Analysis of Green IoT

Nitasha Khan¹², Aznida Abu Bakar Sajak³, Muhammad Alam⁴⁵, M.S Mazliham¹

¹British Malaysian Institute, Universiti Kuala Lumpur, Sungai Pusu, 53100, Malaysia
²Computer Science Department, Iqra University, Karachi, 75500, Pakistan
³MIIT, Universiti Kuala Lumpur, Kuala Lumpur, 52500, Malaysia
⁴Universiti Kuala Lumpur, 1016, Jalan Sultan Ismail, Bandar Wawasan, Kuala Lumpur, Wilayah Persekutuan Kuala Lumpur 50250, Malaysia
⁵Institute of Business Management, Korangi Creek, Karachi, Sindh 75190, Pakistan

Abstract. Internet of Things (IoT) is an idea and theory of connecting billions of devices and enable them to exchange a massive amount of information. Green IoT visualize the theory of IoT with improved energy efficiency. The overview of Green IoT and the challenges that were faced due to the excessive usage of energy hungry IoT devices were given initially. The research of energy efficiency in IoT had been presented extensively in this paper. Authors presented some challenges, existing works, opportunities, and future directions of green IoT.

Index terms Internet of things, Energy Efficiency, Green IoT.

1. Introduction

The blending of renewable energy and expansion of energy use are both critical enablers of sustainable energy transitions and climate change. IoT is increasing globally and its network infrastructure consisting of various devices, e.g. actuators, sensors, and other appliances which are physically embedded objects and having the capability of sensing, processing, and communicate information over the network. Modern inventions like the Internet of Things (IoT) offer an extensive application in the energy sector, i.e., in transmission and distribution, energy supply, and demand.

A numerous amount of sensing devices, processing elements, and communication technologies are involved in the growth and expansion of any IoT based system. A copious amount of sensing devices, processing elements, and communication technologies are included in the growth and development of any IoT based system even though sensing and processing devices operate on battery; they must be efficient in providing high performance. Furthermore, the communication devices must be capable of providing an uninterrupted connection for the QoS of the system. Due to IoT, physical objects are seamlessly integrated into the information network where they can become active participants in business processes [1]. Hence, enabling information transmission about their status, neighboring environment, production, and maintenance processes with scheduling, and much more. However, many severe issues still got to be addressed and both technological, also as social knots, got to be united before the vision of IoT becomes a reality. The main issues are to accomplished full interoperability between interconnected devices and the way to supply them with a high degree of smartness by enabling their behavior while ensuring trust with security, and privacy of the users and their data [2]. On the other hand, increase in energy prices, rising ecological awareness, and changing
its consumer behaviors toward greener products and enabling them to take impulsive decision to put green manufacturing and energy-efficient production processes at the top of their priorities [3]. Thus, the focus on energy efficiency is more required that composes an IoT system. In this paper, the working and initiatives taken by the existing researchers to build energy efficient IoT systems will be discussed.

Based on the United Nations Sustainable Development Goals agenda [4], efficient energy is one of the critical drivers of durable and long-lasting development. Besides, energy efficiency also offers economic benefits by reducing the cost of fuel supply and its imports, generation of energy, and reduction of emissions from the energy sector. For improving energy efficiency and have more optimal energy management, a compelling analysis of the real-time data in the energy supply chain plays a vital role [5].

2. Architecture of IoT

Many researchers have proposed different architectures of IoT. There is no single unity on architecture for IoT, which is agreed universally.[6] It was introduced in the early stages of research in this area. It has three layers, namely, the perception, network, and application layers. [7]

- The perception layer is the physical layer consists of sensors for sensing and gathering information about the surroundings. It detects some physical parameters, and most probably, it identifies other smart objects within the environment.
- The network layer is liable for connecting to other smart things, network devices, and servers. Its features also are used for transmitting and processing sensor data.
- The application layer is liable for delivering application-specific services to the user. It defines various applications during which the web of Things is often deployed, for instance, smart homes, smart cities, and smart health.
- Proposed architecture layers are discussed in this section. The five layers consist of perception, transport, processing, application, and business layers showing in Figure 1. The role of the perception and application layers is the same as previously mentioned. The following are the main function of the remaining three layers.

Figure 1. Architecture of IoT
The processing layer plays the role of a middleware layer as it collects the information from a transport layer. The layer is responsible for eliminating extra information that has no meaning and extracts useful information. However, it also tackles the IoT a significant amount of data that is responsible for its performance.

The processing layer can be affected by exhaustion [9], and malware [10] causes to disturb the performance of IoT.

The business layer has an intended behavior of an application and behaves like a manager of a whole system. It is responsible for managing and controlling applications, business, and profits models of IoT. It can determine creation, storage, and changing of information. Common problems that business layer faces are logic attack [11] and zero-day attack [12,13].

Different layers of IoT architecture discussed in this paper is presented in Table 1.

### Table 1. Classification of IoT layers

| Layer           | Reference | Approach                  | Limitation                        |
|-----------------|-----------|---------------------------|-----------------------------------|
| Perception layer| [49,50]   | Scheduling                | Constant sensing by gateway.      |
| Transport Layer | [51,52]   | Zigbee, Bluetooth         | Insecure remote nodes             |
| Processing Layer| [53]      | Compact sensing           | Complicated task scheduling       |
| Network layer   | [54,55]   | Game theory, Multi-hop    | Inflexible service due to compact positioning |
| Application layer| [56,57,58]| WCCFS, MQTT               | No limitations                    |

3. **Green IoT technology**

Green IoT (Internet of Things) mainly aims on the energy efficiency in the IoT. Green IoT decreases the effects of greenhouse produced [59]. Different scientific solutions for Green IoT proposed by researchers are discussed in this paper and all these strategies details and summaries. For structure execution of Green IoT, some work is proposed in [60]. Additionally, Green IoT may be executed by using Green Cloud Computing [61],[62], Green Datacentres [63], Green Sensor Networks [64] and Green RFIDs. Details of these are discussed in this section. We must tackle the energy resources in large scale by IoT. The more we solve this problem efficiently, the more effective will be the IoT.

Green IoT generally has technologies like Green Cloud Computing [65], Green RFID [66], Green WSN [67], Green Machine to machine [68] and Green Data Centers [69].

- Green Cloud Computing: Green cloud computing system based on technologies like communication and networking both and have a service like IaaS, PaaS, and SaaS. In green structure of IoT, software and hardware are employed in such a way that helps to reduce energy consumption.
- Green Data centers: They are employed in a system for storage, handling and for processing all types of data.
- Green RFID Tags: RFID tags can store information and data of small intensity which are linked altogether. One type of RFID tag is active tags that are designed with built-in batteries for non-stop transmission of their own signal and another type is passive tags that don't have any battery source in it and they can only store energy from the reader. To accomplish the objective of green RFID, numerous research efforts have been done shown in Table 2.

### Table 2. Researchers working on Green RFID

| Reference | Year | Summary                                                                 |
|-----------|------|-------------------------------------------------------------------------|
| [70]      | 2017 | Size reduction of nondegradable material using RFID                     |
| [71]      | 2014 | Removal of overhearing issue in active RFID                             |
| [72]      | 2013 | Low cost RFID tags was designed                                         |
| [73]      | 2012 | Algorithm was designed to energy efficient active tags                  |
| [74]      | 2011 | APS algorithm was designed based on energy efficiency for variable slot lengths |
- Green Machine to Machine (M2M): There must be energy efficient transmission power and improved communication protocols within green machine to machine communication.
- Green Wireless Sensor Network (WSN): WSN has many sensors nodes having small capacity and limited power. Green WSN can be accomplished by Green routing techniques, Radio Optimization technique and Green Energy Conservation technique.

The summary of the methods for enhancing the energy of different components in several layers is presented in Table 3.

**Table 3. Energy Efficient Methods in IoT Components**

| Elements of IoT          | Reference | Energy Efficient Techniques/Tools | Enhanced Parameters       |
|-------------------------|-----------|----------------------------------|---------------------------|
| RFID                    | [75]      | Passive Sensors                  | Improved performance      |
| Data Centre             | [76]      | Distributed Loads                | Precise positioning       |
| Wireless sensor nodes   | [77,78]   | Multihopping                     | Improved Coverage         |
| Actuators               | [79,80]   | Tracing of energy consumption    | Reliability               |
| Cloud                   | [76]      | Scheduling                       | Cost effectiveness        |
| Sink nodes              | [81]      | Optimization and mapping         | Enhanced complexity and cost |
| Sensors                 | [82,83]   | Scheduling                       | Enhanced strength and latency |

4. **Techniques of Green IoT**

4.1. *Green IoT techniques based on software*
Techniques like data centers can be vital for attaining energy efficient IoT network. e-CAB, which is a policy-based design, proposed by a researcher in [84] utilize an Orchestration Agent (OA) in a system based on Client-Server model, that is accountable for management of data centres. A context aware sensing platform (C-MOSDEN) proposed in [85], uses selective sensors to attain energy efficiency which decreases the energy consumption and causes some small overheads.

4.2. *Green IoT techniques based on hardware*
Many energy utilizations models in IoT concentrates on hardware modifications but classification of an objects in an IoT system can help it to make green network. RFID is an important part of IoT so, enhancement of an active RFID was discussed in [86] and development of passive RFID in [87], Wireless Identification and Sensing Platform (WISP) can lead to a more energy efficient system in IoT discussed in [88].

The summary of hardware-centric solutions for enhancing the energy is presented in Table 4.

**Table 4. Summary of hardware-based solutions in IoT**

| Reference | Functions          | Advantages                                           |
|-----------|--------------------|------------------------------------------------------|
| [89]      | LoRa               | Lowers the power consumption and enhances the range   |
| [90]      | Dual-core processor| Enables the system to run in low voltage state       |
| [91]      | RAM arrangement    | Helps to attain energy efficient low voltage         |
| [92]      | RAM arrangement    | Helps to connect internet via IPv6 using thermal aware RAM |

4.3. *Green IoT techniques based on policies*
Strategies and policies based on the real time data obtain from IoT devices can save energy. Different phases of planning policies for attaining energy efficiency are supervising, information management, feedback of user, and automation of system. Automation of systems can help in identification of resident’s location in a building for energy efficiency purpose.
5. Applications of IoT

IoT transforms our life daily activities and scenarios in intelligent decisions so that they improve our lifestyle. Some of the application are discussed below:

- **IoT in Energy:** A joint research initiative of the ETH Zurich and the University of St. Gallen in Switzerland, named The Bits to Energy Lab, started a project that has developed a smart water meter that provides feedback on water consumption directly at individual showerheads or faucets. The device captures temperature, flow rate, and derives the amount of water extracted, energy used, and carbon dioxide emitted. Upgradation of energy usage awareness is under research by researchers at the Swedish Institute of Computer Science. [14]

- **IoT in logistics, Retail, and supply chain management:** Logistics and supply chain management have its advantages. Tracking of items by smart shelves, monitoring of stocks through RFID tags and fast payment solutions, tracking of supply chain and status monitoring of pharmaceutical products with sensors, tracing of food and ingredients across the supply chain, all are now possible through IoT.

- **IoT in Information security:** The Spanish Ministry of Science funded the advanced research on information security and privacy project (ARES) which are working to bring security to the information society. It is the focus in on three application scenarios, that is, Securing critical information infrastructures, universal computing with an emphasis on RFID and W.S.N., safe electronic and digital commerce and content distribution (ARES, 2012). The Institute of Information Systems at the Humboldt-Universitat zu Berlin is working on P2P discovery from RFID-based information production – SHARDIS

- **Food Supply Chains (F.S.C.):** IoT also has its impacts on the supply chain of food business industry. Real-time tracking from farms to consumer possible using IoT. Paper [15] proposes the value-centric business-technology joint design framework. A business-oriented model for F.S.C. using IoT which can enhance food security and can collect the production data.

- **IoT in Mining Industry:** IoT technology such as RFIDS, Wi-Fi and sensors are deploying in mining industries which improves the communication between minors and employees as well as different diseases diagnoses of minors can be done through sensors [16]

- **IoT in Transportation:** IoT is expanding in the industry of Transportation and Logistics. Real-time tracking of vehicles and products are now possible using RFID and sensors. A DNS architecture [16] is developed for IoT where large scale operations are lifting the potential of IoT in supply chain management.

- **IoT in Garments:** An innovation E-Thread [17] gives the idea of collecting data from clothes. It helps in collecting real-time data for tracking activities of a patient without using any extra device.

- **Smart Cities:** A smart city is a city of connecting physical infrastructures, social infrastructures, I.C.T. infrastructures, and business infrastructures [18]. A city can be smart through a large distribution of IoT (especially through communications of machine-to-machine and human-to-machine). W.S.N.s, the sensing-actuation arm of the IoT, Digital Skin that is seamlessly integrated into urban infrastructure. The generated information is shared across platforms and applications to develop a (C.O.P.) Common Operating Picture of the city [19].

- **Smart Health:** A Wireless Body Area Network (WBAN) which is a technology that is formulated on a low-cost wireless sensor network is designed for the convenience of monitoring systems in residential places, hospitals, residential and other work environments [20]. WBAN sensors can be placed inside or outside of the human body and are light weighted having a small battery in the wearable form. The sensors then communicate using technologies like ZigBee, CoAP, 6LowPAN, etc. Through these sensors patient's blood flow, blood pressure, blood P.H. level, the temperature of the body can be analyzed.

6. Previous working of researchers on IoT

In this section, the critical literature review of the researchers proposed models and there working in the field of energy efficiency and IoT are presented. Table 5 discusses and highlights the findings.
Green IoT focuses on energy efficiency concepts. It mainly approaches in IoT is to reduce the greenhouse effect. Ku et al. proposed an energy-efficient smart energy system IoT technology. This service efficiently collects energy resource information in the home. The research should add a feature of enabling a system to continue with its operations even when there is a failure in one part of the system [21]. Miorandi et al. provided an overview of the issues and challenges of IoT technology. It also presented some technique and application fields of IoT. but it lacks in showing Green IoT system model. [22] Chaouch et al. proposed a system based on Energy Management Scheme by using machine-to-machine communication that can reduce extra energy consumption. The researcher emphasis the whole system mainly on HVAC. [23]. Kumar et al. introduced a harvesting system based on an IoT system. This system is not considered as an energy efficient. [24].

| References | Technology | Category | Tools |
|------------|------------|----------|-------|
| [35]       | Energy efficient (E.E.) Green IoT network | Software | Sensors, Home appliances, RESTful webserver, ALG-P algorithm |
| [36]       | Virtualization based E.E. green IoT network | Hardware | Optimal placed virtual machine, ZigBee, minicloude placed in relays |
| [37]       | Reduction of network traffic by embedded sensors on chips | Hardware | CMOS, W.S.N., MSP430 microcontroller |
| [38]       | Multi-Tier framework based on E.E. IoT | Hardware | periodically elected Cluster Heads (C.H.s) s, W.S.N., OMNet++, sensors, area routers. |
| [39]       | Controlling Greenhouse using iot and cloud computing | Hardware + software | TM4C129E, Arduino, ZigBee, PSoC, WSN. |
| [40]       | Digitally smart campus using IoT | Hardware | Sensors, IoT based FTP server, SSH server, Web Server, Proxy Server and Mailing Servers |
| [41]       | Energy management scheme E.M.S. based on I.O.T. | Software | MANET, W.S.N., RFID, NS2 simulator |
| [42]       | Smart homes based on E.M.S. using IoT approach | Hardware + software | Business Intelligence tool, MQTT, RFID, Sensor, Microcontroller, Mobile App, Software: Client App, B.I. |
| [44]       | Power quality analysis with detailed importance of A.M.I. by using smart grid | Hardware | A.R.M. controller-based hardware, E.M.S. system based on LONworks & Modbus technology |

Baliga et al. discuss the thorough overview of energy consumption of cloud and P.C. computing on different scenarios by evaluating the energy consumption associated with three cloud computing services. It also considered that the energy efficiency of cloud computing is not up to the mark. Panahi et al. investigated a model of smart energy harvesting in which mobile can charge through sensors wirelessly practically based on IoT technology. The whole research is only dependable on W.S.N. while neglecting RFID [25]. Prathik et al. introduced a smart meter surveillance system using IoT technology. He used Arduino with the combination of the GSM module. This system cannot consider as energy efficient IoT [26].
Shaikh and Zeadally discuss the extensive review of harvest energy in W.S.N. where it focused on energy harvesting techniques for generating energy for W.S.N. in different ambient environments. Some issues and challenges focusing on miniaturised generic harvesters that still need to be addressed are identified [27].

Srinivasan et al. introduced a system of energy conservation by using two schemes in it. The whole system was designed to calculate the efficiency of energy conservation. The proposed system is workable in different environments, including large scale industries. In addition, the proposed system is not matching the nature of the IoT [28].

Suresh et al. proposed an energy-efficient solution using IoT that can save the energy mechanism as compared to old mechanisms helping to decrease the energy consumption of sensor nodes using only W.S.N. [29].

Akkaya et al. showed a survey of buildings and its infrastructure based on IoT system. Past papers with some working in HVAC, sensors, were also discussed in it. Its focus was on the point of implementing proper systems in HVAC with energy efficiency.[30]

Choi et al. proposed a low-cost renewable energy monitoring system. This system is constructed for an open IoT platform including Arduino, Raspberry Pi. There is a bit inaccuracy in result findings by the system. [31].

Alaudin et al. proposed a system based only on a real-time monitoring device using IoT.[32].

Tcarenko et al. introduced a system design which can modify the energy consumption rate. The whole design is based only for mobiles [33].

Salman et al. proposed an IoT infrastructure deployment for smart homes. He represented his research as a survey for government, regulators and IoT firms. His research was only for cameras and sensors and transmission of information up to kilobytes only. [34]

7. Challenges

Green IoT technologies will play a significant part in energy-efficient technology. Numerous severe problems need to be addressed. Right here, author summarize them and spotlight the key issues that want further attention.

- **Green Infrastructure**: Offering electricity-efficient infrastructure for it is taken into consideration a vital issue closer to greening. However, due to the complexity of deploying significantly new infrastructure, this location of research is less focused and requires in addition to attention.

- **Green Security and QoS**: Execution of algorithms puts the extra load on IoT devices causes the excess consumption of energy and power. In the case of green IoT, safety and security are on high priority. Along with the security, we need to check out excellent mechanisms that consider both strength consumption and the required QoS [48]

- **Green IoT Architectures for IoT**: IoT architecture is nevertheless below standardization. The committees of standardization are trying to allow links between heterogeneous networks and other devices with huge varieties. The mission is to consider protocols as an energy-efficiency while executing their other tasks.

- **Green Communication**: Green IoT has many essential elements, and one of them is communication which is under several issues and challenges. Some of them are mentioned in Table 6:

| Reference       | Challenges                          | Description                                                                 |
|-----------------|-------------------------------------|----------------------------------------------------------------------------|
| Edward A. Lee   | Performance balancing with safety    | Improvement required in design processes with raising the level of abstraction. To realize the full potential of C.P.S., rebuilding computing and networking |

Table 6. Green IoT issue and challenges
A. Sharma, V. Navda, R. Ramjee, V. Padmanabhan, and E. Belding [45]

Energy efficiency requirement for mobile users

Reduction of power is required for mobile users through Wi-Fi tethering.

H. Lei, X. Wang, and P. H. J. Chong [46]

Scalability

Multihopping can improve the scalability issues.

I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci [47]

Fault tolerance

Due to high constraints in W.S.N., new wireless ad hoc networking techniques are required.

N. A. Pantazis and D. D. Vergados [47]

Power controlling

Algorithm are designed to control QoS and make power schemes effective.

More researchers working is needed to create a common architecture for IoT so that it helps in acquiring more generic results for energy efficiency.

- Eco-friendly material for the enhancement of sensors needs to be comprehensively investigated.
- There is a need for a thorough research to set up policies and strategies for establishing awareness among the providers and users for efficient implementation of IoT solutions.

8. Future directions

Green IoT will change our future and can make it greener and healthier in both economically and environmentally. The research work done recently in realizing the gap in green IoT are mostly focusing on Green IoT services, integrated RFIDs, energy-efficient models and planning, and localization. Hence, researchers need to find solutions for following fields mention in Figure 2:

Figure 2. Solutions for Green IoT

9. Conclusion

In conclusion, several possible solutions to overcome the limitations of Green IoT in a specific area is presented in Table 7.

Table 7. Efficient solutions to overcome the limitations of Green IoT [93]

| Limitations | Solutions for Green IoT |
|-------------|-------------------------|
| Green IoT is for achieving high QoS and excellent performance. Suitable techniques of |
enhancing QoS bandwidth, throughput and delay can contribute towards effectively and efficiently green IoT.

2. UAV is an essential element to replace a massive number of IoT devices, especially in controlling traffic and agriculture, which will help in energy efficiency and to limit pollution.

3. Sensor-cloud is an emerging technology in green IoT integrating W.S.N. and mobile cloud and is under investigation by (SNaaS) services.

4. M2M transmission functions to reduce strength use and hazardous emissions. Machine automation lengths must be minimized in case of congestion and should take immediate steps on the spot.

5. Radio frequency energy harvesting plays a vital role in energy balancing for supporting green communication between IoT devices must be taken into consideration.

Authors have tried their best to explain all the significant challenges of energy efficiency in the IoT network, and different solutions have been critically estimated. The author discusses various components of an IoT system with visualization tools that can be employed for different smart applications in the energy sector, from buildings to smart cities, agriculture, and health. The author also reviews the application of IoT in the energy supply chain under different levels, including smart cities, smart buildings, and intelligent transportation, smart grids and discuss few of the challenges in the energy sector as well. The author also highlights solutions for a few challenges, i.e., Green IoT as future directions of research and blockchain.

References

[1] Process engineering.[Online].Available: http://processengineering.theengineer.co.uk/home/control-and-instrumentation/brave-new-world-industry-40-technology/1017121.article

[2] Bandyopadhyay, D.; Sen, J. Internet of Things: Applications and Challenges in Technology and Standardization. Wirel. Pers. Commun. 2011, 58, 49–69.

[3] M. Garetti and M. Taisch, “Sustainable manufacturing: trends and research challenges,” Prod. Plan. Control Manag. Oper., no. 23:2–3, pp. 83–104, 2012.

[4] International, "The State of Affairs in Internet of Things Research", Issuu, 2020. [Online]. Available: https://issuu.com/academic-conferences.org/docs/ejise-volume15-issue3-article829/14.

[5] Tan, Y.Q AS.; Ng, Y.T.; Low, J.S.C. Internet-of-things enabled real-time monitoring of energy efficiency on manufacturing shop floors. Procedia CIRP 2017, 61, 376–381.

[6] H. Ning and Z. Wang, "Future internet of things architecture: like mankind neural system or social organisation framework?" IEEE Communications Letters, vol. 15, no. 4, pp. 461–463, 2011.

[7] R. Khan, S. U. Khan, R. Zaheer, and S. Khan, "Future internet: the internet of things architecture, possible applications and key challenges," in Proceedings of the 10th International Conference on Frontiers of Information Technology (F.I.T. ’12), pp. 257–260, December 2012. M. Young, The Technical Writers Handbook. Mill Valley, CA: University Science, 1989.

[8] M. Wu, T.-J. Lu, F.-Y. Ling, J. Sun, and H.-Y. Du, “Research on the architecture of internet of things,” in Proceedings of the 3rd International Conference on Advanced Computer Theory and Engineering (ICACTE ’10), vol. 5, pp. V5-484–V5-487, IEEE, Chengdu, China, August 2010.

[9] Bandyopadhyay, D., Sen, J., Internet of Things: Applications and Challenges in Technology and Standardization. Wirel. Pers. Commun. 2011, 58, 49–69.

[10] Canzanese R., Kam M., Mancoridis S. Toward an automatic, online behavioural malware classification system; Proceedings of the IEEE 7th International Conference on Self-Adaptive and Self-Organising Systems (SASO); Philadelphia, PA, U.S.A. 9–13 September 2013; pp. 111–120. [Google Scholar].
[11] What is business logic attack? - Definition from WhatIs.com", WhatIs.com, 2020. [Online]. Available: https://whatis.techtarget.com/definition/business-logic-attack. [Accessed: 10-Aug-2020].

[12] Bilge L., Dumitras T. Before we knew it: An empirical study of zero-day attacks in the real world; Proceedings of the 2012 A.C.M. Conference on Computer and Communications Security; Raleigh, NC, U.S.A. 16–18 October 2012; New York, NY, U.S.A.: A.C.M.; 2012. pp. 833–844. [Google Scholar] [Ref list]

[13] International, "The State of Affairs in Internet of Things Research", Issuu, 2020. [Online]. Available: https://issuu.com/academic-conferences.org/docs/ejise-volume15-issue3-article829/14.

[14] Z. Pang, Q. Chen, W. Han, and L. Zheng, "Value-centric design of the internet-of-things solution for food supply chain: Value creation, sensor portfolio and information fusion," Inf. Syst. Front., vol. 17, no. 2, pp. 289–319, 2015.

[15] L. Da Xu, W. He, and S. Li, “Internet of things in industries: A survey,” IEEE Trans. Ind. Informatics, vol. 10, no. 4, pp. 2233–2243, 2014.

[16] KIOURTI, C. Lee, and J. Volakis, “Fabrication of Textile Antennas and Circuits with 0.1 mm Precision,” IEEE Antennas Wirel. Propag. Lett., vol. P P, no. 99, pp. 1–1, 2015.

[17] Colin Harrison, Barbara Eckman, Rick Hamilton, Perry Harts wick, Jayant Kalagnanam, Jurij Parasyczak, and Peter Williams. Foundations for smarter cities. I.B.M. Journal of Research and Development, vol. 54, no. 4, pp. 1-16, 2010. Available: 10.1147/jrd.2010.2048257.

[18] Jiong Jin, Jayavardhana Gubbi, Slaven Marusic, and Marimuthu Palaniswami. An information framework for creating a smart city through internet of things. IEEE Internet of Things Journal, 1(2):112–121, 2014.

[19] Carmen CY Poon, Yuan-Ting Zhang, and Shu-Di Bao. A novel biometrics method to secure wireless body area sensor networks for telemedicine and m-health. IEEE Communications Magazine, 44(4):73–81, 2006.

[20] T.-Y. Ku, W.-K. Park, and H. Choi, “IoT energy management platform for microgrid,” in Proc. IEEE 7th Int. Conf. Power Energy Syst. (ICPES), Toronto, ON, Canada, Nov. 2017, pp. 106–110.

[21] D. Miorandi, S. Sicari, F. De Pellegrini, and I. Chlamtac, “Internet of Things: Vision, applications and research challenges,” Ad Hoc Netw., vol. 10, no. 7, pp. 1497–1516, Sep. 2012.

[22] H. Chaouche, A. S. Bayraktar, and C. Ceken, “Energy management in smart buildings by using M2M communication,” in Proc. 7th Int. Istanbul Smart Grids Cities Congr. Fair (ICSG), Istanbul, Turkey, Apr. 2019, pp. 25–26.

[23] Suresh Kumar, R. Kaviyaraj, L. A. Jeni Narayanan, and Saleekha, “Energy harvesting by piezoelectric sensor array in road using Internet of Things,” in Proc. 5th Int. Conf. Adv. Comput. Commun. Syst. (ICACCS), Coimbatore, India, Mar. 2019, pp. 482–484.

[24] J. Baliga, R. W. A. Ayre, K. Hinton, and R. S. Tucker, “Green cloud computing: Balancing energy in processing, storage, and transport,” Proc. IEEE, vol. 99, no. 1, pp. 149–167, Jan. 2010.

[25] M. Prathik, K. Anitha, and V. Anitha, “Smart energy meter surveillance using IoT,” in Proc. Int. Conf. Power, Energy, Control Transmiss. Syst. (ICPECTS), Chennai, India, Feb. 2018, pp. 22–23.

[26] F. K. Shaikh and S. Zeadally, “Energy harvesting in wireless sensor networks: A comprehensive review,” Renew. Sustain. Energy Rev., vol. 55, pp. 1041–1054, Mar. 2016.

[27] Srinivasan, K. Baskaran, and G. Yann, “IoT based smart plug-load energy conservation and management system,” in Proc. IEEE 2nd Int. Conf. Power Energy Appl. (ICPEA), Singapore, Apr. 2019, pp. 27–30.

[28] K. Suresh, M. RajasekhararBabu, and R. Papan, “EEIoT: Energy efficient mechanism to leverage the Internet of Things (IoT),” in Proc. Int. Conf. Emerg. Technol. Trends (ICETT), Kollam, India, Oct. 2016, pp. 21–22.

[29] K. Akkaya, I. Guvenc, R. Aygun, N. Pala, and A. Kadri, “IoT-based occupancy monitoring
techniques for energy-efficient smart buildings,’” in Proc. IEEE Wireless Commun. Netw. Conf. Workshops, Mar. 2015, pp. 58–63

[30] C.-S. Choi, J.-D. Jeong, I.-W. Lee, and W.-K. Park, "LoRa based renewable energy monitoring system with open IoT platform,” in Proc. Int. Conf. Electron., Inf., Commun. (ICEIC), Honolulu, HI, U.S.A., Jan. 2018, pp. 24–27.

[31] H. B. Alaudin, M. M. M. Zan, A. R. Mahmud, C. K. H. C. K. Yahaya, M. I. Yusof, and Y. M. Yussoff, “Real-time energy-efficient monitoring device using Internet of Things,” in Proc. IEEE 8th Int. Conf. Syst. Eng. Technol. (ICSET), Bandung, Indonesia, Oct. 2018, pp. 97–101.

[32] Tcarenko, Y. Huan, D. Juhasz, A. M. Rahmani, Z. Zou, T. Westerlund, P. Liljeberg, L. Zheng, and H. Tenhunen, "Smart energy efficient gateway for Internet of mobile things," in Proc. 14th IEEE Annu. Consum. Commun. Netw. Conf. (CCNC), Las Vegas, NV, U.S.A., Jan. 2017, pp. 8–11.

[33] L. Salman, S. Salman, S. Jahangirian, M. Abraham, F. German, C. Blair, and P. Krenz, "Energy efficient IoT-based smart home," in Proc. IEEE 3rd World Forum Internet Things (WF-IoT), Reston, VA, U.S.A., Dec. 2016, pp. 526–529.

[34] Abedin, S. F., Alam, M. G. R., Haw, R., & Hong, C. S. (2015). A system model for energy efficient green-IoT network. 2015 International Conference on Information

[35] Al-Azez, Z. T., Lawey, A. Q., El-Gorashi, T. E. H., & Elmirghani, J. M. H. (2015). Virtualisation framework for energy efficient IoT networks. 2015 IEEE 4th International Conference on Cloud Networking (CloudNet).

[36] Boll, D., De Vos, J., Botman, F., de Streef, G., Bernard, S., Flandre, D., & Legat, J.-D. (2013). Green SoCs for a sustainable Internet-of-Things. 2013 IEEE Faible Tension Faible Consommation.

[37] M. R. Helal and A. Elmougy, "An energy-efficient service discovery protocol for the IoT based on a multi-tier W.S.N. architecture," in Proc. IEEE 40th Local Comput. Netw. Conf. Workshops (L.C. N Workshops), Oct. 2015, pp. 862–869.

[38] Vatari, S., Bakshi, A., & Thakur, T. (2016). Green house by using I.O.T. and cloud computing. 2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT).

[39] Subbarao, V., Srinivas, K., & Pavithr, R. S. (2019). A survey on internet of things based on smart, digital green and intelligent campus. 2019 4th International Conference on Internet of Things: Smart Innovation and Usages (IoT-SIU).

[40] Said, O., Al-Makhadmeh, Z., & Tolba, A. (2020). E.M.S.: An Energy Management Scheme for Green IoT Environments. IEEE Access, 1–1.

[41] Al-Ali, A. R., Zualkernan, I. A., Rashid, M., Gupta, R., & Alikarar, M. (2017). A smart home energy management system using IoT and big data analytics approach. IEEE Transactions on Consumer Electronics, 63(4), 426–434.

[42] Selvam, C., Srinivas, K., Ayyappan, G. S., & Venkatachala Sarma, M. (2012). Advanced metering infrastructure for smart grid applications. 2012 International Conference on Recent Trends in Information Technology.

[43] E. A. Lee, “Cyber physical systems: Design challenges,” in Proc. ISORC, 2008, pp. 363–369

[44] Sharma, V. Navda, R. Ramjee, V. Padmanabhan, and E. Belding, “Cool-tether: Energy efficient on-the-fly wifi hot-spots using mobile phones,” in Proc. ENET, 2010, pp. 109–120

[45] H. Lei, X. Wang, and P. H. J. Chong, "Opportunistic relay selection in future green multihop cellular networks," in Proc. IEEE 72nd V.T.C., 2010, pp. 1–5

[46] F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless sensor networks: A survey,” Comput. Netw., vol. 38, no. 4, pp. 393–422, Mar. 2002

[47] N. A. Pantazis and D. D. Vergados, “A survey on power control issues in wireless sensor networks,” IEEE Commun. Surveys Tuts., vol. 9, no. 4, pp. 86–107, Fourth Quarter 2007.

[48] L. Caviglione, A. Merlo, and M. Migliardi, “What is green security?” in Conf. Rec. IEEE 7th IAS Annu. Meeting, 2011, pp. 366–371.

[49] Kaur, Navroop, and Sandeep K. Sood., "An energy-efficient architecture for the Internet of
Things (IoT)," IEEE Systems Journal, vol. 11, no. 2, pp. 796-805, 2017

[50] Wang, Kun, et al., "Green industrial internet of things architecture: an energy-efficient perspective," IEEE Communications Magazine, vol. 54, no.12, pp. 48-54, 2016.

[51] Sethi, Pallavi, and Smruti R. Sarangi., "Internet of things: architectures, protocols, and applications." Journal of Electrical and Computer Engineering 2017.

[52] Aazam, Mohammad, Pham Phuoc Hung, and Eui-Nam Huh. "Smart gateway based communication for cloud of things." Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), IEEE Ninth International Conference, 2014.

[53] Wu, Miao, et al., "Research on the architecture of Internet of things." Advanced Computer Theory and Engineering (ICACTE), 3rd IEEE International Conference on. Vol. 5., 2010.

[54] Jiang, Dingde, et al., "Energy-efficient multi-constraint routing algorithm with load balancing for smart city applications," IEEE Internet of Things Journal, vol.3, no. 6, pp. 1437-1447, 2016

[55] Gubbi, Jayavardhana, et al., "Internet of Things (IoT): A vision, architectural elements, and future directions," Future generation computer systems, vol. 29, no.7, pp. 1645-1660, 2013

[56] Zhu, Chunsheng, et al., "Green internet of things for smart world." IEEE Access 3 , pp. 2151-2162, 2015.

[57] Eijaz, Waleed, et al., "Efficient energy management for the internet of things in smart cities," IEEE Communications Magazine, vol. 55, no.1, pp. 84-91, 2017.

[58] Rani, Shalli, et al., "A novel scheme for an energy efficient Internet of Things based on wireless sensor networks," Sensors, vol. 15, no. 11, pp. 28603-28626, 2015.

[59] F. K. Shaikh, S. Zeadally, and E. Exposito, “Enabling technologies for green Internet of Things,” IEEE Syst. J., to be published.

[60] J. Huang, Y. Meng, X. Gong, Y. Liu, and Q. Duan, “A novel deployment scheme for green Internet of Things,” IEEE Internet Things J., to be published.

[61] F. Farahnakian et al., “Using ant colony system to consolidate VMs for green cloud computing,” IEEE Trans. Services Comput., vol. 8, no. 2, pp. 187–198, Mar./Apr. 2015.

[62] Y.-J. Chiang, Y.-C. Ouyang, and C.-H. Hsu, “An efficient green control algorithm in cloud computing for cost optimization,” IEEE Trans. Cloud Comput., vol. 3, no. 2, pp. 145–155, Apr./Jun. 2014

[63] E. Oró, V. Depoorter, A. Garcia, and J. Salom, “Energy efficiency and renewable energy integration in data centres. Strategies and modelling review,” Renew. Sustain. Energy Rev., vol. 42, pp. 429–445, Feb. 2015.

[64] S. Li, L. Da Xu, and X. Wang, “Compressed sensing signal and data acquisition in wireless sensor networks and Internet of Things,” IEEE Trans. Ind. Informat., vol. 9, no. 4, pp. 2177–2186, Nov. 2013.

[65] A. Kiourti, C. Lee, and J. L. Volakis, “Fabrication of textile antennas and circuits with 0.1 mm precision,” IEEE Antennas Wireless Propag. Lett., vol. 15, pp. 151–153, 2015.

[66] Z. Pang, Q. Chen, W. Han, and L. Zheng, “Value-centric design of the Internet-of-Things solution for food supply chain: Value creation, sensor portfolio and information fusion,” Inf. Syst. Frontiers, vol. 17, no. 2, pp. 289–319, 2015.

[67] L. Da Xu, W. He, and S. Li, “Internet of Things in industries: A survey,” IEEE Trans. Ind. Informat., vol. 10, no. 4, pp. 2233–2243, Nov. 2014

[68] A. Caragliu, C. Del Bo, and P. Nijkamp, “Smart cities in Europe,” J. Urban Technol., vol. 18, no. 2, pp. 65–82, 2011.

[69] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, “Internet of Things for smart cities,” IEEE Internet Things J., vol. 1, no. 1, pp. 22–32, Feb. 2014

[70] F. Shaikh, S. Zeaddally, E. Exposito, "Enabling Technologies for Green Internet of Things," IEEE Systems Journal, vol. 11, no. 2, pp.983 - 994, 2017.

[71] C. Lee, D. Kim, and J. Kim, "An energy efficient active RFID protocol to avoid overheating problem," IEEE Sensors Journal, vol. 14, no. 1, pp. 15-24, 2014.

[72] Y. Amin, "Printable green RFID antennas for embedded sensors," PhD dissertation, KTH School of Information and Communication Technology, Kista, Sweden, 2013
[73] T. Li, S. Wu, S. Chen, and M. Yang, "Generalized energy-efficient algorithms for the RFID estimation problem," IEEE ACM Transactions on Networking, vol. 20, no. 6, pp. 1978 - 1990, 2012.

[74] X. Xu, L. Gu, J. Wang, G. Xing, and S. Cheung, "Read more with less: An adaptive approach to energy-efficient RFID systems," IEEE Journal on Selected Areas in Communications, vol. 29, no. 8, pp. 1684 - 1697, 2011.

[75] Da Xu, Li, Wu He, and Shancang Li., "Internet of things in industries: A survey," IEEE Transactions on Industrial Informatics, vol. 10, no. 4, pp. 2233 - 2243, 2014.

[76] Asensio, Ángel, et al., "Protocol and architecture to bring things into internet of things," International Journal of Distributed Sensor Networks, vol. 10, no. 4, pp. 28603 - 28626, 2015.

[77] Jiang, Dingde, et al., "Energy-efficient multi-constraint routing algorithm with load balancing for smart city applications," IEEE Internet of Things Journal, vol.3, no. 6, pp. 1437-1447, 2016.

[78] Bagula, Antoine, Lorenzo Castelli, and Marco Zennaro., "On the design of smart parking networks in the smart cities: An optimal sensor placement model." Sensors, vol. 15, no.7, pp. 15443 - 15467, 2015.

[79] Coppola, Riccardo, and Maurizio Morisio., "Connected car: technologies, issues, future trends." ACM Computing Surveys (CSUR), vol. 49, no. 3, pp. 46, 2016.

[80] Arshad, Rushan, et al., "Green IoT: An Investigation on Energy Saving Practices for 2020 and Beyond." IEEE Access 5, pp. 15667-15681, 2017

[81] Rani, Shalli, et al., "A novel scheme for an energy efficient Internet of Things based on wireless sensor networks," Sensors, vol. 15, no. 11, pp. 28603-28626, 2015

[82] Kaur, Navroop, and Sandeep K. Sood., "An energy-efficient architecture for the Internet of Things (IoT)," IEEE Systems Journal, vol. 11, no. 2, pp. 796-805, 2017

[83] C. Peoples, G. Parr, S. McClean, B. Scotney, and P. Morrow, ‘‘Performance evaluation of green data centre management supporting sustainable growth of the Internet of Things,’’ Simul. Model. Pract. Theory, vol. 34, pp. 221–242, May 2013.

[84] B. G. Weber, ‘‘Internet of Things—New security and privacy challenges,’’ Comput. Law Secur. Rev., vol. 26, no. 1, pp. 23–30, 2010.

[85] C. Occhiuzzi, S. Caizzone, and G. Marrocco, ‘‘Passive UHF RFID antennas for sensing applications: Principles, methods, and classifications,’’ IEEE Antennas Propag. Mag., vol. 55, no. 6, pp. 14–34, Dec. 2013.

[86] A. P. Sample, D. J. Yeager, P. S. Powledge, and J. R. Smith, ‘‘Design of a passively-powered, programmable sensing platform for UHF RFID systems,’’ in Proc. IEEE Int. Conf. RFID, Mar. 2007, pp. 149–156.

[87] Alsamhi S, Ma O, Samar Ansari M & Meng Q (2018). Greening Internet of Things for Smart
“Everything with A Green Environment Life: A Survey and Future Prospects. Arxiv.org. Available at: https://arxiv.org/ftp/arxiv/papers/1805/1805.00844.pdf.”