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Green Internet of Things (IoT): An Overview

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***Abstract*—Internet of Things (IoT) connects everything in the smart world, and thus, energy consumption of IoT technology is a challenge and attractive research area. Motivated by achieving a low power consumption IoT, a green IoT is proposed. This paper provides an overview regarding green IoT. It also discusses the life cycle of green IoT which contains green design, green production, green utilization, and green recycling. Furthermore, green IoT technologies such as green tags, green sensing networks and green internet technologies are discussed. In addition, studies of IoT in 5G and IoT for smart cities are presented. Finally, future research directions and open challenges about green IoT are presented.**

***Index Terms*—Internet of Things (IoT), green IoT, 5G, wireless sensor networks, cloud computing, smart cities, energy efficiency.**

I. INTRODUCTION

During the past decade, the energy consumption levels have reached distressing rates due to the large scale of digital context, number of subscribers, and the number of devices. The rise in the number of connected devices will be up to 50 billion by 2020 [1] and 100 billion by 2030 [2]. Therefore, scientists expect a tremendous data rate and a huge content-size (10,000 times more in 2030, than it was in 2010) at the price an exceptional carbon emissions into the environment. In [3], it has shown that the amount of carbon dioxide (CO_2) emissions from the cellular networks will be 345 million tons by 2020 and it is expected to increase in the later years. A projection of total emissions by 2020 is provided in [4]. Due to this tremendous (CO_2) emissions, environment and health concerns, a renewable or green technology is becoming an attracting research area in the evolution of technology. In addition, current battery technology of devices is another major concern which leads to a green technology [5].

Experts expect that the fifth generation (5G) of wireless communications (5G) will be available in 2020, and it will be able to handle about 1000 times more mobile data than todays cellular systems [6]. As shown in Fig. 1, There are five efficient technologies of 5G network. Device-to-Device (D2D) communication boosts the reliability of communication between the users by latency reduction. In addition, the UDNs involve dense small cell deployment, in areas with enormous traffic. Besides that the massive MIMO supports hundreds of antennas and providing a high data rate. The role of spectrum sharing is to avoid low spectrum utilization efficiency and the role of IoT is to connect billions of users in a short time period with high efficiency. This five efficient technologies should allow minimization of energy usage of the coming 5G networks to eliminate the (CO_2) emissions.

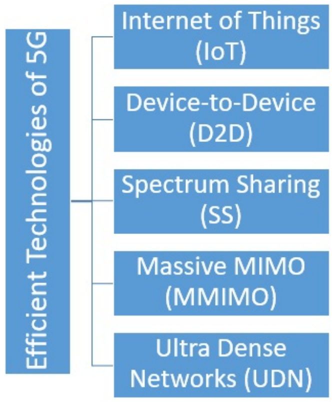

Fig. 1. Efficient Technologies of 5G

The main objective of this paper is to provide an overview of green IoT in terms of concepts, applications, technologies and challenges. Section II describes the basic concepts of IoT and its demands. Section III presents the life cycle of green IoT. Section IV discusses the required technologies for green IoT. Section V discusses the IoT in 5G. Section VI presents the IoT for smart cities. Section VII presents challenges and future research directions of green IoT. Finally, Section VIII concludes the paper.

II. INTERNET OF THINGS

The term ”Internet of Things” was firstly proposed by Kevin Ashton in a presentation in 1998 [7] where he mentioned that *”The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so”*. In 2001, the MIT Auto-ID centre introduced their IoT vision [8]. In 2005, the IoT term was formally used by the International Telecommunication Union (ITU) [9].

Last decade, Internet of Things (IoT) has been considered as one of the charming technologies. It allows people and things to be connected anywhere, anytime, with anyone and anything, using any link and any service. It offers a platform for sensors and devices to be connected seamlessly within a smart environment in order to provide advanced and intel-

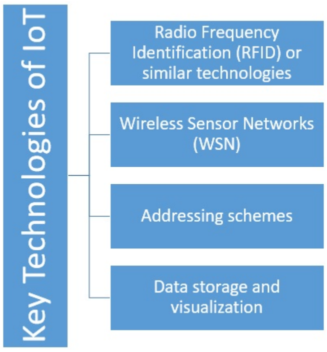

Fig. 2. Key Technologies of IoT

ligent services for human-beings. Figure 2 presents the key technologies needed in IoT where sensors and devices sense and collect all kinds of data about the target and then, the data can be further processed and analyzed to extract a useful information to enable intelligent services. In general, there are four main elements in IoT technology:

- Internet: to provide anytime, anywhere communication between everything. It contains the cloud computing, smart web services, and IP for smart objects.
- Hardware: the embedded communication hardware such as sensors, tags, actuators and transceivers.
- Middleware: for data storage, computing, and context-awareness.
- Presentation: to understand visualization and interpretation tools for different platforms and applications.

As shown in Fig. 3, there are different applications of IoT such as, data management, analytic, visualization, heterogenous network management, application development and research purposes. Figure 4 shows a beautiful infographic comprising smart cities and IoT applications proposed by Libelium World [10]. It is clear that the verticals that are changing with the IoT and understand why it is the next technological revolution.
However, the research into the IoT is still in its infancy and there are many key challenges needed to be addressed such as the battery life concerns [23][24][25], the technology simplicity [14], [21], [26], data and context-awareness [27], [28][29][30], privacy and security concerns [31][22], multiple active things and interference-free connectivity [21], the cost of terminal devices [32], scalability [21][33], and heterogeneous terminal devices matter [34].
The Internet Of Things (IoT) is an ecosystem which is not only a network to transfer data, but also interconnected with Big Data and Cloud Computing to provide intelligence, in order to be able to recognize the behaviors, and even explain actions according to the information captured by the smart objects that are available around the emerging smarter cities without human requiring human-to-human or human-to-computer interaction [15]. IoT ecosystem architecture is shown in Figure 5, where the received data from the Smarter Cities is integrated into the Cloud Computing. The presented flow enables the interaction between the cloud and the humans,

Fig. 3. Applications of IoT

who is starting to be more actives (prosumers) [16]. The cloud computing system is responsible of the centralization of the data of each sensor and object. It also allows them to to interact and communicate through the creation of an ubiquitous network. Moreover, it solves the interconnection problem. The cloud is also enabling the integration of Big Data analysis in order to reach an understanding that allows the determination of human dynamics patterns. Finally, human dynamic pattern provides the tools and feedback mechanisms in order to inspire the change of the behaviors [16], [22].

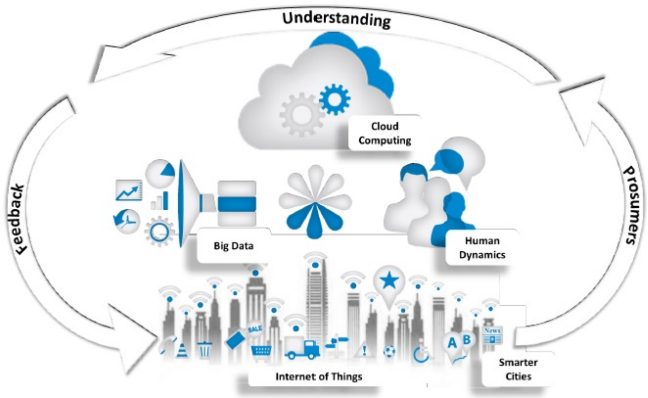

Fig. 5. IoT Ecosystem [16]

III. Green IoT

The internet of Things (IoT) contains the enormous expected growth network usage and the number nodes in the future. Therefore, there is a need to reduce the resources for implementing all network elements and the energy consumed for their operation. Energy consumption is becoming a state-of-art in order to achieve a green IoT reliability and smart

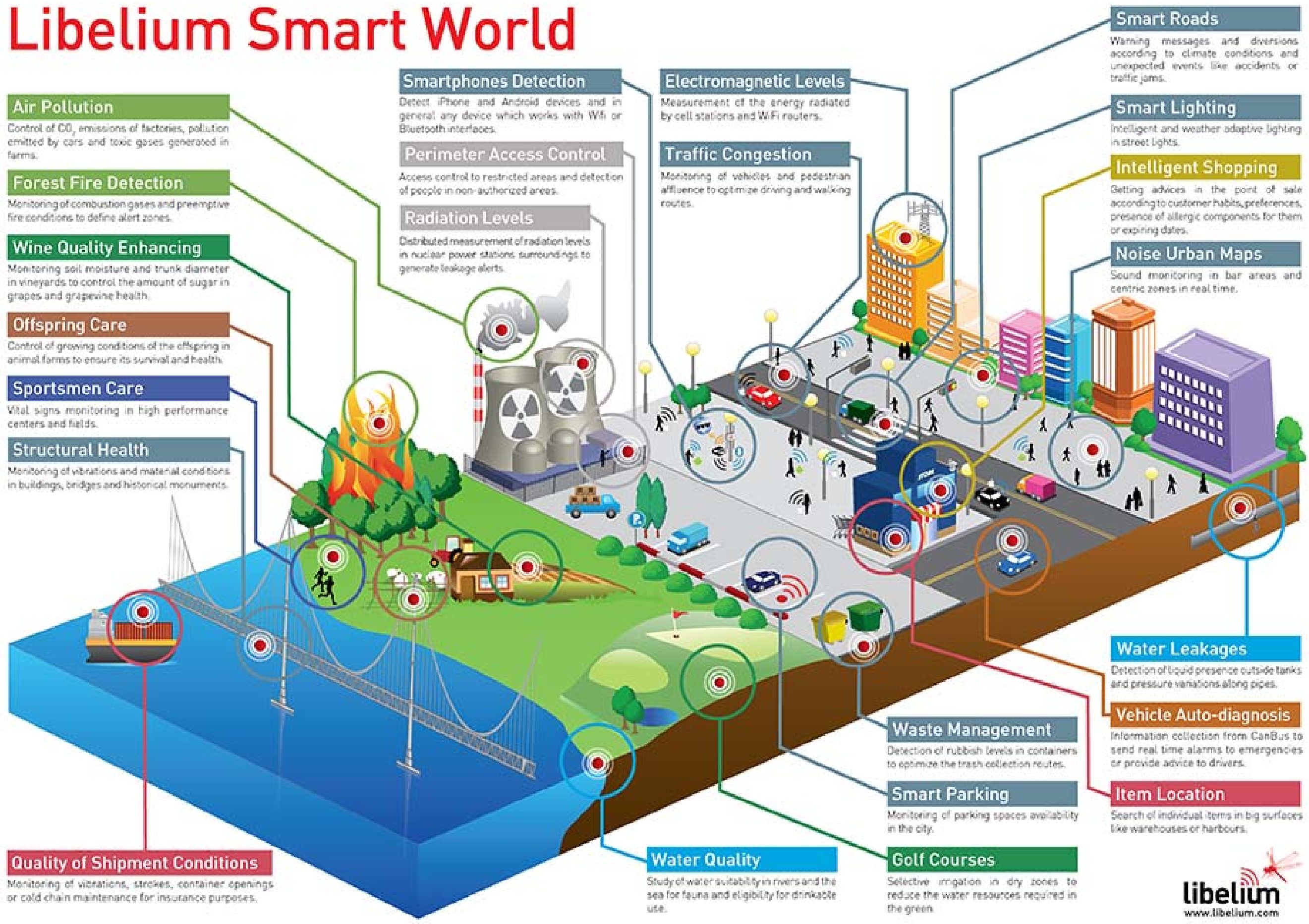

Fig. 4. Applications of IoT: Libelium smart world [10]

world implementation. In order to have a sustainable smart world, the IoT should be depicted by energy efficiency to reduce the greenhouse effects and carbon dioxide (CO_2) emissions of sensors, devices, applications and services.
Fig. 6 presents the life cycle of green IoT which takes into consideration the green design, green production, green utilization and finally green disposal and recycling to have minimal or no impact on the environment [35].

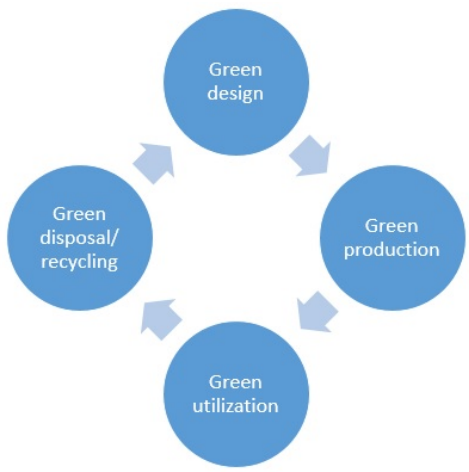

Fig. 6. Life cycle of green IoT

IV. TECHNOLOGIES FOR GREEN IOT

Towards green IoT, several green technologies should be included such as green RFID tags, green sensing network and green cloud computing network. Figure 7 shows the key technologies to accomplish a green IoT system.
Radio Frequency Identification (RFID) is a small electronic device that includes several RFID tags and a very small tag readers. RFID tags can store information regarding the objects to which they are linked. In general, the transmission range of RFID systems is a few meters. There are two kinds of RFID tags named as active tags and passive tags. The active tags have batteries to continuously transmit its own signal while the passive tags does not have its own battery. Instead of onboard battery, the passive tags need harvest energy from the reader signal. To achieve the goal of green RFID, several research efforts have been done. As shown in Table I, one

TABLE I
CHRONOLOGY OF RESEARCH ACTIVITIES IN GREEN RFID

Year	Summary of the research	Reference
2008	Proposed biodegradable RFID tags for healthcare field	[11]
2010	Proposed three protocols to maximize energy savings at the reader by reducing collisions among tag responses	[13]
2011	Proposed an energy-efficient RFID inventory algorithm called automatic power stepping (APS) based on tag response states and variable slot lengths	[17]
2012	Proposed two energy-efficient probabilistic estimation algorithms to reduce the energy consumed by active tags	[12]
2013	Proposed a low-cost RFID tags with printing technologies in order to achieve eco-friendly tag antennas	[19]
2014	Proposed Reservation Aloha for No Overhearing (RANO) to inform a tag of its effective communication intervals, thus, eliminating overhearing problem in active RFID	[18]
2017	Proposed a size reduction of RFID by using minimal amount of nondegradable material in their manufacturing	[14]

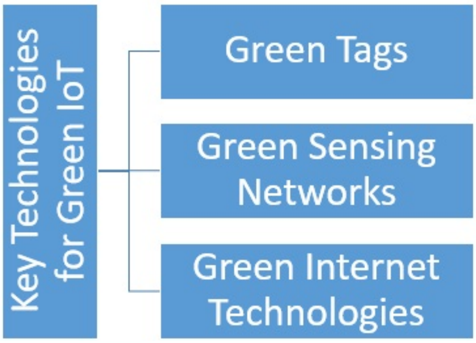

Fig. 7. Key technologies for green IoT

of the proposed solution is to reduce the size of RFID tags and, thus, minimize the amount of nondegradable material. Also printable RFID tags are proposed.In addition, different protocols are proposed to achieve an energy-efficient RFID tags. In addition, a green wireless sensor network (WSN) is another key technology to enable green IoT. Wireless sensor network (WSN) contains a tremendous number of sensor nodes with limited power and storage capacity. To achieve green WSN, different techniques should be considered:

- The sensor uses energy for the required activity and then is placed into idle or sleep mode.
- Use renewable energy for charging and utilization purposes. In addition, kinetic energy and vibrations can be used.
- Use energy-efficient optimization techniques.
- Use data and context-awareness algorithms to reduce the data size and thus, reduce the storage capacity.
- Use energy-efficient routing techniques to reduce the mobility power consumption.

For green internet technology, hardware and software consideration should be taken into consideration where hardware solution manufactures devices that consume less energy without a reduction of the performance. On the other hand, the software solutions offer efficient designs that consume less energy by minimum utilization of the resources. In addition, power-saving virtual machine techniques should be implemented.
As shown in Fig. 8, with respect to green IoT technology, there are a lot of applications and services. It consists smart cities, smart energy and smart grid systems, smart infrastructure, smart factory, smart medical systems and smart logistics.

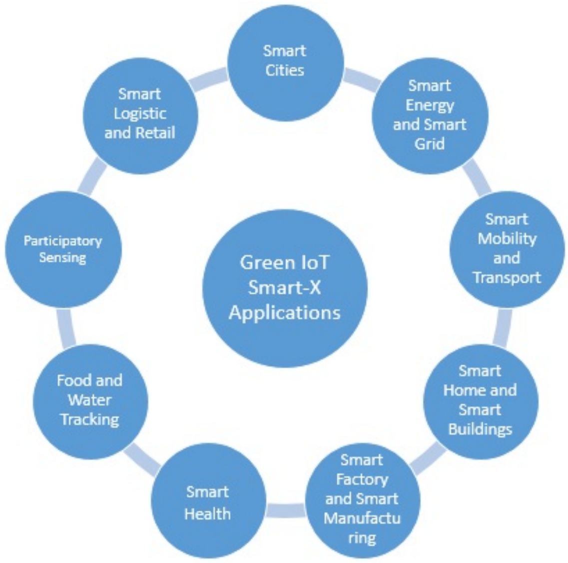

Fig. 8. Green IoT Applications

V. INTERNET OF THINGS IN 5G WIRELESS COMMUNICATIONS

Experts expect that the fifth generation (5G) of wireless communications (5G) will arrive in 2020, and it will be able to handle about 1000 times more mobile data than todays cellular systems [6]. It is going to achieve user demands in affordable rates, much reliability as well as exceptional applications [36]. It will also become a pillar of the IoT technology, linking up fixed and mobile devices becoming part of a new industrial and economic revolution. IoT and 5G are two of the hottest trends in technology. They are combined to transform our future by interconnecting everything [37]. However, there are many emerging challenges are on the horizon in designing IoT based systems that can efficiently be integrated with 5G wireless communications [43]. Security is one of the biggest challenges faced by IoT in 5G. In addition, IoT technology is characterized by small data packets, massive connections of devices with limited power source, and delay tolerant communication. In 5G, narrow band system design can improve system coverage, power consumption, and reduce terminal cost [38]. In [38], several designs of IoT in 5G networks to support massive connection density of low-rate, low-power devices have been proposed.

VI. Internet of Things for Smart Cities

The Smart City market is estimated at hundreds of billion dollars by 2020, with an annual spending reaching nearly 16 billions [20]. It depends on centralized architecture, where a dense and heterogeneous set of peripheral devices positioned over the urban area generate different types of data that connected via any connectivity method. Therefore, extensive research on IoT is taking place on sensing and automatic control, network infrastructure and communication, and big data analytic [46]. The applications of the IoT to the Smart City is particularly attractive such as smart parking [39], environmental monitoring [47][48][40], traffic management [41], waste management [42], water management and quality, and energy consumption. In [49], a classification of the IoT platforms and a generic IoT architecture for smat cities is presented. A practical solutions are presented to the main challenges faced during the deployment and management of a city-scale IoT infrastructure in the city of Santander, Spain [44]. In [20], the research presents the technical solutions for the hindrances in the Padova Smart City project, Italy. In [45], the relationship between big data analysis and IoT is discussed. It also proposed a new architecture for big IoT data analytics.

VII. Challenges and Future Research Directions

Although there are a tremendous research efforts to achieve a green technology, green IoT technology is still in infancy stage. There are many obstacles and challenges matters that need to be addressed. Hereunder, we list the key challenges:

- Integration between energy efficiency across the IoT architecture to achieve an acceptable performance.
- Applications should be green to minimize their effects on the environment.
- Reliability of green IoT with energy consumption models.
- Context-awareness with energy efficient IoT system.
- Both devices and protocols used to communicate should be energy efficient with less power consumption.
- Complexity reduction of the green IoT infrastructure.
- Tradeoff between efficient dynamic spectrum sensing and efficient spectrum management.
- Efficient energy mechanism for IoT such as wind, solar, vibration, thermal to make IoT promising.
- Efficient cloud management with respect to power consumption.
- Efficient security mechanism such encryption and control commands.

VIII. Conclusion

In this paper, the green IoT technology had been discussed. The paper motivation behind green IoT, challenges and benefits. It also reviewed the green IoT life cycle as well as the required technologies to achieve green IoT system. The role of IoT in 5G and smart cities is also presented. Moreover, a future research directions and challenges are also reviewed.

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