1-1-2020

Internet of Things for Sustainable Community Development: Introduction and Overview

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Salam, Abdul, "Internet of Things for Sustainable Community Development: Introduction and Overview" (2020). *Faculty Publications.* Paper 23.
https://docs.lib.purdue.edu/cit_articles/23

https://doi.org/10.1007/978-3-030-35291-2_1

Chapter 1

Internet of Things for Sustainable Community Development: Introduction and Overview

Abstract The two-third of the city-dwelling world population by 2050 poses numerous global challenges in the infrastructure and natural resource management domains (e.g., water and food scarcity, increasing global temperatures, and energy issues). The IoT with integrated sensing and communication capabilities has the strong potential for the robust, sustainable, and informed resource management in the urban and rural communities. In this chapter, the vital concepts of sustainable community development are discussed. The IoT and sustainability interactions are explained with emphasis on Sustainable Development Goals (SDGs) and communication technologies. Moreover, IoT opportunities and challenges are discussed in the context of sustainable community development.

1.1 Introduction

The sustainability is one of the vital factors in realization of the digital future. The Internet of Things (IoT) is envisaged as one of the enabling paradigms of this sustainable digital transformation and community development. In this book, the community is referred as any geographical zones that function under some sort of structure and resources at its disposal to meet their current and future needs. The community sustainability depends on risk tolerance. The combined economic value of the industrial IoT along with public and consumer sector is likely to be more than $15 trillion by 2030 [28, 67, 71]. Moreover, the convergence of the IoT with other technologies (e.g., artificial intelligence (AI), technological revolution, blockchain, cluster and cloud computing) presents a tremendous potential for sustainable community development.

1.1.1 Global Efforts to Address Sustainability

A United Nations conference on the human environment was held in Stockholm, Sweden in 1992. It was the first conference to discuss environmental issues. A report titled "Our Common Future" (also referred to as Brundtland report [38]) published by World Commission on Environment and Development defined sustainability as:

> "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

This report played an important role in increasing the awareness of environmental sustainable development. It identified many issues and changed our thinking towards the sustainability. Accordingly, the United Nations started developing indicators and systems for sustainable development. Since then many conferences are held for sustainable development. The progress made these conferences is outlined below:

- In 1983, the General Assembly (resolution 38/161) established a special commission to report on strategies for sustainable development, environment, and the global problems by 2000. The commission was later renamed to World Commission on Environment and Development.
- Earth Summit, United Nations Conference on Environment and Development (UNCED), June 1992. Approximately, 100 heads of state met in this Earth Summit to discuss pressing problems in environmental protection and socio-economic sustainable development.
- Barbados Programme of Action (BPOA). UN General Assembly resolution 47/189. UN Global Conference on the Sustainable Development of SIDS, Barbados, 1994. A 14-point program identified priority areas recommended actions.
- A UN General Assembly review session was held to review progress of sustainable development in New York, USA in 1997.
- World Summit on Sustainable Development (WSSD). The Johannesburg summit was held in 2002 to address challenges in improving human lives, natural resources conservation, increasing water, sanitation, energy, food, shelter, and health.
- Mauritius Strategy of Implementation (MSI 2005). It was held in Port Louis, Mauritius to review sustainability progress in 2005.
- MSI+5. It was held in New York, USA in 2010 to review Mauritius Strategy of Implementation.
- The UN Conference on Sustainable Development (Rio+20) in Rio de Janeiro, Brazil, in June 2012. It was decided to develop a set of Sustainable Development Goals (SDGs) on top of the millennium development goals (MDGs).

Fig. 1.1 The UN Sustainable Development Goals [41]

1.1.2 *Sustainable Development Goals (SDGs)*

In 2015, UN General Assembly set forth the Sustainable Development Goals (SDGs) in its resolution 70/1 with 2030 [71] as the target year [66]. These goals have been developed with the community involvement including academia, governments, and private sector. It encompasses three major sustainable community development dimensions (e.g., protection of the environment, social diversity and inclusions, and economic growth). The SDGs have become the widely accepted and adopted standard system to attain the aim of sustainable community development. These goals are important in the entire IoT paradigm to increase the sustainability and social impact. The UN Sustainable Development Goals are shown in Fig. 1.1. The IoT with its ability to sense and communicate through interconnection of things and systems in different environments has the great benefit of achieving these sustainable development goals. In the sustainability area, the IoT along with technology is going to be a huge game changer in the near future. It is a comprehensive, commercially viable, widely available and accepted technology to achieve these goals with many social and economic benefits at the regional and national level to broader community.

1.1.3 *Sustainability Indicators*

The indicators of sustainability are useful to describe minimum and contemporary requirements for sustainability. Accordingly, management policies and actions can be evaluated to make a reliable forecast of future changes.

> "indicators must provide information relevant to specific assessment questions, which are developed to focus monitoring data on environmental management issues."—Evaluation Guidelines for Ecological Indicators [37].

The sustainability indicators alone cannot help to achieve sustainable goals. More detailed actions are required at appropriate levels coupled with policy decisions. For example, surface water quality indicators only provide information about issues only at a small spatial and temporal scale requiring extrapolation for decision making. Accordingly, the sustainable development guides policies considering all these factors. In the next section, the potential of the IoT as a comprehensive enabling paradigm to achieve SDGs is discussed.

1.2 IoT as Enabling Paradigm for Sustainability

The Internet of Things (IoT) for sustainable community development is envisaged to develop the engineered systems that enable sustainability by protecting the natural and environmental systems [14, 16]. Through interconnection of systems, sensing and communication technologies, IoT for sustainability aims to provide a paradigm that balance community's need to provide ecological and environmental protection, and maintains secure economic society.

The strong relationship between the Internet of Things and sustainability cannot be overemphasized [9, 25, 32, 35, 59, 60, 65, 67, 68, 72]. For example, a flood, sewerage, and storm overflow monitoring [53] Internet of Things solution based on sensing and communications supports sustainable communities (SDG 11) by reducing water related disasters and economic losses. An IoT for condition based maintenance of smart grid supports infrastructure (SDG 9). A city-scale smart lighting IoT supports improvements in energy efficiency (SDG 7). The next-generation wireless IoT has the potential of advancements in multiple fronts to accommodate the ever-increasing demands of commercial applications, scientific infrastructures, governmental agencies, and public, in general; for better and larger-scale connectivity (SDG 9). In the area of human health (SDG 3), instead of a single major technological breakthrough the community can rely on the culmination of several key enabling IoT technologies. The wireless data harvesting IoT technologies can provide managers and users real-time access to crop and soil moisture data, which supports effective water management decision making (SDG 2 and 12). In digital forest management, the early warning system for drought stress can help to initiate and prioritize actions (SDG 13). The forest soil moisture detection can guide restoration decisions. These examples clearly show that sustainable community development is the mainstream benefit of Internet of Things.

In a study [28], the relationship between the Internet of Things and sustainability has been explored. Particularly, the 640 different Internet of Things projects were compared with the 17 SDGs in order to analyze the relationship between sustainability and Internet of Things. It has been shown that 84% of the analyzed IoT projects exhibited stronger potential to attain these goals. The five SDGs (SDG# 3, 7, 9, 11, and 12) were emphasized by 75% of the projects. The IoT supports sustainable development in following areas:

- Ecological Engineering. The IoT enables sustainable development in the area ecological engineering (e.g., rehabilitating and enhancement of ecological functions to natural systems and natural capital) [60].
- Earth Systems Engineering. The sustainable development of IoT supports monitoring of earth systems (e.g., greenhouse gas emissions). It has strong potential to guide adaption to varying climate, forestry, mining, energy systems, and related global scale concerns through development of decision support systems [42].
- Industrial Ecology. The IoT fosters advancements and innovations in the area of industrial ecology, including evolution of life cycle assessment and economic models, and measurements for sustainable systems [84].
- Environmental Sustainability and Green Engineering. The IoT paradigm has great potential to advance the sustainability of infrastructures (e.g., water, recycling and reuse of drinking water, stormwater, waste water, climate assessment) [47]. Accordingly, the IoT guides innovations and growth strategies in distribution and collection systems based on its sensing and monitoring paradigm.

1.3 SDG Goals and Sustainable IoT Systems

The examples of the sustainable IoT systems in developing and developed countries are explained in the following.

1.4 Examples from Developing Countries

In developing and emerging countries the IoT paradigm has the strong potentials to make big improvements in sustainability and human life [28]. With the increasing coverage of wireless networks in developing countries, it has become easier to form IoT networks with interconnection of "things." The second/third generation wireless/cellular networking infrastructure in emerging countries surpasses than electricity, water, and sewage infrastructure. The adaption of modern technology such as technological innovations in the field of digital agriculture, health, environmental monitoring, energy systems, water resource monitoring, and livestock, is lacking due to lack on basic resources and supporting infrastructure required for technology operation in developed countries. Consequently, the IoT monitoring systems are either in their infancy or do not exist. Scarce connectivity and spectrum availability are some of the other limiting factors. Therefore, there is need of ubiquitous connectivity with energy efficient, low-cost wireless, machine to machine (M2M), and sensing technologies. Moreover, great potential exists for sustainable community development using IoT in various areas. The prospects for a variety of sustainable IoT use cases are very high. Higher level of efficiency can be achieved by using meaningful IoT paradigm and implementation. Accordingly, SDGs can be monitored for achieving sustainability goals.

There are many examples of IoT deployments around the globe which highlight sustainable community development. In the following some examples from the developing countries are presented [28].

- SDG 10, and 16: Secure biometric cash is being provided to refugees in Jordan by using the retina scan connected to financial IoT
- SDG 7,9, 11: Fire and smoke detection IoT with alarms is being used in highly dense urban settlements in Kenya and South Africa
- In Indian Ocean, the buoy IoT supports an early warning tsunami monitoring system
- In east Africa and India, the low income households are being powered by micro solar electricity off-grid IoT
- Black carbon sensing IoT supports cooking stoves monitoring in Sudan
- Public transportationconnected mini buses IoT in Kenya is being used to monitor acceleration, speed, and braking to control risky driving
- SDG 12, 13, 14, 15: In East Timor, cloud based IoT supports motoring the illegal fishing activity
- Air pollution monitoring IoT to sense outdoor air pollution in Benin
- Acoustics based sensing IoT are being used to monitorsee bird migration patterns and population count
- In Africa, animal tracking IoT supports game parks management
- In UAE, drone and ground camera monitoring IoT is being used by national park service
- In Indonesia, digital forestry IoT supports monitoring for illegal logging activity
- SDG 4: In South Africa, school attendance IoT has interconnected the students, faculty with the automated attendance system using biometric features
- SDG 1,2, and 8: In Kenya, a weather monitoring IoT supports accurate weather forecasting
- In India, pumps are interconnected using irrigation IoT for mobile-based irrigation management
- Agriculture IoT based on soil moisture sensing to tea crop in Sri Lanka and Rwanda
- Herd IoT in Namibia, Senegal, and Botswana, for animal tracking, keeping health records, and theft control.
- SDG 3 and 6: In Rwanda and Kenya, SMS and sensor-enabled water pumps to support villagers

- Cellular connected cool chain IoT is being used for refrigerated delivery of vaccines
- In west Africa, the medical IoT supports pulse, oxygen, and temperature, monitoring
- River monitoring IoT to sense river depth and rate of flow in Honduras

1.4.1 Examples from Advanced Countries

Examples of the sustainable IoT systems towards achieving SDG goals are discussed below:

- Internet of Things in Transportation and Logistics (IoTTL) [15]
- Agricultural IoT (Ag-IoT) [77]
- Internet of Battlefield Things [5]
- Wearable IoT [75]
- Internet of Body Things [20]
- Internet of Things in Smart Lighting and Heating [13]
- School Buses Transportation and Tracking IoT [26]
- IoT of autonomous vehicle and unmanned aerial systems [18]
- Payment facilitator [39]
- Micro-Transit IoT [10]
- Truck fleet IoT with charging stations [30]
- Multi-model transportation and logistics IoT [30]
- Garbage Monitoring IoT [29]
- Waste and Storm overflow monitoring IoT [53]
- Energy, Smart Meter, and Renewable Energy Systems IoT [45]
- Urban parking IoT [4]
- Mobility modeling and management IoT [63]
- Traffic Counting IoT [62]
- City utilities IoT [61]

1.5 IoT Challenges for Sustainability

Since IoT market is still in infancy, there is need of comprehensive business models and proof-of-concept implementation. By employing the sustainability goals during the design phase of the IoT is required to attain its full potential and economic benefit. Regulations, governmental incentives, monetary benefits, and tax credits, industry goodwill are some of the methods to encourage consideration of the sustainability goals at the system analysis and design of the IoT projects. An efficient business model is vital for sustainable IoT development. Introduction of accreditation programs to certify sustainability goals of the IoT is needed.

The management of huge amount of data being generated through connected ubiquitous IoT projects is a major challenge because of its competitive and analytical value. The collection, ownership and storage of data, its usage and sharing, sensitivity and privacy are some of the contentious issues that need to be solved.

The emergence of multitude of IoT platform providers has caused fragmentation which is hindering the critically desired consensus for standard development in the area of sensors, interfaces, and radios. The interoperability issues limit the choice of available hardware for IoT projects and inter-system integration also suffers because of the closed standards. Collaboration among different stake holders particularly the standardization efforts can help to reduce the impact of fragmentation. Opening up the data will also lead to development of cross-industry systems. These technical partnerships can also be used to integrate different technologies together to provide a unified front end.

The lack of large-scale IoT infrastructure due to low interest from investments from public and private sector is also hindering sustainability goals. The utilization of existing infrastructure, encouraging investors for IoT infrastructure through policy incentive, simplified legal and regulatory frameworks will help in development of IoT infrastructures at a scale. Joint symposium of government, academia, and industry leaders should be organized to discuss the sustainability promise of IoT in water, energy, urban environment, and transportation areas.

1.6 IoT Definitions

In this section, the IoT definitions as conceived by different standard bodies are presented.

1.6.1 Institute of Electrical and Electronics Engineers

> A network of items, each embedded with sensors which are connected to the Internet [1].

1.6.2 International Telecommunication Union

The International Telecommunication Union Telecommunication Standardization Sector (ITU-T) has defined IoT as a vision with technological and societal implications:

> Internet of things (IoT) is a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving inter-operable information and communication technologies [36].[1]

According to this recommendation, the IoT, by using sensing and communications capabilities, utilizes things to serve different types of application needs while ensuring security and privacy. The elements (terms) of the IoT paradigm are given below [36]:

- Device. A piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, data capture, data storage, and data processing.
- Things. An object of the physical world (physical things) or the information world (virtual thing).

> An infrastructure of interconnected objects, people, systems, and information resources together with the intelligent services allow them to process information of the physical and the virtual world and react—[79].[2]

1.6.3 Internet Engineering Task Force

The Internet Engineering Task Force (IETF) excludes TCP/IP based Internet from the IoT domain because of private networks. To be considered an IoT it has to contain both IP and other protocols. IETF defines IoT as:

> The Internet of Things is the network of physical objects or "things": embedded with electronics, software, sensors, and connectivity to enable objects to exchange data with the manufacturer, operator, and/or other connected devices [34].[3]

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[1] ITU-T Rec. Y.2060 (06/2012) Overview of the Internet of things.

[2] IT4IT References Architecture—ISO/IEC JTC1 WG10.

[3] IETF.

IETF definition of “things”:

> In the vision of IoT, “things” are very various such as computers, sensors, people, actuators, refrigerators, TVs, vehicles, mobile phones, clothes, food, medicines, books, etc. These things are classified as three scopes: people, machine (for example, sensor, actuator, etc.), and information (for example, clothes, food, medicine, books, etc.). These “things” should be identified at least by one unique way of identification for the capability of addressing and communicating with each other and verifying their identities. In here, if the “thing” is identified, we call it the “object.” [34]

1.6.4 National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST) defines IoT as:

> Internet of Things (IoT)—involves connecting smart devices and systems in diverse sectors like transportation, energy, manufacturing and healthcare in fundamentally new ways. Smart Cities/Communities are increasingly adopting CPS/IoT technologies to enhance the efficiency and sustainability of their operation and improve the quality of life [48].[4]

Internet of Things Architecture (IoTIA) describes IoT in the following manner:

> It can be seen as an umbrella term for interconnected technologies, devices, objects, and services [8, 33].

1.7 Architecture of IoT Paradigm for Sustainability

The Internet of Things (IoT) for sustainability concept is based on the defining network of things and people in various environmental and natural settings goals to achieve sustainable goals. This pertains to application of IoT concepts to these

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[4] NIST.

settings using sensing and communication technologies, systems and tools tailored to various applications domains and for different use cases. The sensing elements provide the interface to physical world which and are linked through communication technologies.

1.7.1 IoT Elements

The Internet of Things for sustainability consists following elements:

- Sustainability Things. It is integral part of the IoT paradigm with the ability to have physical or virtual connection to the IoT system.
- Sensors/Actuators. An instrument/equipment for environmental, climate, forestry, water, and energy sensing. It consists interface for networking and communications, and may have on-unit processing, data storage capabilities.
- Networking and Communications. To support interconnection of sustainability things and sensors/actuators components.
- Sustainability IoT System. It consists of interconnection of different elements such as things, sensors, and communication components integrated together to perform certain unique functions,
- Holistic Sustainability IoT Paradigm. It is the paradigm in which different IoT systems work together in order to achieve sustainability goals for a particular environment These environments are shown in Fig. 1.2.

1.7.2 IoT Functions

The proper functionality of these sustainability IoT components is vital to meet requirements and achieve sustainability goals. A clear description of these sustainability goals coupled with requirement is need for integration into the holistic sustainability IoT paradigm for various applications. A detailed list of these functions along with examples is given in the following.

- In IoT, the sensing function is used to sense physical, logical, and biological properties of different environments in the physical world in the analog and digital domains. Accordingly, this data becomes as input to subsequent functions of the IoT can be used by data collection, networking, data storage, processing, and decision making functions. Examples include cloud sensing, soil sensing, and water sensing. Different examples of sensing mechanisms in various sustainability IoT sensing phenomena are discussed in detail in this book in subsequent chapters.
- The data collection is a major function of the IoT in which data is gathered, combined, and processed for a particular environment that provides the ability to combine and process some data of interest within a given IoT system.

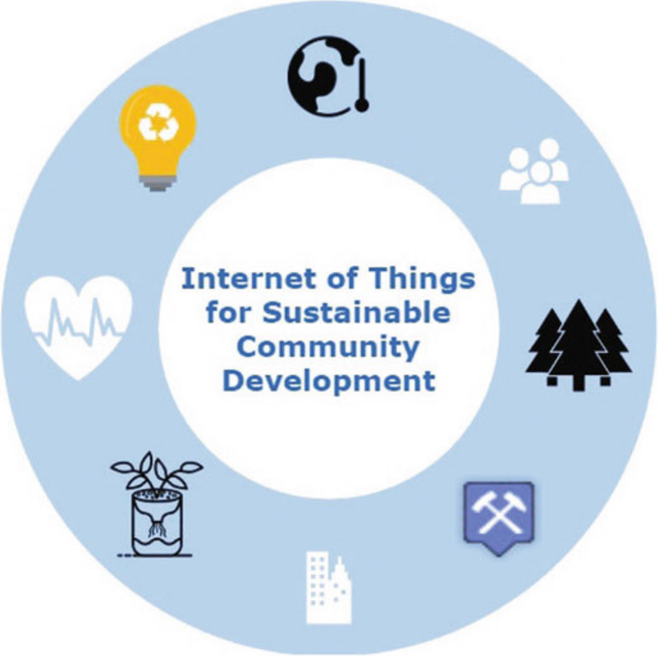


Fig. 1.2 The Internet of Things (IoT) for sustainable community development

- The networking function of the IoT is used to transport sensed data from different locations to storage location and cloud for subsequent decision making function. These could function in delay tolerant and delay sensitive fashion depending on the latency requirement of a particular sustainability paradigm. In the IoT for sustainability paradigm the networking tiers contain many layers including satellite, aerial, terrestrial, underwater, and underground networks. These network tier functions are discussed in the next section. The network interface cards are used to implement the networking and communications functions in the IoT paradigm and provide connective between links. The Ethernet adapter (IEEE 802 Standard), long-term evolution (LTE) Bluetooth, and ZigBee are some examples of these networking interface cards.
- The data storage and cloud function of the IoT are related to storing the data and information over the spatial and temporal variation. The examples of data storage functions include precipitation data, soil moisture data, hydrometer data, air temperature, wind speed and direction, water flow in different water bodies, nutrients and ion concentrations, and forest inventory.
- The processing function of the IoT converts raw sensed data to the useful information and provide it to decision making function, where it can be utilized by managers and policy makers. The center pivot control algorithms of actuator units in the sensor-guided irrigation management systems are one example of the

processing function where data is fed from underground sensors in the field of digital agriculture. Feedback control is another example.

- Decision making. In this IoT function, a decision is made based on the data collection and processing and accordingly, appropriate actions are taken which results into corresponding changes in the physical world to achieve the desired sustainability goal. Some of the examples these functions include flow control based on flow nutrients sensing, correct application of water treatment based on contaminants sensing, proper irrigation based on soil moisture sensing, cardiac treatment based on hear conditions, and fertilizer application based on the crop needs. It also includes functionality related to the human interaction with the IoT systems using graphical user interfaces, touch displays, and voice interfaces. The cybersecurity, encryption, and authentication are other functionalities.

1.8 Networking for Sustainability IoT Paradigm

The IoT for sustainable development will be deployed at large scales by using networking and advanced 5G/6G communication architectures to serve a wide variety of applications in different area. These communication networks are discussed below.

1.8.1 Five-Tier Network

The potential of current terrestrial networks is too less to support ubiquitous coverage connectivity requirement of sustainable IoT in climate, water, ocean, and energy areas. Therefore, to support these IoT paradigms, a multi-dimensional network with capability to integrate terrestrial and non-terrestrial systems is required. A five-tier network can support this integration and consists of five different tiers including space, ground, air, underwater, and underground. In Fig. 1.3, a design of multi-tier network is shown [83]. The sixth generation (6G) networks will have this capability to integrate multiple tiers which are explained below.

1.8.1.1 Terrestrial Network Tier

The terrestrial networks are the main tool to provide wireless connectivity for most of the sustainability IoT paradigms discussed in this book. Terrestrial networks will have the capability to operate in low frequencies, microwave spectrum, mm-wave, and THz bands. To support higher data rated (e.g., Tb/s), such as sustainable water and climate measurements, the THz band can be utilized. Energy-efficient mmWave communication devices based on a hybrid beamforming approach can also support real-time high-data rate communication needs. These networks will have high density deployments because of the higher attenuation in mm-wave and THz.

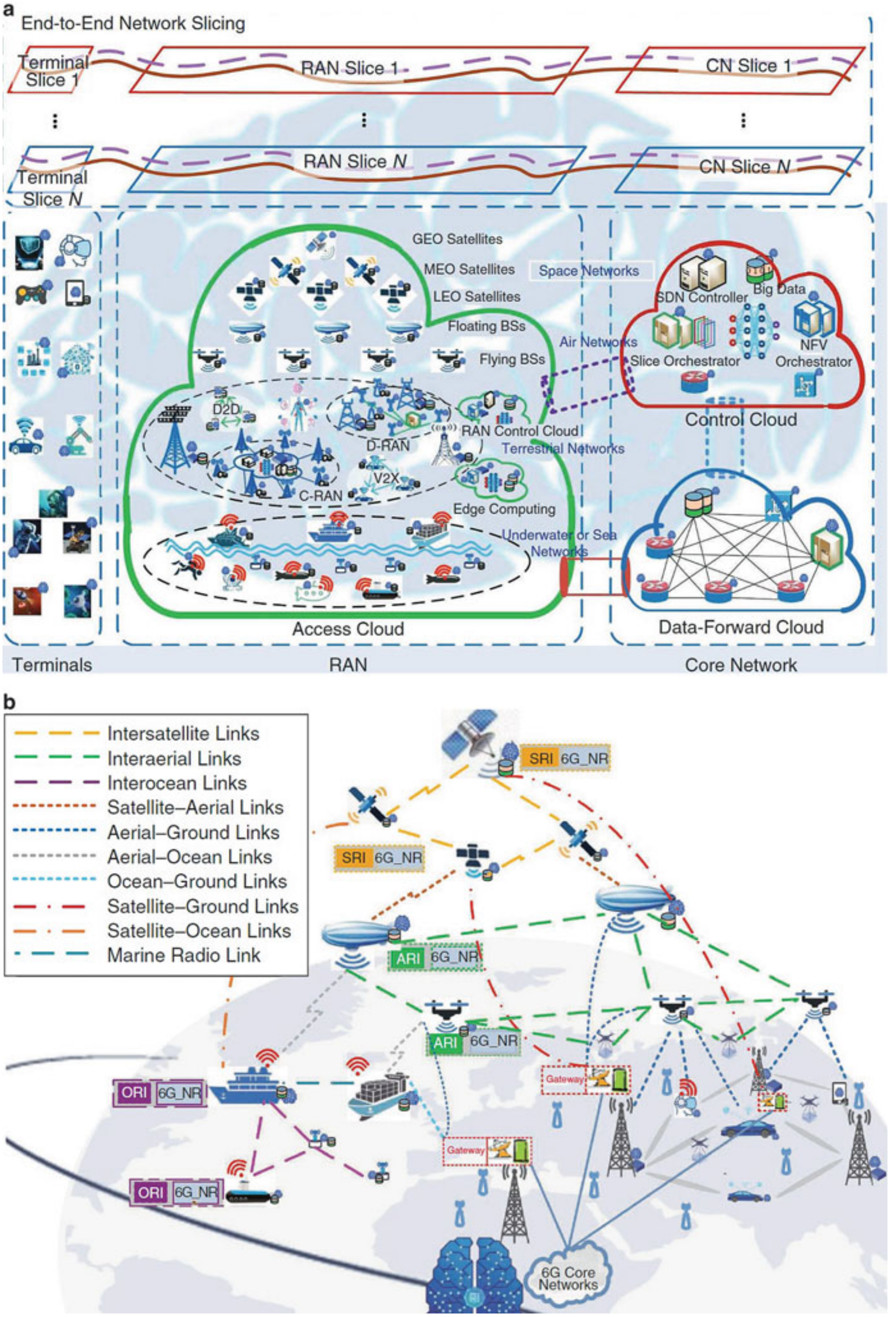


Fig. 1.3 The multi-tier network design [83]. The (**a**) network architecture and (**b**) interface design and operation of large-dimensional and autonomous networks. GEO: geostationary Earth orbit; LEO: low-Earth orbit; MEO: medium-Earth orbit; CN: core networks; D2D: device to device; C-RAN: cloud radio access networks; D-RAN: distributed radio access networks; ORI: ocean radio interface; SRI: satellite radio interface

Optical fiber is needed as backbone of these networks. The important technologies for the terrestrial networks are shown below [82]:

- The millimeter wave, Terahertz communications, full-duplex communication
- MIMO, distributed antenna arrays, DMIMO
- Interference cancellation, cognitive radio networks, NB-LPWAN
- Underwater/underground, large-scale network design, sensor networks
- Cellular networks, device-to-device, cyberphysical systems
- vehicular networks, UAV connectivity, safe UAV operation, green cellular networks
- Cyber threat defense, mobile computing, network estimation, content delivery networks
- Statistical signal processing, multimedia networking, security, and privacy
- Smart grid, cloud-fog platforms, software-defined networking, and mobile edge networking

Moreover, the conventional SDRs with novel mmWave radio can be used to create unique solutions by combine beam agility for highly directional communication in mobile environments with ultra-low-power characteristics. The design of novel low-loss hybrid electronically scanned arrays (ESA) capable of beamforming at millimeter wave (mmW) frequencies for next-generation high data-rate communications systems will be central for sustainable IoT realization.

1.8.1.2 Space-Based Wireless Network Tier

The wireless coverage requirements of the IoT for sustainability can be supported by space network by using satellites [6]. The future space network can utilize densely deployed low-medium-geostationary Earth orbit satellites to provide connectivity uncovered and undeserved area (e.g., IoT for sustainable digital agriculture). In agriculture, the irrigation and water management community has measured soil moisture to inform water management and irrigation decisions for decades. Automated technologies have largely replaced the use of hand-held/manual soil moisture technologies because of difficulties associated with taking manual soil moisture readings in production fields in remote locations.

In the last decade, wireless data harvesting technologies have developed that provide managers and users real-time access to soil moisture data, which, has resulted in more effective water management decision making. Unfortunately, advanced automated and wireless soil moisture measurement technologies still face practical application challenges. One challenge is a lack of consistent and robust wireless service in rural communities that prevent immediate access to soil moisture data. Another is the difficulty of installing soil moisture sensors early in the growing season and removing them at season end. Currently, users must drive long distances to install and remove sensors in different locations during the growing season, which creates problems in deploying advanced technologies in production fields.

Therefore, wireless underground soil moisture devices imbedded permanently in the soil, coupled with robust, reliable, and continuous wireless network services through satellites in rural agricultural communities, will significantly contribute to the adoption of technology and sustainable practices in production fields. For long-range, high data rate satellite to field communications in sustainable digital agriculture, the satellites with mm-wave communications can be deployed.

1.8.1.3 Aerial Network Tier

The recent advancements in technology have made possible to deploy air networks in low frequency bands, microwave spectrum, and mm-wave bands using aerial base stations mounted on unmanned aerial vehicles complemented by space networks. The aerial networks can enable IoT paradigms in the harsh areas where terrestrial networks are unable to provide coverage [12]. One application of aerial networks is in IoT for sustainable water where pollution level monitoring and advanced nutrient measurements are used in water bodies to assess water quality to assists regulators for pollution policy making.

Currently, the UAV potential in sustainability IoT is limited in part by their ability to navigate spaces precisely and in a cost-effective manner. The existing mechanisms to support localization are often hampered by cost (e.g., GPS-RTK), service gaps (cell towers), or crowded environments (e.g., GPS).

1.8.1.4 Underwater Network Tier

The underwater networks will enable sustainable IoT monitoring applications oceans, estuaries, rivers, lakes, streams, canals, and wetlands [7, 17, 64, 78]. Due to different wave propagation characteristics in the water medium from over-the-air (OTA), the acoustics and laser propagation can be utilized to attain higher data rates for in underwater communication and networking. It has applications in sustainable climate IoT in tsunami and undersea earthquake monitoring.

1.8.1.5 Underground Network Tier

In a new type of wireless communications (wireless underground (UG) communications) [2, 76], radios are buried underground and communication is conducted partly through the earth. The underground communication (UG) solutions are in their infancy and depend on off-the-shelf radios, which are not designed for the medium. For example, the maximum attainable communication ranges for underground-to-undeground links are limited to a few meters, which prohibits the establishment of multi-hop underground networks. On the other hand, UG radios can establish communication with aboveground devices at distances over 200 m. While promising, these distances are still limited for some applications, e.g., agricultural automation where large fields need monitoring with a limited network architecture to mobile data harvesting components [19]. In addition, the data rates attained by commercial off-the-shelf (COTS) solutions are limited to a tens of kbps, which prohibits data-hungry applications, including real-time control and navigation components.

To enhance wireless UG communication ranges, a novel theoretical framework for UG beamforming using adaptive antenna arrays to improve wireless underground communications performance [55] has been devised. A soil moisture adaptive beamforming (SMABF) algorithm was developed for planar array structures and simulations show, with different optimization approaches, range can be significantly improved. Similarly, multi-carrier underground communication through soil-adaptive sub-carrier and system bandwidth operation can significantly improve data rates [54, 57]. Currently, practical *and large-scale* evaluations of these techniques are cost prohibitive, limiting rapid commercialization for practical applications.

Underground networks support many unique applications in sustainability IoT by using wireless UG communications (e.g., stormwater and wastewater monitoring IoT and agricultural IoT). Existing over-the-air (OTA) wireless communication solutions face significant challenges in meeting the unique requirements of Ag-IoT applications. Therefore, these IoT paradigms for sustainability can use a diverse set of UG communication requirements and realistic scenarios to implement the communication range- and capacity-enhancing solutions in large scales. The integration of UG communications with Ag-IoT will help conserve water resources and improve crop yields [24, 27, 70, 74]; advances in Ag-IoT will benefit underground infrastructure and landslide monitoring, pipeline assessment, underground mining, and border patrol [3, 19, 54, 56–58, 76].

1.9 Wireless Communications for Sustainability IoT

In the following section, the key wireless communication technologies and drivers are discussed for the sustainability IoT.

1.9.1 Key Drivers for Next-Generation Wireless Systems in Sustainability IoT

- The operation frequency in the spectrum is moving from the radio bands to sub-terahertz (THz) bands and visible spectrum (e.g., visible light communications).
- The drive for automation and intelligence in wireless networks is relying on use of advanced technologies such as artificial intelligence (AI) and machine learning.

- More robust and dynamic networking architectures to meet goals of sustainable development.
- These innovations will also drive development in novel applications based on networking architectures.

1.9.2 Wireless Requirements for Sustainability IoT

The wireless communications and networking requirements for sustainability IoT requires innovation to increase data rates, capacity, connectivity, spectrum usage, energy efficiency, and mobility [23]. The key requirements are listed in the following:

- Peak Data Rates. The current peak data rates of 5G are around 10 gigabits per second (Gbps), whereas to meet sustainability IoT demands, the data rates of 1 Tb/s are required. This hundred times higher data rates demand than the current can be met by the next-generation technologies such as 6G, where the peak back-hual and front-haul data rates of 10 Tb/S can be achieved.
- Due to multitude of technologies operators vying for the scarce spectrum, spectrum efficient communications are vital for sustainability IoT. Particularity, in multi-tier networks, the same connectivity zones will be covered by multiple access network tiers, causing severe interference among tiers within in the paradigm. Therefore, advancement in interference mitigation, suppression, and cancellation techniques are required. Integration of licensed and unlicensed technologies (e.g., short-range Wi-Fi and long-range cellular) is also necessary to connect all sustainability things in different IoT applications.
- Application Specific Data Rates. For some scenarios, such hyper-spectral mineralogy sensing techniques, application specific data rates of 1–10 10 Gb/s rates are required.
- Extreme energy efficient technology and devices are required to support prolonged uninterrupted operation in some of the sustainability IoT scenarios such as urban underground infrastructure monitoring, storm and sewer overflow monitoring, and underground soil sensing. For example, IoT devices can awake from the sleep mode for data reception after periods of longer duration to extend battery life.
- Latency and Mobility. To archive quality of service (QOS), an OTA latency of 0.01–0.1 ms and extremely high mobility (621 miles/h) is required for sustainability IoT paradigm. More, low latency space-to-air and space-to-ground links are needed.
- Novel gateways, protocols, and standards are required to integrate different network tiers. One example of this link is interconnection between IoT devices in aerial networks and sensors in underground and underwater networks. Other examples include aerial to ground stations, space to aerial to ground. Things to people interaction gateways can utilize computer vision, always-on discovery and

awareness, and machine learning. Moreover, advancements in Things-to-Things (T2T) communication technologies are needed.

- Connectivity Density. For water climate monitoring IoT applications, a very high density of approximately 145 devices/mi^2 and with subnetwork capacity of more than 1 Gb per second per square mile. This will help to attain interoperability across multiple sustainability paradigms.
- Cybersecurity. It is discussed in detail in Chap. 10.

1.9.3 Wireless Standard Applications to Sustainability IoT

1.9.3.1 RF Wireless Modem Chipset

The chipset with ability to support multiple wireless and cellular standards will play cortical role to achieve the regional and local connectivity in different applications in sustainability IoT paradigm (e.g., health, security, and energy). In this regard, innovations are needed to produce cost-effective and scalable RF wireless modem chipset design [52]. Any such chipset will support multiple bands and modes with power saving, battery life for up to a decade through advanced power saving with Bluetooth, voice, and Wi-Fi interfaces with backward compatibility. Other important wireless interfaces include GSM, LTE FDD and TDD, EDGE/EGPRS, DC-HSPA, LR-WPAN, and TD-SCDMA. AllJoyn Open Connectivity Foundation (OCF) is an open source framework inter- interface/device/application secure communication protocol supports discovery of devices manufactured by different vendors.

1.9.4 Standardization for Sustainability IoT

1.9.4.1 Long-Term Evolution (LTE) IoT

The long-term evolution (LTE) is an enabler for high performance and scalable sustainability IoT services can provide high data rate (Gigabit) [46]. It has high energy and power efficiency to address sustainability IoT needs. It combines improved machine type communication (eMTC Cat-M1) and the narrowband IoT (NB-IoT) for narrowband applications (Cat-NB1) and supports grant-free uplink, and multi-hop mesh. The low complexity, long range, and low power communications in sustainability IoT can be supported by using NB-IoT and eMTC (e.g., agriculture, wearable, health, smart meters, and climate). The LTE Direct is a device-to-device (D2D) protocol that uses LTE user authentication, resource allocation and timing features to provide neighbor discover, and connectivity to mobile nodes in the node proximity.

1.9.4.2 802 Wi-Fi Standards

The Wi-Fi has the great potential to provide connectivity to many IoT devices and things to achieve sustainability. These 802.11 Wi-Fi standards which can be utilized for sustainability IoT are shown below [31]:

- 802.11ah for low power operation in the 902–928 MHz frequency bands
- 802.11ac for 5 GHz spectrum unlicensed uses
- 802.11ad for WiGig networking
- 802.11ay for 60 GHz unlicensed uses
- 802.11ax for dense networking environment

Many important alliances include: HomePlug Alliance [49], Bluetooth Special Interest Group (Bluetooth SIG) [11], Open Connectivity Foundation (OCF) [43], the Thread Group [40], the Powerline technologies, and oneM2M. In a recent trail of high data rate communications, it has been shown that it is possible to achieve 100 Gb/s in microwave spectrum using multiple-input, multiple-output (MIMO) for a communication range of approximately 1 mile. This trial has shown the feasibility of better communications in microwave as compared to the millimeter (mm-wave) communications [81]. The important trial parameters are: 8 × 8 LOS MIMO, 2.5 GHz channel bandwidth in the 70 and 80 GHz (E band) with high spectrum efficiency of 55.19 b/s/Hz. Recently, an autonomous unmanned broadband smart surface vessel was operated remotely using 4G network for water quality and pollutants sensing.

1.9.4.3 5G and 6G Wireless Communications

Currently, the 5G communications [22] are envisioned as big technology driver for the Internet of Things particular for sustainable community development (e.g., smart cities, public safety, transportation, smart energy usage, connected and autonomous vehicles, and health care). Through its better than 4G speeds, energy and spectrum efficiency, low latency and higher reliability, the 5G wireless networking the vital to realize sustainability IoT and its real-time data-intensive communication needs in applications such real-time video streaming for police body cams and medical imaging.

Currently, there are many challenges in 5G. Although in 5G, the ultra-reliable, low latency communications (URLLC) [69] has the potential to support sustainability IoT applications, its performance suffers from the small packet size issues that is a limiting factor for higher data rates. More, the support for sensing, communications, things, and system convergence is limited in 5G and more improvements are needed in this area. Another needed feature in regard to IoT the support for visualization the radio access network (vRAN) due to front-haul challenges. Moreover, in 5G dynamic pricing models are needed based on capacity and usage. The limitations of slow data rates, convergence of IoT sensing, systems,

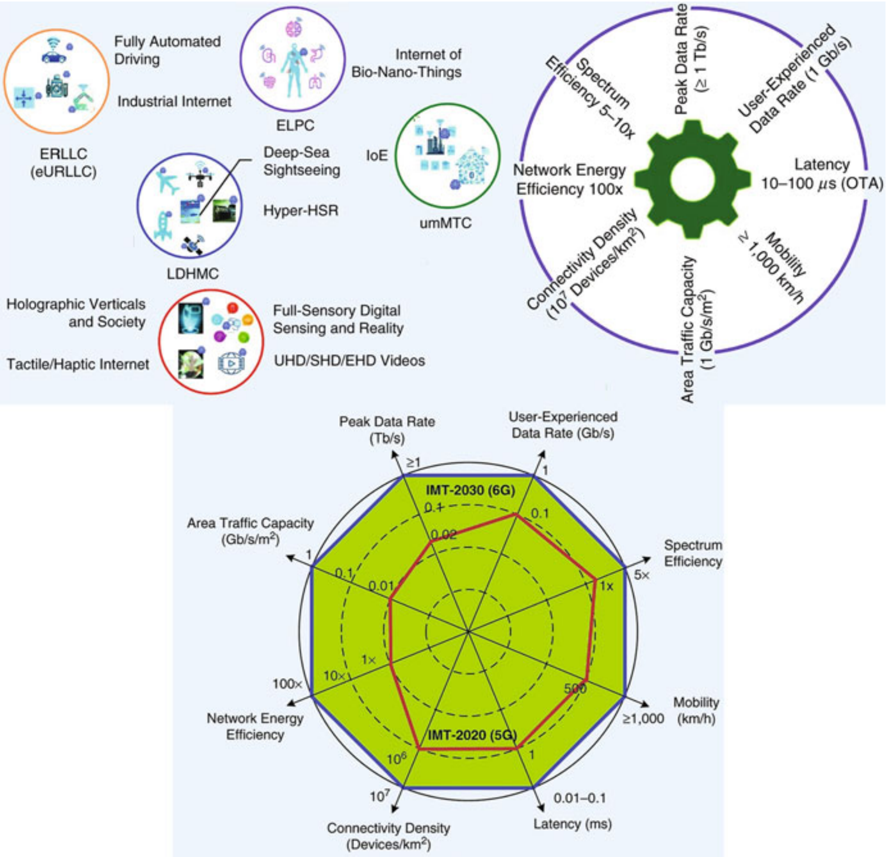


Fig. 1.4 The 6G application scenarios [83]. (**a**) The 6G application scenarios, (**b**) typical scenarios and (**c**) key capabilities of 6G networks

and wireless communication, and open interfacing related issues can be solved with novel networking architectures of 6G wireless communications which is discussed next (Fig. 1.4).

The road-map to 6G wireless communications has already started to take shape. The requirements and trends are being defined with 6G enabling technologies for connected intelligence and things. The prominent 6G goals and desirable features are listed below [83].

- Support of extremely high data rates (in Tb/S) as compared to current 4G wireless communications
- High energy efficiency, energy harvesting, and wireless power transfer to support IoT
- The ultra-low latency in data and control planes in few microseconds

- Support for a very wide spectrum in GHz and THz bands such as from 72 GHz to 141 GHz and 1000 GHz to 3000 GHz,
- Convergence of space and ground based wireless networks to provide global connectivity and coverage
- Intelligence built into the network through machine learning, enhanced mobile broadband (eMBB) [44] ultra-reliable, low latency communications (URLLC) [69], and massive machine-type communications (mMTC) [50].

1.9.5 Artificial Intelligence and Wireless

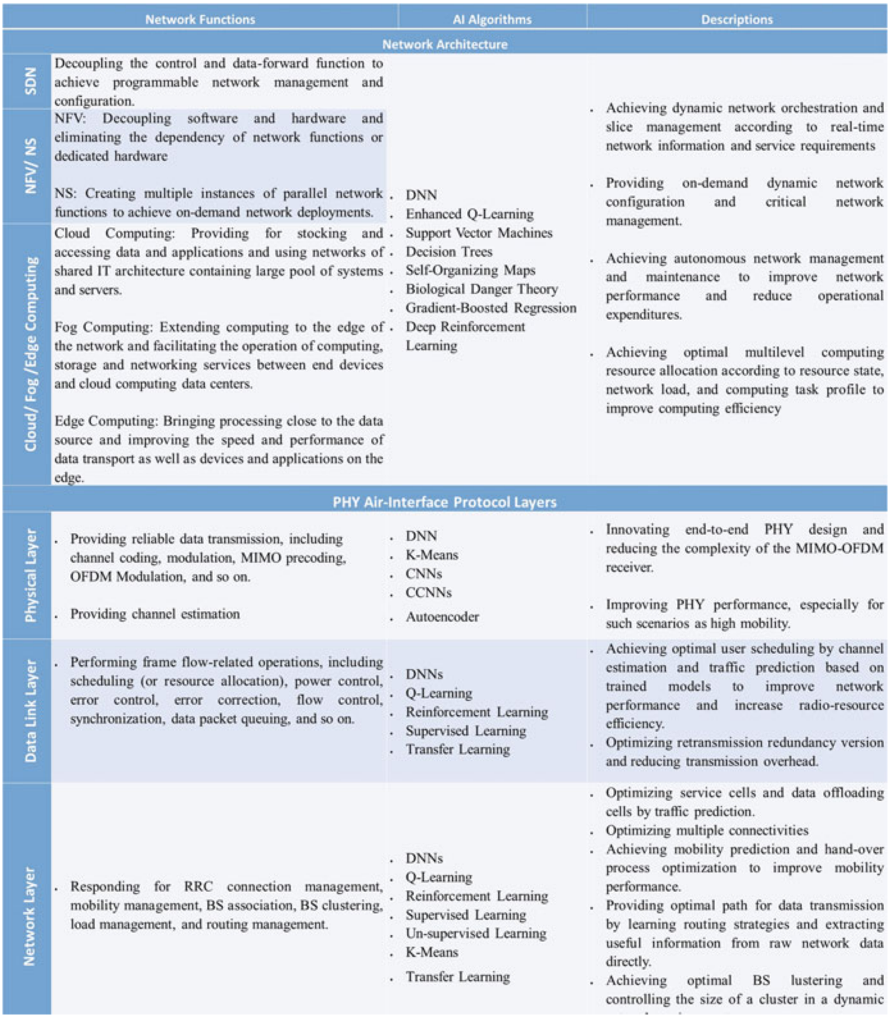
The artificial intelligence (AI) will play a key role in optimization and autonomous functionality of the network [80]. A list of AI algorithms in networking is shown in Fig. 1.5. The AI enabling technologies in wireless communications are discussed below:

- Application of AI training methods specifically the machine learning in wireless communications will bring innovation and performance improvements. This can be achieved intelligence management and autonomous agent.
- The neural networks based deep learning for data driven approaches in wireless.
- AI applications to address network management, complexity, and QoS issues in next-generation wireless networks.

1.9.6 Wireless Spectrum Paucity

The wireless spectrum scarcity is major challenge for heterogeneous wireless systems. The demand for wireless spectrum to meet the needs of sustainability IoT applications is increasing which could be met the identification and allocation of additional spectrum. Spectrum sharing through cognitive radios is another approach to address the issue of dearth of spectrum where unlicensed users can use the spectrum when the primary user is not present in the licensed spectrum. The efforts of the United States Federal Communications Commission (FCC) to address this issue through rulemaking are presented below [21, 73]:

- Use of Spectrum Bands Above 24 GHz For Mobile Radio Services
- Establishing a More Flexible Framework to Facilitate Satellite Operations in the 27.5–28.35 GHz and 37.5–40 GHz Bands
- Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42–43.5 GHz Band
- Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42–43.5 GHz Band



Network Functions		AI Algorithms	Descriptions
Network Architecture			
SDN	Decoupling the control and data-forward function to achieve programmable network management and configuration.	DNN Enhanced Q-Learning Support Vector Machines Decision Trees Self-Organizing Maps Biological Danger Theory Gradient-Boosted Regression Deep Reinforcement Learning	Achieving dynamic network orchestration and slice management according to real-time network information and service requirements Providing on-demand dynamic network configuration and critical network management. Achieving autonomous network management and maintenance to improve network performance and reduce operational expenditures. Achieving optimal multilevel computing resource allocation according to resource state, network load, and computing task profile to improve computing efficiency
NFV/ NS	NFV: Decoupling software and hardware and eliminating the dependency of network functions or dedicated hardware NS: Creating multiple instances of parallel network functions to achieve on-demand network deployments.		
Cloud/ Fog /Edge Computing	Cloud Computing: Providing for stocking and accessing data and applications and using networks of shared IT architecture containing large pool of systems and servers. Fog Computing: Extending computing to the edge of the network and facilitating the operation of computing, storage and networking services between end devices and cloud computing data centers. Edge Computing: Bringing processing close to the data source and improving the speed and performance of data transport as well as devices and applications on the edge.		
PHY Air-Interface Protocol Layers			
Physical Layer	Providing reliable data transmission, including channel coding, modulation, MIMO precoding, OFDM Modulation, and so on. Providing channel estimation	DNN K-Means CNNs CCNNs Autoencoder	Innovating end-to-end PHY design and reducing the complexity of the MIMO-OFDM receiver. Improving PHY performance, especially for such scenarios as high mobility.
Data Link Layer	Performing frame flow-related operations, including scheduling (or resource allocation), power control, error control, error correction, flow control, synchronization, data packet queuing, and so on.	DNNs Q-Learning Reinforcement Learning Supervised Learning Transfer Learning	Achieving optimal user scheduling by channel estimation and traffic prediction based on trained models to improve network performance and increase radio-resource efficiency. Optimizing retransmission redundancy version and reducing transmission overhead.
Network Layer	Responding for RRC connection management, mobility management, BS association, BS clustering, load management, and routing management.	DNNs Q-Learning Reinforcement Learning Supervised Learning Un-supervised Learning K-Means Transfer Learning	Optimizing service cells and data offloading cells by traffic prediction. Optimizing multiple connectivities Achieving mobility prediction and hand-over process optimization to improve mobility performance. Providing optimal path for data transmission by learning routing strategies and extracting useful information from raw network data directly. Achieving optimal BS lustering and controlling the size of a cluster in a dynamic

Fig. 1.5 AI algorithms in networking [83]

- Allocation and Designation of Spectrum for Fixed-Satellite Services in the 37.5–38.5 GHz, 40.5–41.5 GHz, and 48.2–50.2 GHz Frequency Bands
- Allocation of Spectrum to Upgrade Fixed and Mobile Allocations in the 40.5–42.5 GHz Frequency Band
- Allocation of Spectrum in the 46.9–47.0 GHz Frequency Band for Wireless Services
- Allocation of Spectrum in the 37.0–38.0 GHz and 40.0–40.5 GHz for Government Operations

1.9.7 Rural Broadband Telecommunications

The broadband infrastructure is vital for the proper functionality of sustainability IoT. In rural areas, there are many challenges being faced by the service providers (e.g., network extension to under covered areas, need of infrastructure upgrades to meet increasing demand) [51]. Rural broadband is important to provide connectivity to agricultural users and things.

1.9.8 Satellite Communications

The satellite communications also play an important role to provide connectivity to the sustainability IoT paradigm things. A Global Low Power Wide Area Network (LPWAN) to support IoT devices around the world by combining the Inmarsat's global connectivity as backhaul connectivity and Actility' s LoRaWAN technology. Various applications are enabled by this network such cattle tracking systems for remote ranches, water and soil moisture monitoring in agriculture, and remote oil facility monitoring in areas where cellular coverage does not exist. Other sustainability IoT applications that can benefit from satellite communications include smart grid, underground and surface pipeline monitoring, vehicular fleet tracking, water resource management, disaster response, remote and critical infrastructure monitoring, environmental protection, wind turbine monitoring, and border security.

1.10 Organization of the Book

The book covers the research and innovation ecosystem of the sustainable Internet of Things in the following major areas:

- Climate change
- Sustainable energy systems
- Sustainable water
- Human health
- Sustainable mining
- Decision agriculture
- Storm and wastewater
- Sustainable forestry

While each of these areas will emphasize a core IoT research challenges and solutions while leveraging their shared traits, interdependencies, and expertise to converge on applications of IoT to sustainability challenges. In the following, we highlight the above mentioned areas each with a collection of supporting concepts that are developed and explored in this book. Many of these areas emphasize cross cutting activities that support major cohesive goal of sustainability.

Chapter 2: Internet of Things for Environmental Sustainability and Climate Change Our world is vulnerable to climate change risks such as glacier retreat, rising temperatures, more variable and intense weather events (e.g., floods, droughts, frosts), deteriorating mountain ecosystems, soil degradation, and increasing water scarcity. However, there are big gaps in our understanding of changes in regional climate and how these changes will impact human and natural systems, making it difficult to anticipate, plan, and adapt to the coming changes. The IoT paradigm in this area can enhance our understanding of regional climate by using technology solutions, while providing the dynamic climate elements based on IoT sensing and communications that is necessary to support climate change impacts assessments in each of the related areas (e.g., environmental quality and monitoring, sustainable energy, agricultural systems, cultural preservation, and sustainable mining). In the IoT in Environmental Sustainability and Climate Change chapter, a framework for informed creation, interpretation and use of climate change projections and for continued innovations in climate and environmental science driven by key societal and economic stakeholders is presented.

Chapter 3: Internet of Things in Agricultural Innovation and Security The agricultural Internet of Things (Ag-IoT) paradigm has tremendous potential in transparent integration of underground soil sensing, farm machinery, and sensor-guided irrigation systems with the complex social network of growers, agronomists, crop consultants, and advisors. The aim of the IoT in agricultural innovation and security chapter is to present agricultural IoT research and paradigm to promote sustainable production of safe, healthy, and profitable crop and animal agricultural products. The chapter covers the IoT platform to test optimized management strategies, engage farmer and industry groups, and investigate new and traditional technology drivers that will enhance resilience of the farmers to the socio-environmental changes. A review of state-of-the-art communication architectures, and underlying sensing technology and communication mechanisms has been presented with coverage of recent advances in the theory and applications of wireless underground communication. Major challenges in Ag-IoT design and implementation are also discussed.

Chapter 4: Internet of Things for Water Sustainability The water is a finite resource. The issue of sustainable withdrawal of freshwater is a vital concern being faced by the community. There is a strong connection between the energy and water which is referred as energy-water nexus. The agriculture industry and municipalities are struggling to meet the demand of water supply. This situation is particularly exacerbated in the developing countries. The projected increase in world population requires more fresh water resources. New technologies are being developed to reduce water usage in the field of agriculture (e.g., sensor guided autonomous irrigation management systems). Agricultural water withdrawal is also impacting ground and surface water resources. Although the importance of reduction in water usage cannot be overemphasized, major efforts for sustainable water are directed towards the novel technology development for cleaning and recycling. Moreover, currently, energy technologies require abundant water for energy production. Therefore, energy sustainability is inextricably linked to water sustainability. The water sustainability IoT has a strong potential to solve many challenges in energy-water nexus. In this chapter, the architecture of IoT for water sustainability is presented. An in-depth coverage of sensing and communication technologies and water systems is also provided.

Chapter 5: Internet of Things for Sustainable Forestry Forests and grasslands play an important role in water and air purification, prevention of the soil erosion, and in provision of habitat to wildlife. Internet of Things has a tremendous potential to play a vital role in the forest ecosystem management and stability. The conservation of species and habitats, timber production, prevention of forest soil degradation forest fire prediction, mitigation, and control can be attained through forest management using Internet of Things. Use and adoption of IoT in forest ecosystem management are challenging due to many factors. Vast geographical areas and limited resources in terms of budget and equipment are some of the limiting factors. In digital forestry, IoT deployment offers effective operations, control, and forecasts for soil erosion, fires, and undesirable depositions. In this chapter, IoT sensing and communication applications are presented for digital forestry systems. Different IoT systems for digital forest monitoring applications are discussed.

Chapter 6: Internet of Things in Sustainable Energy Systems Our planet has abundant renewable and conventional energy resources but technological, capability and capacity gaps coupled with water-energy needs limit the benefits of these resources to citizens. Through IoT technology solutions and state-of-the-art IoT sensing and communications approaches, the sustainable energy-related research and innovation can bring a revolution in this area. Moreover, by the leveraging current infrastructure, including renewable energy technologies, microgrids and power to gas (P2G) hydrogen systems, the Internet of Things in sustainable energy systems can improve challenges in energy security to the community with a minimal trade off to environment and culture. In this chapter, the IoT in sustainable energy systems approaches, methodologies, scenarios, and tools is presented with detailed discussion of different sensing and communications techniques. This IoT approach in energy systems is envisioned to enhance the bidirectional interchange of network services in grid by using Internet of Things in grid that will result in enhanced system resilience, reliable data flow, and connectivity optimization. Moreover, the sustainable energy IoT research challenges and innovation opportunities are also discussed to address the complex energy needs of our community and promote a strong energy sector economy.

Chapter 7: Internet of Things for Sustainable Human Health The sustainable health IoT has the strong potential to bring tremendous improvements in human health and well-being through sensing, monitoring, of health impacts across the whole spectrum of climate change. The sustainable health IoT enables development of a systems approach in the area of human health and ecosystem. It allows integration of broader health sub-areas in a bigger archetype for improving sustainability in health in the realm of social, economic, and environmental sectors. This integration provides a powerful health IoT framework to sustainable health and community goals in the wake of changing climate. In this chapter, a detailed description of climate related health impacts on human health is provided. The sensing, communications, and monitoring technologies are discussed. The impact of key environmental and human health factors on the development of new IoT technologies is analyzed.

Chapter 8: Internet of Things for Sustainable Mining The sustainable mining Internet of Things deals with the applications of IoT technology to the coupled needs of sustainable recovery of metals and a healthy environment for a thriving planet. In this chapter, the IoT architecture and technology is presented to support development of a digital mining platform emphasizing the exploration of rock-fluid-environment interactions to develop extraction methods with maximum economic benefit, while maintaining and preserving both water quantity and quality, soil, and, ultimately, human health. New perspectives are provided for IoT applications in developing new mineral resources, improved management of tailings, monitoring and mitigating contamination from mining, and tools to assess the environmental and social impacts of mining including the demands on dwindling freshwater resources. The cutting-edge technologies that could be leveraged to develop state-of-the-art sustainable mining IoT paradigm are also discussed.

Chapter 9: Internet of Things in Water Management and Treatment The goal of the water security IoT chapter is to present a comprehensive and integrated IoT based approach to environmental quality and monitoring by generating new knowledge and innovative approaches that focus on sustainable resource management. Mainly, this chapter focuses on IoT applications in sewer and storm water management, and the human and environmental consequences of water contaminants and their treatment. The IoT applications using sensors for sewer and storm water monitoring across networked landscapes and water quality assessment, treatment, and sustainable management are presented. The studies of rate limitations in biophysical and geochemical processes that support the ecosystem services supporting water quality are presented and the application of IoT solutions based on these discoveries is discussed.

Chapter 10: Internet of Things for Sustainability: Perspectives in Privacy, Cybersecurity, and Future Trends In the sustainability IoT, the cybersecurity risks to things, sensors, and monitoring systems are distinct from the conventional networking systems in many aspects. The interaction of sustainability IoT with the physical world phenomena (e.g., weather, climate, water, and oceans) is mostly not found in the modern information technology systems. Accordingly, the actuation, the ability of these devices to make changes in real world based on sensing and monitoring, requires special consideration in terms of privacy and security. Moreover, the energy efficiency, safety, power, performance requirements of these device distinguish them from conventional computers systems. In this chapter, the cybersecurity approaches towards sustainability IoT are discussed in detail. The sustainability IoT risk categorization, risk mitigation goals, and implementation aspects are analyzed. The openness paradox and data dichotomy between privacy and sharing is analyzed. Accordingly, the IoT technology and security standard developments activities are highlighted. The perspectives on opportunities and challenges in IoT for sustainability are given. Finally, the chapter is concluded with sustainability IoT cybersecurity case studies.

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