding fluctuations in energy usage over time. The users would manage the utility charges, and the environment is also protected simultaneously. 47% people said obtaining information via IoT sensors would assist the user in carrying predictive maintenance and cut down on energy usage. IoT-connected lights can be activated or deactivated automatically according to the premises busy or empty. IoT sensors can be fixed in water management system to measure the water flow rate, detect leaks, and a statistical report can

be generated to check the overall water usage. Some significant strategies can be followed to prevent the water wastage with the help of IoT sensors.

4.2 Smart Home and Buildings

IoT-connected devices are used for remote monitoring and managing home appliances such as heating and lighting. Smart home automation allows the user to control the smart devices like automated doors, smart locks, security cameras, electrical appliances (washing machine, refrigerator, air conditioner, dishwasher, microwave oven, etc.) with the application on a smart phone or any other connected devices. In a smart home, the temperature in air conditioner would be automatically adjusted according to the weather forecast. Security surveillance, door unlocking, thermostat, lighting, etc., can be covered. The renewable energy sources like solar panels and wind turbine are incorporated into already existing energy sources for automating the home appliances to reduce the amount of electric charge. If the refrigerator works continuously, the fluctuation in the power load might occur due to the cooling process and compressor system. The compressor will function till the temperature is below or equal to the threshold level.

Today's lifestyle is changed even to be more efficient and smarter by remote access of home appliances such as air conditioner, microwave, refrigerator, geyser, and robotic devices. Green IoT enables home as a smart home where lighting, heating appliances, and various electronic devices are controlled remotely by using a smart phone. The centralized mobile in-house receives voice commands and gives responses to the connected devices. In a smart home, a model is formulated QoS provisioning of different IoT devices based on channel assigned optimization. Scheduling the execution of all home appliances is based on the weather condition, resident behavior, discomfort index, etc., and it can be done either statically or dynamically. In static scheduling, the profile of home appliances is defined based on user activities. Scheduling is prepared based on the amount of received power supply, power generation capacity, and energy demand of all electrical and electronic appliances. Suppose the forecasted data and user activities vary, rescheduling is done to meet the energy demand. This is the process called run-time scheduling. With the tremendous increase in population, digital transformation, automation, and modern lifestyle the globe is facing a very big energy crisis because of climate change, depletion of fossil fuels, and a lot of carbon emission. IoT-enabled smart home is essential to conserve sustainable and renewable energy resources, where it provides connectivity, convenience, and comfort.

4.3 Smart Grid

The power resources should be controlled in such a way that it can be provided proportionally to the population growth. Thus, the energy consumption of different building premises could be reduced. The services offered by them can be enhanced once the area is connected to the network and is monitored persistently [42]. The capability of grid should be dynamically adjustable to afford energy at low cost and high quality. A low-cost remote memory proof for smart grid is proposed [43, 44]. Furthermore, the approaches to increase data validity for smart cities are proposed. In the future, the smart grid can monitor the energy consumption level and able to construct full energy-based systems [45].

Smart grid is a network of substations, transmission lines, and transformers that provides electricity from the power station to the residential or office premises. It allows two-way communication between the sensor devices and users via transmission lines. If some appliances such as washing machine or dishwasher are used during peak hours, the pay is more at that time. Smart thermostats and smart meters will suggest the best time to use the appropriate home appliances in such a way the utility bills can be minimized. In addition, smart surveillance allows the safety of elderly people and children to be watched continuously using applications.

4.4 Smart E-Health

The performance of healthcare applications is enhanced by implanting sensors in human body for monitoring. Data is gathered and analyzed to provide suitable treatment for the patients in real time. The various types of sensors and actuators can be fixed in human body for tracking the human body [46, 47]. Advanced IoT sensors are introduced to produce real-time data about human health makes a drastic revolution in the healthcare industry [48–50]. It improves quality, access and cost in efficient healthcare services.

Due to the emission of CO_2 from decentralized data centers, the environment is polluted and data can be shared with personal health record (PHR) by reusing data centers. Flexibility, compatibility, and availability are increased, and the high emission of CO_2 is avoided. Due to flexibility, the updated information can be shared with other data centers for reusable resources and e-healthcare services [49].

4.5 Smart Industry and Manufacturing

With minimal human intervention, robots are designed to complete the manufacturing task. The functionalities are automatically tracked and handled in a controlled manner. Hence, industries are automated with automatic functioning of machines with little or without human intervention [51]. The industrial Green IoT converges smart manufacturing systems and IoT architecture which enables remote access and reduces downtime. It also enables efficient data sharing among industrial firms, factory floor and extensively improves market agility, equipment efficiency, labor productivity, etc.

4.6 Smart Logistics and Retail

RFID and smart shelves play a significant role in retail and logistics which draws the attention in achieving accuracy and providing the required customer services. A pallet fixed on a truck or in a warehouse can send messages which include the detail about the product such as sizes and style variations. Juniper's research estimates that the investment of IoT in retail will reach $2.5 billion by 2020. The interconnected physical devices in retail industry significantly modify the operational way of supply chain. The requirements for digitally transformed logistics are energy saving, contextual data analysis, cost efficiency, integrated end-to-end management, real-time activity oversight, and remote tracking.

GPS can be attached with sensors to track the functionality of every part in the logistics exercise and predictive maintenance for climate and atmospheric changes, vehicle, route optimization, and complete traceability. Data should be available to the customers and there should be an option for tracking their purchases in real time.

4.7 Smart Agriculture

In smart agriculture, all devices should be equipped with sensors and communication add-ons for effective sensing and communication; in fact, it requires more energy. The energy demand is further increased greatly because of the remarkable interest from several organizations. Hence, the Green IoT recently focuses on decreasing the energy consumption by satisfying the smart world with sustainability. Energy-efficient algorithms with IoT facilitate the reduction of the greenhouse effect in various applications. The strategies should be followed by industries to deal with limited land availability, water scarcity, and cost management factors. IoT and cloud computing can reduce the power consumption in smart agriculture. Green IoT and Green nanotechnology in combination can create the sustainable smart agricultural industry [52].

With smart agriculture gadgets, the smart farming gained in the process of growing farms and rising livestock. According to the BI intelligence report, the number of connected IoT devices will reach 75 million by 2020 and global smart agriculture market size prediction says it will reach $15.3 billion by 2025. Some of the benefits are

1. Immense amount of data is collected by agriculture sensors, and it senses soil quality, crop's growth progress, cattle health, or weather condition.
2. Able to plan for the better product distribution by having the control over the internal process.
3. Anticipate the risk of losing the yield.
4. The multiple processes such as fertilizing, pest control, and irrigation are automated.
5. Easy to maintain good standards for growth capacity and crop quality with the automation.

IoT sensors of agriculture:

1. Smart farming sensors monitor the climate condition for choosing the suitable crops, and the appropriate steps are taken to improve the capacity. Smart agriculture IoT devices are smart elements, allMETEO, Pynco, etc.
2. Greenhouse automation uses smart agriculture sensors which have smart sprinkler controller to manage the lighting systems and irrigation remotely.
3. The significant element of precision farming is crop management where the sensors collect data about the temperature, leaf water potential, and crop health for improving the farming practices.
4. Smart agriculture sensors (collar tags) are used to observe the physical conditions such as temperature, nutrition insight, and activity about the herd.

The quality of sensors is significant for the product to be hit, and it depends on its reliability and accuracy of the gathered data. The efficient data analytic techniques and predictive algorithms are required to gain deep insight into the gathered information. The maintenance of sensors is a challenge in smart agriculture because the sensors fixed in the field can be easily damaged. The farm owner should have a control over the field remotely via smart phone. The adequate wireless range is required for proper communication and to transmit the data to the server through the connected devices are autonomous. The concrete internal infrastructure is compulsory for handling the immense load to ensure the performance of smart farming application [53, 54].

5 Open Challenges and Future Research Direction

The Green IoT is recently focused on most exciting areas, namely green design and implementations, Green IoT services and applications, green communication and networking, mobility and network management, energy-saving mechanisms, smart objects, integrating RFIDs with sensor networks, green localization, and compatibility of heterogeneous networks. Some of the key challenges in searching of optimal solutions for Green IoT are as follows:

- Achieving acceptable performance by integrating energy-efficient mechanisms across IoT architecture.

- Smart applications should be focused on green technologies to decrease the impact on the atmosphere.
- Green IoT infrastructure should be designed in such a way that it affords ease of accessibility.
- Context awareness applications of energy-efficient Green IoT system can be designed.
- Energy-efficient devices and protocols with low power consumption should be used for communication.
- There should be a trade-off between the efficiency of spectrum sensing and management techniques.
- Reliable power use models of Green IoT systems are needed.
- Energy-efficient system architecture and service composition strategies should be clearly investigated.
- Achieving efficient energy-saving scheduling techniques for Green IoT communications.
- Users should have ease of access and control of their virtual private IoT.
- There is a demand for UAV to restore huge amount of IoT devices in various fields such as traffic monitoring, agriculture in order to minimize the toxic waste and energy utilization. Hence, UAV is a hot and prominent technology that leads Green IoT with high efficiency and less cost.
- Sensor cloud is a technology which transmits information from sensor to mobile cloud by integrating WSN and mobile cloud. Green social network as a service (SNaaS) clearly examines the energy efficiency of WSN, cloud management, and its services.
- M2M plays a vital role in reducing hazardous emissions and energy usage by enabling automated systems. The delay in machine automation should be reduced in traffic management system to take immediate necessary action.
- Devising suitable techniques with improved QoS parameters such as delay, bandwidth, and throughput for the effective contribution of Green IoT.
- The radio-frequency energy harvest should be considered to support green communication among IoT devices.
- For smart and green environmental life, reduce the energy usage and CO_2 emission by designing smarter IoT devices.

6 Conclusion

In this chapter, the major challenges in IoT and its elements to produce intelligence services to the users have been discussed. Furthermore, in order to solve environmental problems, energy-efficient IoT and its technology have been discussed. Green IoT helps the environment by improving energy efficiency, minimizing greenhouse gas emissions, using carbon-free materials, and promoting reusability. With respect to Green IoT, principles have been suggested to save energy. Moreover, the lifecycle of Green IoT focuses on green design, green construction, green operation and maintenance, and green disposal to have very minimal consequences in the atmosphere which have been discussed. The Green IoT technologies include hot green ICT such as green tags that are reduced in size to minimize the amount of non-biodegradable materials and green sensing networks should deploy energy management by enabling power saving mode and green Internet technologies that consume less energy without compromising performance should be manufactured have been discussed in this chapter. Also, potential solutions are suggested on migrating to green cloud computing and later move on to the topic of green ICT principles for a sustainable environment with smart living. Finally, headed over applications of Green IoT such as smart home which helps to monitor and operates the home appliances with more easier and convenient manner, smart health care for monitoring and tracking patients in real time, smart grid to control and manages resources so that power can be offered and smart city helps to obtain information of interest for residents by making it more convenient and easier have been discussed.

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