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Green IoT: An Investigation on Energy Saving Practices for 2020 and Beyond

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ABSTRACT Internet of Things (IoT) is an emerging concept, which aims to connect billions of devices with each other. The IoT devices sense, collect, and transmit important information from their surroundings. This exchange of very large amount of information amongst billions of devices creates a massive energy need. Green IoT envisions the concept of reducing the energy consumption of IoT devices and making the environment safe. Inspired by achieving a sustainable environment for IoT, we first give the overview of green IoT and the challenges that are faced due to excessive usage of energy hungry IoT devices. We then discuss and evaluate the strategies that can be used to minimize the energy consumption in IoT, such as designing energy efficient datacenters, energy efficient transmission of data from sensors, and design of energy efficient policies. Moreover, we critically analyze the green IoT strategies and propose five principles that can be adopted to achieve green IoT. Finally, we consider a case study of very important aspect of IoT, i.e., smart phones and we provide an easy and concise view for improving the current practices to make the IoT greener for the world in 2020 and beyond.

INDEX TERMS Internet of things, green IoT, datacenter, green computing, smart phones.

I. INTRODUCTION

Internet of Things (IoT) is a concept that envisages the connectivity between daily life things by using different types of sensors like Radio-frequency identification (RFID) [1], actuators that work collaboratively to sense, collect and transmit important information from their surroundings on to the Internet. IoT is a term that envisions connectivity between physical and digital world by using felicitous technologies [2]. IoT has been one of the hot topics in the technology domain for the last few years and it is expected to revolutionize the world similar to that the Internet itself did [3]. Frost & Sullivan (2011) projected the increase in RFID sales over the years and it is going to increase exponentially in the next few years. If the predictions are even closely accurate, then the energy consumption concerns are going to arise because Active RFIDs [4] need battery powered energy and to handle this issue we need to make the IoT technology Green by implementing various strategies. Some of them are discussed in the later sections. It could be observed by Figure 1 that the number of Internet connected devices are growing with a very fast pace. The mechanism of IoT consists of several elements such as Identification, sensing, communication, computation, services and semantics. Identification is the most important one as it ensures that the required data or service reaches to the correct address. Sensing deals with the collection of the information from different resources and this information is then sent to datacenters. This data is then analyzed using different conditions and parameters for the purpose of various services. The sensors can be used to collect humidity, temperature etc. Communication in IoT performs the combination of heterogeneous objects to offer specific services. Communication is usually performed by using Wi-Fi, Bluetooth etc. Computation is performed by different microcontrollers, microprocessors, Field Programmable gate arrays and many software applications. Services can be related to identity, information aggregation, collaborative or ubiquitous. Lastly, Semantics deals with the intelligent knowledge gathering to make decisions [5].

In order to make the IoT green, there is a need to study more state-of-the art techniques and strategies that can fulfill the energy hunger of billions of devices. In this article, we aim to provide a comprehensive overview of energy saving practices and strategies for the green IoT. We consider a case study of smart phones to show that how different stakeholders

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can play their roles for the green IoT. For the remaining part of this paper, Section II provides the current IoT trends and challenges. Section III reviews the existing approaches that for the green IoT. Here, we also propose our 5 principles for the green IoT. Section IV provides the comparative analysis of modern approaches and discusses the tradeoffs to achieve the green IoT. The case study on smart phones and its impact on environment are presented in Section V which also evaluates the usage of smart phones for different parameters such as carbon emission and recycling. The open issues are discussed in Section VI and the paper is concluded in Section VII.

II. IoT TRENDS

The current era is considered to be fully Internet based. Our dependence on the Internet and the devices is rapidly increasing. How does IoT influence in routine things? This is the main question to be addressed in the subsequent section.

TABLE 1. Applications of IoT.

Paper	Application
[7]	Food Supply Chain
[8]	Mining Industry
[8]	Transportation Industry
[9]	Garments Industry
[10]	Smart Cities
[6]	Smart Homes

A. APPLICATIONS OF IoT

IoT is revolutionizing our daily life activities by tracking different scenarios and making intelligent decisions to improve our lifestyle and to protect our environment. There are numerous applications of IoT in daily life. We explore several of them below and are highlighted in Table 1.

- *Smart Homes*: As described in [6], by equipping our home or office with the IoT technologies like RFIDs, we can track the activities of in-habitants in the building and can make decisions that can save energy, money and whole environment in the process. For example, a smart fridge can have RFIDs on every item inside it and we can decide when to go shopping and what we need to buy on the basis of information provided by the sensors attached on the items.
- *Food Supply Chains (FSC)*: IoT can have a huge impact on business industry. Using IoT technologies, vendors can track the production of their products from the farm to the end users. A framework for such an application is proposed in [7]. Paper [7] proposes a Business-oriented model of IoT for FSC which can enhance food security and can be used to collect the data related to production processes and that data can be manipulated to make better decisions regarding the business process model.
- *IoT in Mining Industry:* IoT technology can be used to ensure safety for miners and can provide Mining Companies with important information regarding mining process which can help them in enhancing the current practices [8]. RFIDs, Wi-Fi and sensors can be deployed to improve communication between miners and their employers. Furthermore, diagnosis of different diseases in miners can be done by collecting symptoms using these sensors.
- *IoT in Transportation:* IoT is revolutionary in the Transportation and Logistics industry. We can track vehicles and products using RFIDs and sensors from source to destination in real-time. A DNS architecture [8] is developed for IoT where large scale operations enhances the capabilities of IoT in supply chain management.
- *IoT in Garments:* A new type of E-Thread [9] envisions the idea of collecting data from clothes. This can help in collecting real-time data to track the activities of a patient without using any extra device.
- *Smart Cities:* One of the most scintillating and emerging applications for IoT is Smart Cities [10] which has gained popularity in the last few years. A smart city is a combination of different smart domains like Smart Transportation, Smart Energy Saving Mechanism, Smart Security [11] and many more which provide the users with latest technological facilities all under one umbrella.

B. CHALLENGES OF IoT

IoT is at its cutting edge and could prove to be revolutionary in the IT industry, but everything comes at a cost. There are many challenges posed by the IoT technologies like Security and Privacy challenges as described in [12] and [13] as one of the key areas that experts need to work on in order to gain trust of the users. The cited paper described that the RFID tags can follow a person without this consent or information and this could lead to a very serious distrust among the people. However, the most significant challenge that we will face in implementation of IoT will be energy. It has been predicted by National Intelligence Council of US that by 2025, daily life objects such as food items, pens etc. will be a part of Internet. This means that there could be billions of devices connected to the Internet.

According to [14], each active RFID needs a small amount of power to operate depending upon its functionality and active RFIDs are necessary for the efficient services. Therefore, imagine billions of such devices consuming energy on daily basis and millions of GBs of data transmitted by the sensors needs to best or edited by huge Data Centers thus huge processing and analytics capabilities are needed [15], [16], which consume a lot of energy resources, and to further deepen the crisis, we are running short of traditional energy sources. Moreover, emission of $_{CO2}$ due to ICT products is increasing rapidly which is damaging our environment [17] and it is projected to do so if sufficient measures are not taken

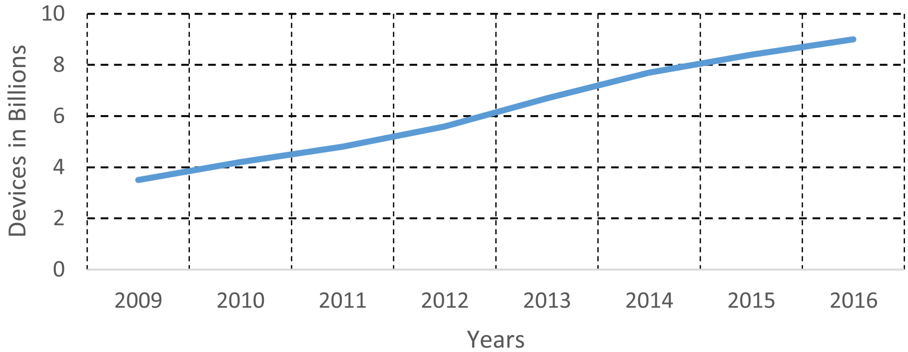

FIGURE 1. Growth in the number of Internet connected devices.

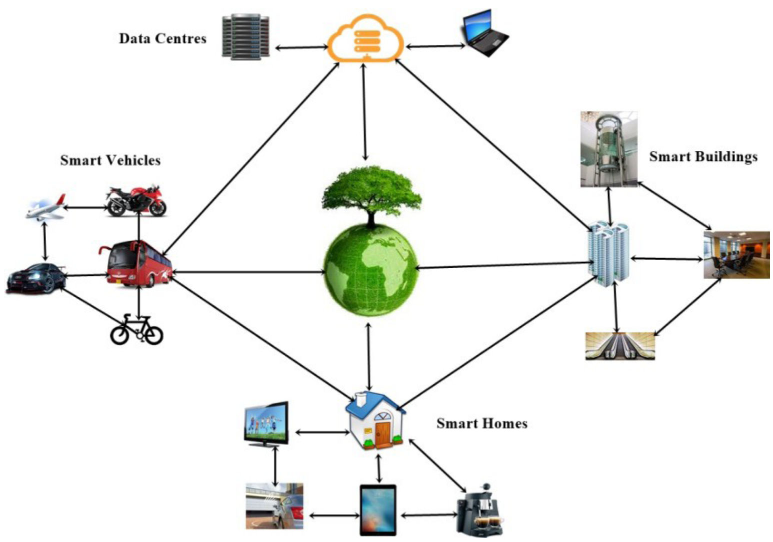

FIGURE 2. Green internet of things.

to address this concern. To solve these critical problems, the Green IoT is an important topic.

C. GREEN IoT

Green Internet of Things basically focuses on the energy efficiency in the IoT principles. Green IoT is defined as the energy efficient ways in IoT either to reduce the greenhouse effect caused by existing applications or to eradicate the same in IoT itself [18]. In the first case, IoT will help in eliminating the greenhouse effect but in the second scenario, the IoT will be further optimized to stop the greenhouse effect. Every step in IoT should be made green, from design to implementation. The Green IoT concept is shown in Figure 2.

In order to implement the Green IoT, a number of strategies should be adopted. Various technological solutions for Green IoT are proposed in [8]. The details of all these strategies will be discussed in the later sections but we will provide a summary in this section. For implementation of Green IoT a framework was proposed in [19] for the energy efficient optimization of IoT objects. Furthermore, Green IoT may be implemented by using Green RFIDs, Green Datacenters [20],Green Sensor Networks [21], Green Cloud Computing [22], [23]. Details of these will be discussed in later sections. IoT is an emerging technology that is changing the way we see the IT industry. IoT is going to have a huge impact on how we deal with certain problems in our daily life and it is certainly going to make our lives easier and better but with ease come the challenges. We have to deal with the large scale consumption of energy resources by IoT and the earlier we tackle this problem, the more efficient will be the IoT.

III. DIFFERENT WAYS TO MAKE THE IoT A GREEN IoT

In this section, we give a critical literature review of all the models proposed recently for energy efficient deployment of IoT, which are briefly highlighted in Table II. We categorize the energy efficient models on the basis of the technologies used in them and a detailed taxonomy is presented in Figure 3. Green IoT is a very hot research topic in ICT industry as the traditional energy resources are decreasing rapidly and the use of energy is increasing exponentially.

TABLE 2. Comparative analysis of different green IoT approaches.

Papers	Focus Technology	Type	Energy Saving Mechanism	Practical	Trade Offs
[27]	Data Centre	Software Based	Context Aware Allocation of Servers	Practical	Extra Resources for QoS.
[29]	Sensors	Software Based	Selective Sensing	Highly Practical	Privacy, Energy Overheads for Context Aware Sensing
[30]	Sensors	Software Based	Sleep Scheduling	Highly Practical	Extra Resources for QoS.
[31]	Data Centre	Software Based	Workload Distribution Among Geographically Dispersed DCs	Not Practical	Too Much Complexity.
[53]	Smart Buildings	Policy Based	Policies and Strategies to Minimize Energy Consumption.	Highly Practical	User Dependency (User needs to participate actively for efficient policies)
[10]	Processor	Hardware Based	Assigning Different Tasks to Difference Cores by Scheduling.	Practical	High Cost and complexity For Large Scale Network
[12]	Sensors	Hardware Based	Minimizing Processing at Sensor-end.	Practical	Communication Delays in extreme Situations
[39]	Sensors	Software Based	Compressed Sensing	Practical	Quality of Service
[41]	Cloud Computing	Software Based	Reducing Data Path	Practical	Quality of Service Might Fall.
[42]	RFID	Hardware Based	Use of Passive Sensors	Practical	Communication Delays
[44]	Integrated Circuits	Hardware Based	Reducing Network Traffic using Sensor on Chip.	Slightly Practical	High Cost
[47]	Sensors	Hardware Based	Categorization of Objects in Layers	Slightly Practical	Communication Delay between sensor nodes.
[48]	Sensors	Hardware Based	Dividing Network into Parts and assigning specific area to specific nodes.	Practical	Transmission Latency
[49]	Sensors	Hardware Based	Divide workload among different types of nodes (Sensor and Relay).	Practical	Communication Delays.
[52]	Smart Metering	Policy Based/Awarenes s Based	Tracking Different Types of energy consumption and devise measures to mitigate energy loss.	Highly Practical	Privacy, Security of Data
[47]	Mobile Phones/ Sensors	Recycling Based	Recycling the unused elements to make them productive again.	Highly Practical	Chance of wastage of recyclable material
[32]	Virtualization	Software Based	Separating Network and IoT Devices using MILP.	Practical	Performance Issues in Large Scale Network.
[36]	Smart Phones	Software Based	Prediction of Energy Consumption for different applications of smart phones	Practical	Privacy and Security of Data.
[39]	Sensors	Software Based	Combination of MAC with Wireless Smart Sensors to reduce communication between nodes.	Practical	Communication Delays between the nodes.
[52]	Information Management	Policy Based	Data Collected from different parts of building to devise energy efficient policies.	Highly Practical	Data Privacy and Security.
[43]	Cloud Computing	Software Based	Dynamic Packet Downloading using Access Points to reduce communication and overall traffic	Practical	Quality of Service might be compromised.

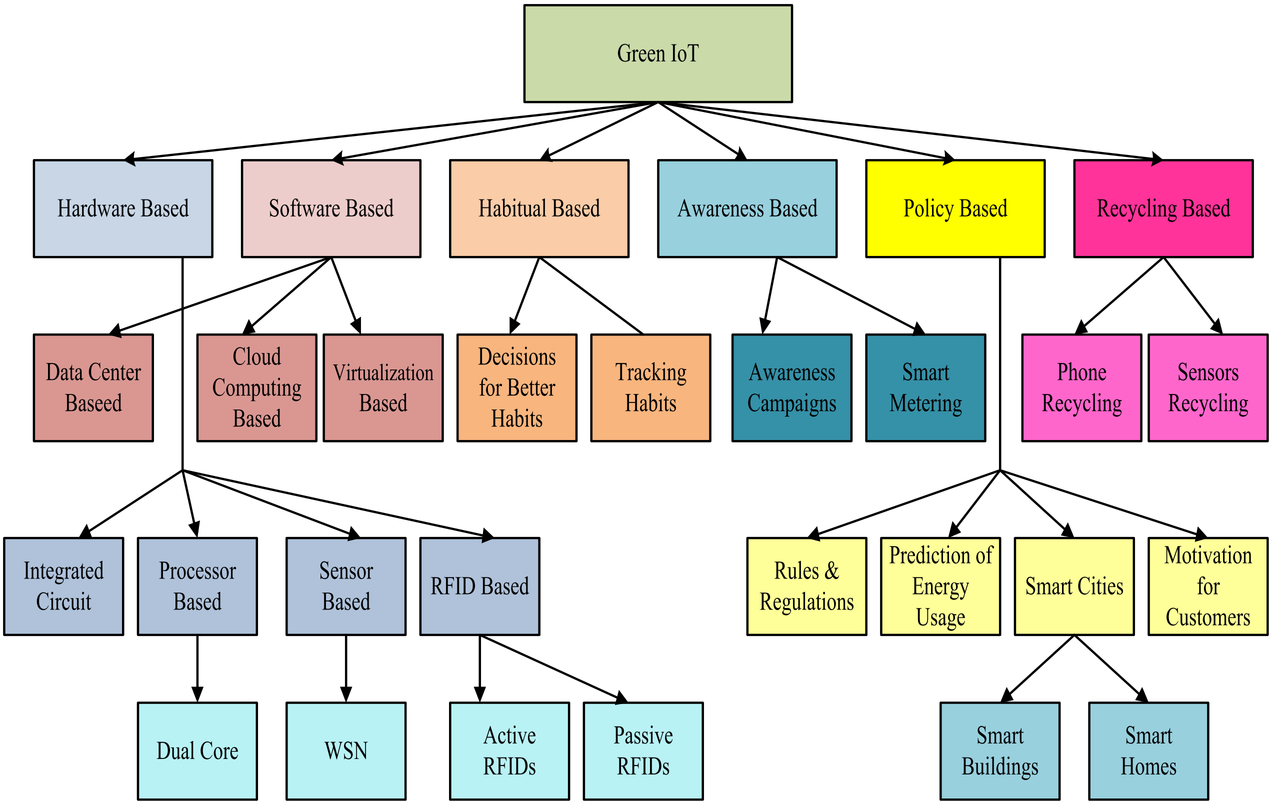

FIGURE 3. Taxonomy of green IoT techniques.

Miorandi *et al.* [2] discussed different techniques and technologies that can be used to achieve energy efficiency in the IoT but the system models explicitly designed for Green IoT were not discussed.

Baliga *et al.* [24] compared the energy consumption of cloud and PC computing over a variety of scenarios and it was deduced that the situation-wise choice of models would be the best option. Furthermore, Quality of Service (QoS) concerns are not addressed in their models which could further increase the energy consumption in certain situations. Green Technologies to implement IoT while maintaining QoS across various domains were elaborated in [9] which explicitly focused on the solutions for Green IoT. Data Centre and Cloud Computing and their Green solutions, which are the backbone of an IoT network, were not discussed.

Various strategies to conserve energy using Smart Buildings via data collected through IoT were elaborated by Akkaya *et al.* [25] and it was deduced by the described systems that if the heating, ventilating and air conditioning strategies are implemented, a lot of energy can be saved. In spite of all the discussion of the existing systems, the comparative analysis of energy conservation of the models was not discussed at all.

Wireless sensor networks (WSN) are a vital component in the deployment of the IoT. Shaikh and Zeadally [26] provided a detailed taxonomy of the techniques that can be used to harvest energy in WSN using different environmental resources. However, using another medium for energy storage instead of batteries could lead to more energy efficiency; hence a comprehensive research in this area is needed.

A. SOFTWARE-BASED GREEN IoT TECHNIQUES

Data Centers can be pivotal to an energy efficient IoT network but energy efficiency needs to be introduced in data centers to make them viable for IoT. e-CAB, a policy based architecture, proposed in [27] makes use of an Orchestration Agent (OA) in a Client-Server Model, that is responsible for context evaluation of Servers with respect to their efficiency in consumption of resources, for management of Data Centers. The intelligently selected servers then send the processed information back to client devices. However, this architecture requires to install OA on each device at the Client-side and backup servers to ensure reliability should be used which may result in high energy consumption. C-MOSDEN [28], a context aware sensing platform makes use of Selective Sensing to achieve energy efficiency. The results prove to decrease the energy consumption but generates some small overheads, which, if minimized, can make this model a very efficient one.

Sensors consume unnecessary energy when they are idle but are powered on, so, to conserve unnecessary usage of energy, an energy efficient scheduling algorithm [29] is proposed which changes states of sensors to on-duty, pre-off-duty and off-duty according to the requirements of the situations in order to prevent unnecessary energy usage. However, the requirement of an embedded server to ensure privacy in the proposed system may generate some energy overheads due to an extra server needed in case of server failure. Etelapera *et al.* [30], proposed an energy efficiency model by reconfiguring Virtual Objects (VO) at runtime on three different operating modes. To estimate the energy consumption on these modes, an analytical model was introduced which resulted in 47.9% less energy consumed in one mode than the other.

An optimal workload distribution framework, in [31] evaluates the workload in different servers on different locations having renewable power generators, by taking into account servers' resource consumption, electricity cost etc. The data from 1998 football world cup was used to estimate the power consumption which may lead to contradiction when applied to the data of today due to a change in nature and size of the data in 18 years since. Virtualization can decrease the amount of hardware resources consumed within architecture and hence decrease the energy consumption. A virtualization framework using Mixed Integer Linear Programming (MILP) proposed in [32] having a four layer architecture in which IoT devices are placed in upper layers and networking elements in lower layer. Results show that 36% less energy is consumed by applying this framework.

For deploying IoT on a very large scale, WSN paradigms cannot be re-used. So, Gemini, proposed in [33] for green and scalable IoT, is an optimization model and a minimal consumption algorithm makes the model work in energy efficient way. Results show that Gemini can work with distinctive Networking environments and can achieve a good level of energy efficiency. However, the experiments were done on just 15-20 nodes, therefore, it needs to be implemented on a large scale network to get valuable results of energy efficiency. IoT is being used in various domains of the industry. Due to the robustness and scalability of IoT, Medical industry is also opting it to store real-time patient data [34]. By using cloud storage and Access Points (AP), a solution for such a scenario is proposed by Kim [35] in which a dynamic packet downloading algorithm is used for energy efficient data transfer and communication. However, the APs in this model are battery-powered and consume lots of energy resources but if these APs generate their own energy like Passive RFIDs, the amount of energy resources can be significantly decreased.

Smart Phones, having strong sensing power, are a driving force in the technology industry especially in the emerging IoT domain, but energy efficiency is a big challenge in mobile devices which need to be addressed. Using data logging, prediction models and resource behavior analysis, a novel solution, propounded in [36], records data in different applications, contexts, locations and time to predict the energy consumption in smart phones. In spite of all the impressive results produced by this model, it still needs more research in efficient data mining techniques to predict energy efficiency for a broader IoT network.

The consumption of energy during the arbitration in the RFID systems is one of the most challenging issues that need to be resolved. The solution to the anti-collision problem was proposed in [37]. To reduce collisions among tag responses during the arbitration, the proposed solution makes use of multiple slots per node of a binary search tree. Three different variations of this approach were examined to provide a comparison for choosing the better energy consumption model. Results showed that all three protocols were successful in reducing the energy consumption during the arbitration and two of these have potential to decrease tag identification delay as well. Compressed sensing (CS) is an emerging theory with which the data and signals can be efficiently sampled and can be precisely reconstructed [38]. A CS framework to achieve energy efficiency using priori data sparsity information proposed in [12] can minimize the redundant data collection. The algorithms are designed to decrease the energy and resource consumption in WSN and IoT.

Wireless smart sensor network (WSSN) could be very useful in the implementation of the IoT and developing energy efficient ways for WSSN can pave the way for Green IoT. Medium Access Control (MAC) is used with WSSN to limit the extra communication between nodes of the network hence increasing the lifetime and decreasing the energy consumption in WSSN [39]. However, to optimize this strategy, MAC protocols need to be evaluated to enhance their capabilities.

A Programming Language named EPDL was designed to help the non-experts to write energy policies for a smart environment like IoT. Many processing tools were introduced in EPDL but addition of new features and possibly an extensive library of functions should be added to make it more robust [40]. Centrally managed data replication in Cloud Computing is necessary to provide the Quality of Service and reliability to the customers [41] but it results in excessive energy and bandwidth consumption which can be reduced by using the method in [42]. It reduces the communication delays, achieved by replicating data closer on the cloud applications that are close to the consumers.

Energy is wasted in the RFID as the tags remain idle but powered on because they don't know when to communicate in advance. This is called the overhearing problem which is responsible for a huge wastage of energy resources. To overcome this, RANO [8], proposed a method to calculate the communication periods in advance and to put the tags to sleep when not in use. Although this model saved a lot of energy but extra resources are wasted in determining the communication time and the change of states from ON to sleep and vice versa. The increase in emission of carbon footprints steers the need for ICT industry to design mechanisms keeping in mind the efficient energy consumption. A routing protocol for Internet of Multimedia Things (IoMT) and IoT [41] is a practical example of such a strategy which selects efficient routes among the nodes of the network to save the energy.

However, the assumption made regarding the green and non-green nodes in a network is quite vague as this ratio can vary a lot when the nodes are in millions or billions and might result in an increase in carbon footprints rather than decreasing.

B. HARDWARE-BASED GREEN IoT TECHNIQUES

Most of the models of energy consumption in IoT focus on algorithm or some hardware changes but categorization of objects in an IoT network can be very effective to make it a green network. Paper [10] uses 3-layer architecture to design the network for green objectives and the MECA algorithm is used in their architecture to address the optimization problem. RFID plays a central role in the IoT. Although, the optimization of Active RFID was discussed in [12], advancement in passive RFID [42], Wireless Identification and Sensing Platform (WISP) [43] can lead to a more efficient and low power computation in the IoT. Passive RFIDs take energy from the Radio Frequency signals around them and capacitors are used to store energy for performing tasks that require more power. Apart from this, some energy-expensive commands in series could cause communication delays between sensors nodes and interrogators which could lead to serious energy overheads.

Design of Integrated Circuit (IC) in an IoT network is vital in energy conservation. A concept of Green Sensors on Chip (SoC) [44] improves the design of IoT networks by combining sensors, processing power on a single chip to reduce the traffic, e-waste, carbon footprint and the energy consumption of the overall infrastructure. Although, Sleep Walker example depicts the conservation of the energy by using Green SoC but more energy can be conserved using recyclable material for this model.

The Time Reversal Technique [45] reduces the power consumption by powering the sensors from the Radio Frequency signals from the surrounding, simplifying the sensor nodes by minimizing the work done at sensor-end. The base stations (BS) are introduced to communicate with sensors for data processing. Although, power consumption is significantly decreased but if a series of high-end data processing tasks arrive along with the routine data transmissions, the communication delays between sensor nodes and BS could cause some severe energy overheads.

CoreLH [46], an energy efficient dual core processor for IoT, has a CoreL for low-computation tasks and CoreH for high-computation tasks. It reduces the energy consumption by using a scheduling framework that assigns different tasks to these cores on the basis of the resources they may require. Although, this processor resulted in 2.62 times less energy consumption as compared to other models, the switching and assigning the tasks to different cores may result in inefficient energy utilization. It is predicted that there will be approximately20Billion 'things' as the part of the IoT environment by 2025 [47]. Consequently, the network of this magnitude will consume a lot of energy and will generate massive amount of carbon footprints.

A hierarchical architecture [48] using a novel service discovery protocol reduces the energy consumption by introducing Cluster Heads (CHs), having information about neighboring sensors and Area Routers, which are responsible for providing services to sensors. A service request that can be entertained within a specific range will be completed by CHs instead of going to an area router or a dedicated gateway. However, CHs require constant battery supply to ensure quality, if Smart Passive Sensors are used in this architecture, further energy can be saved. The usual method to save energy in a sensor based network is to schedule the power on and off according to the usage of the sensors. Apart from this, reducing the hardware by introducing Sensor-on-Chips in healthcare systems [49] has produced impressive results for energy conservation in IoT. The network traffic and communication overheads are minimized hence decreasing the energy consumption. Discontinuous Reception/Transmission (DRX/TX) is a mechanism that allows devices in IoT like sensors to switch them off when they are idle to conserve energy. A three stage optimized DRX/TX scheme is introduced in [50] which focuses on energy saving and Quality of Service (QoS) for IoT in LTE-A networks by using a sleep-scheduling scheme which switches the power on and off on basis of the workload on the sensors. Shee and Chandrasekaran [51] introduced a layered architecture in which a relay node (responsible for efficient path determination, processing) and sensor node (responsible for sensing and communication) are placed in a hierarchical way to divide the burden between the two types of sensors. A Relay node needs more frequent power supply as compared to a sensor node and energy consumption is reduced by sharing different types of tasks between the two types of nodes. However, sensor nodes also require energy on frequent basis and this can be minimized by introducing passive sensors for sensor nodes which will further decrease the energy consumption and energy wastages. Apart from all the solutions discussed above, each one with its own advantages and disadvantages, we need to look at beyond them and work for the inception of ingenious new solutions that are both visionary and effective. Devising these solutions and implementing them in lieu of these slow-paced solutions can result in a drastic improvement in the ways the World handles energy efficiency.

C. POLICY-BASED TECHNIQUES

Policies and strategies based on the real time data from IoT devices can help saving energy on a large scale. There are different stages of devising policies for achieving energy efficiency such as monitoring (different situations of energy consumption), information management, user feedback, and automation system. We can use data collected from different parts of a building where occupants' behavior differs and energy consumption varies and then we can devise policies and strategies for different parts of the same building. Automation Systems can help identify location of residents of a building and environmental changes with which we can make decisions to save energy. *City Explorer* [52], a home automation solution, used in [53] to make strategies consists of 3 layers having data collection, data processing and services such as energy efficiency as their respective duties. The above Policy based system when applied to real-life scenario minimized energy consumption by 20%.

D. AWARENESS BASED TECHNIQUES

Awareness campaigns are a vital factor in decreasing the energy consumptions but this varies from culture to culture and country to country because you cannot predict or estimate how many people will listen and follow your campaigns. So, Smart Metering Technology can be used to provide home-owners with a real time feedback of their energy consumption from various sources of their homes, offices, buildings and then we can advise them on how to control and minimize their energy consumption based on that real-time data. This can save the energy from 3-6% [54].

E. CHANGING HABITS TOWARDS GREEN IoT

Another strategy that can be adopted to achieve energy efficiency and to extenuate carbon footprints is to adopt some basic habits by which we can decrease energy consumption in our daily life activities. Although, this is a small scale measure but if we add up the small savings on a world wide scale, it can make a huge difference. One way is to track the habits of energy consumption in offices, homes, industries through automation systems proposed in [42], [55], and [56] and then mitigate the energy losses in our daily routine tasks. Though, we cannot rely much on this technique but it can still save some decent amount of energy.

F. RECYCLING FOR GREEN IoT

Use of recyclable material for the production of devices in an IoT network can help make it an environment friendly one. For example, Mobile phones are made from the some of the scarcest natural resources like copper, plastic and consist of some elements that are non-biodegradable and can increase greenhouse effect if not properly dealt with when the phones are no longer in use. According to an estimate, 23 Million mobile phones are present in the drawers and cupboards in Australia [47] which are no longer used and 90% of the material in the phones is recyclable so the need for recycling is ever increasing if we are to tackle the problem of greenhouse effect and huge energy consumption. Although, it is an unrealistic assumption to recover 90% material but it still can make a considerable difference to save energy. Figure 4 depicts the process of Mobile Phone Recycling. Many methods were introduced in [57] for the improvement of the power consumption and performance of the smart phones. As a source of metal, EEE (electric and electronic equipment) recently focused and take into account the effective collection and recovery system of the specific feature for the each EEE type [58]. In [59], the sensitivity analysis showed that it is recommended to use the solar energy when the charger is connected, more than 20 % of use. In the next

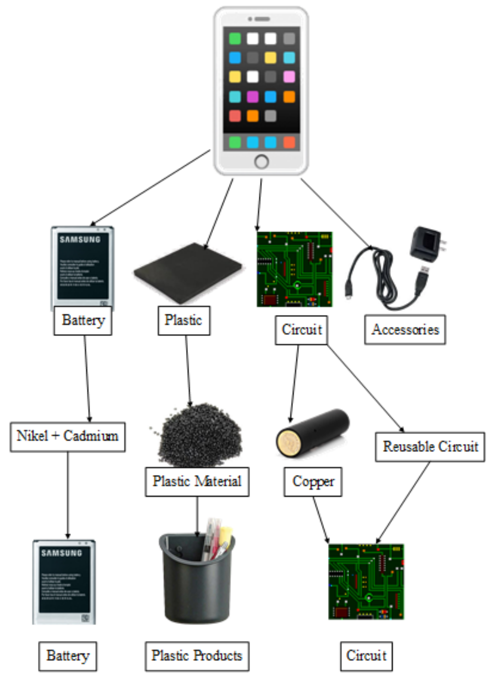

FIGURE 4. Mobile phone recycling process.

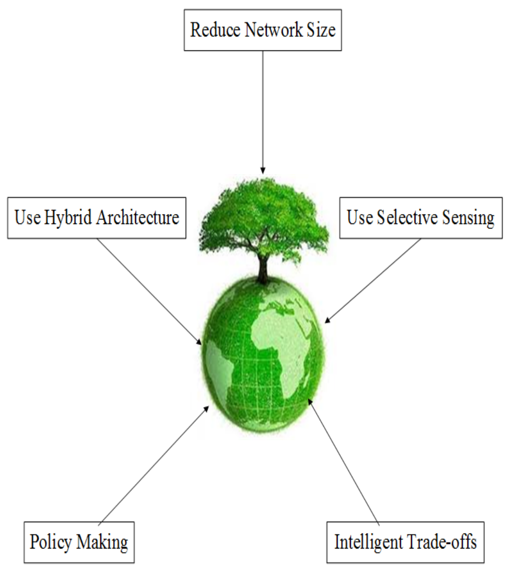

FIGURE 5. Green IoT principles.

two generations of the product expected to increase energy consumption correspondingly [60], [61].

On the basis of above literature and evaluation, we propose five principles (depicted in Figure 5), to achieve Green IoT and reduce carbon footprints.

1. Reduced Network Size: Reduce the network size by efficient placement of nodes and by using ingenious routing mechanisms. This will result in high-end energy savings.
2. Use Selective Sensing: Collect only the data that is required in that particular situation. Eliminating extra data sensing, a lot of energy can be saved.

3. Use Hybrid Architecture: Use of Passive and Active sensors for different types of tasks in an IoT network can reduce the energy consumption.
4. Policy Making: Devise efficient policies to reduce energy consumption in smart buildings. Policies can have a direct impact on the consumption of energy and as a result, a considerable amount of energy can be saved.
5. Intelligent Trade Offs: We have to do trade-offs everywhere, so we can intelligently prioritize cost and in some situations processing or communication to save energy like compressive sensing [62] and data fusion. Trade-Offs must be chosen according to a particular scenario.

IV. PERFORMANCE COMPARISON

In this section, we evaluate different models and approaches previously discussed and on the basis of our devised criteria to provide the best energy efficient model for an IoT scenario. Table 1 analyzes and compares different IoT models to achieve the energy efficiency and to make the IoT green. We evaluate if an approach is realistic or not on the basis of its performance in real life scenarios or whether that model can be implemented or not in a large scale IoT network and all the proposed models are found to be realistic. We also discuss the trade-offs to be considered which is a very important aspect as it highlights the shortcomings that one may face if they choose a specific technique. Furthermore, we also evaluate whether a model can have a practical implementation by calculating the balance between advantages and trade-offs. IoT is becoming prevalent in the market and its popularity is only going to increase more with time. However, in order to control the energy usage in the IoT environment, there are certain tradeoffs on processing, communication and sometimes on Quality of Service.

V. CASE STUDY: IMPACT OF SMART PHONES ON THE ENVIRONMENT IN PRESENT AND FUTURE TRENDS

The main purpose of green computing is to see the impact of mobile devices such as PDA (personal digital assistance) laptops and mobile phones or smart phones on environment. Since we are facing the problem of pollution in the environment, environment friendly products should be invented, promoted and used. Smart phones are one of the main causes of emissions and here considers the impact of these smart phones in both present and future. In this section, we consider the case study of smart phones which are a very important component of the IoT. We investigate and foresee its usage, impact and the recycling.

A. REDUCE THE ENVIRONMENTAL IMPACT

Smart phones play a vital role nowadays. Alongside using smart phones, we also need to consider achieving green environment. Green IT focuses on the energy- efficient equipment and eco-friendly hardware in terms of using, designing, manufacturing, and disposing [63], [64]. Technology is causing environmental encumbrance as a result of the desired resources. To reduce the smart phone emissions impact on environment, the researchers in [65] suggested to choose green material, change contract length, cut down on packaging and accessories, and design for disassembly and energy saving batteries.

1) TOXIC MATERIAL

In [66] a smart phones charger can be the cause of the environmental damage because its main component is print wiring boards [67], the main problem was the electronic components. The CO2 emissions generated from the incineration of plastics were almost the same as they were by metals [68]. Metals are harmful for the environment [69]. The mobile phones are the more toxic substances, a number of standing and are bio accumulative chemicals ‘‘waste minimization of the US EPA is bio accumulative and toxic chemical substances’’ [70]. PCBs from the mobile phone are made up of 13% polymers, 63% metals and 24% ceramics [71]. The eco toxicity in the water is due to cell phones material that is cu(copper) [72].

2) RECYCLING

Recycling is the process of applying some techniques on existing equipment, usually faulty, and to make same material or some other useful material [73] . In [74], china collection rate of the mobile phones for recycling is less because many of them are reused in the secondhand market; this reuse does not affect the environment. The entire approach is financially headquartered on reselling refurbished cell phones and recycled substances to developing international locations which signify a potent and strong market [75], [76]. The results suggest that of the State of California First Mobile Phone recycling (AB 2901) act, which is the only place of the prohibition on the questionnaire and a significant and positive effect on the recycling of mobile phones. Approximately 15% of the mobile devices are returned for the recycling in the countries that are industrialized [77], [78] The misery of the mobile use, implement correctly a global urgent need of the mobile phone waste management. For environmental benefits should be encouraged to draw the attention of the consumer that what is important and good management [79]. At the national level less than 3% of the mobiles treated as one of the main EEE recycling plants [80]. In china, the mobile phone waste recycling examples are the green card recycling activity and the green box environmental program [81], [82]. The main reason for the mobile phones replacement is the physical damage [83]. E-waste is the cause of environmental damage and green IT is achieving by managing e-waste and this analysis also gives a solution like print both sides of the paper in the organizational level.

3) GREEN METRICS

The research carried out in [61] improved the energy efficiency of mobile system networks and some special devices were extended, so many energy efficient metrics (called green metrics) were proposed. There are mainly two types of metrics [84], the facility metrics and the equipment metrics.

Equipment level metrics report for lower efficient rating of a single piece of the equipment of mobile network with particular functionalities in micro aspects, such as the TEER (Telecommunications Energy Efficiency Ratio) proposed by the ATIS (Alliance for Telecommunications Industry Solutions) [85], the TEEER (telecommunications equipment energy efficiency rating) by the Verizon NEBS Compliance [85], the CCR (consumer consumption rating) [86], the ECR (energy consumption rating) [84] etc. The green rate can be estimated by the energy consumption of the network or by total power consumption [86], [87]. By using clusters of green metrics we can find what amount of energy consumes at the run time in an application.

4) DESIGN FOR DISASSEMBLY AND REPAIR

Many phones are intentionally glued within a case that stops customers from opening them. Designing smart telephones which are less complicated to take apart, to restore or exchange components would make a massive change. And it will make it more price-effective to extract and reuse components and metals.

5) CHOOSE GREENER MATERIALS

Similar to polylactic acid plastic (PLA), which is made completely from corn starch or glucose and is renewable and biodegradable; recycled plastic and ordinary substances like bamboo or use fewer substances.

6) ENERGY-SAVING BATTERIES

The natural and organic radical battery (ORB) uses no heavy metals that may be detrimental to humans and charges in just 30 seconds.

7) CUT DOWN ON PACKAGING AND ACCESSORIES

Are all these manuals, chargers and packaging substances relatively needed? 70% of purchasers have already got suitable chargers for the 30 million new phones offered annually. HTC, Nokia and Sony now promote some units with simply USB leads alternatively of needless chargers, as part of O_2 (it was the primary community to strengthen an eco-ranking in the UK in 2010 with independent sustainability group discussion board for the longer term. It's the one eco-score presently to be had within the UK) Chargers out of the field campaign.

B. LIFE CYCLE ASSESMENT OF SMATPHONES

An environmental LCA (life cycle assessment) method is used for conducting the analysis of smart phones product life cycle [88], it exceeded the traditional production and manufacturing processes so that the environmental and social and economic effects of the entire life cycle of the product, including the consumption and should be taken into account during use. In a mobile phone functional unit, the LCA method is used for 3 years in production [59]. LCA results showed that refurbishing creates the highest environmental impacts of the three reuse routes in every impact category

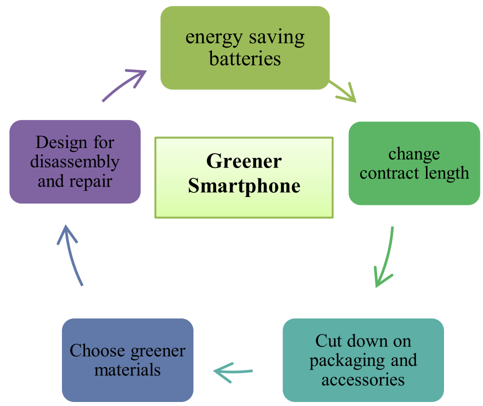

FIGURE 6. Lifecycle assessment of smart phones.

except ODP (ozone depletion potential) [89]. The usage of electricity and the CO_2 emission is reduced by 20-55% and 18-74% in virtual desktops (VD). Through this method environmental effect/impact of recycling was analyzed [68], [90]. This method is used to compare the environmental effect of the various chargers, efficiency and the environmental impact of the material selection. LCA software found that the damage assessment of a charger is higher as compare to the other parts of a smart phone [66]. In the comparison of the feature phone of 2008 and the smart phone LCA result shows an increment of 34 kg CO_2 [91], [92]. It is more consistent than PCs, for the mobile phone and TVs. Figure 6 presents the LCA of smart phones.

C. SMART PHONE EMISSION AND SELLING RATE

To fulfill the modern IT requirements, the substructure of the smart phone industry has been expanded and ascended which brings many issues related to the green IT [93]. According to the reports information, following table shows the emission rate of different smart phones [94], [95]. Samsung galaxy S4 emission was certified by the Japan environmental management association for industry (JEMAI). It includes the iphone6s, galaxy s4 and Nokia Lumia 1520 [96]. Table 4 shows the approximate sales of the mentioned mobile phones. By taking the selling rate of 2014 and 2015 into account, we calculate the growth rate per year. We assume that the growth rate will be same as previous years and we forecast the impact of carbon dioxide emission in year 2020. This forcast is illustrated in Figure 7.

VI. DISCUSSION AND OPEN ISSUES

IoT is an impeccable technology and it could prove to be vital for the dynamic needs of the modern technological world. It is going to have a drastic impact on the World's economy in the comings years (depicted in Figure 8). Analysts at Business Insider predicted that out of 34 billion devices connected to Internet in 2020, 24 billion will be IoT based (Increased usage of Smart Phones is shown in Table 5) and almost \$6 trillion will be spent for IoT

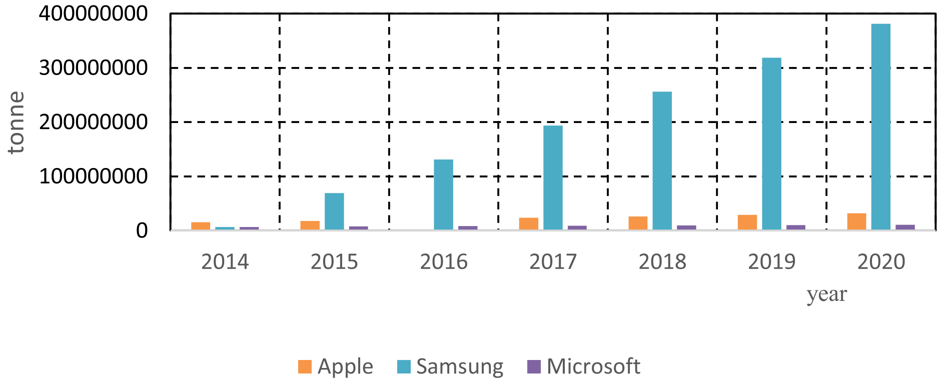

FIGURE 7. Forecast illustrating CO^2 emission of smart phones.

TABLE 3. CO_2 emission percentage.

Ref.	Method	Media impact	Main theme	Total CO^2 %
[88]	LCA method is used for measuring the performance of the smart phones	Air	Effect of charger on life cycle	2%
[1]			Power consumption reduce	35%
[74]			In china power consumption calculate.	0.17%
[20]			Power consumption decrease.	10%
[98]			Reduction	65%
[91]			During 3 years' life time of Sony XperiaTM T total emission.	45%
[99]			Whole life cycle of mobile phone emits.	60-80%
[71]			Copper concentration in printed circuit boards from mobile phones.	34.5 wt.%
[61]			For cooling devices power consumption.	50%
[83]			Achieve reduction before 2020.	20%
[100]			Achieve reduction in 2020.	40%

TABLE 4. Emission of smart phones.

Smart phones	Production	Customer use	Transport	Recycling	Total CO2
iPhone 6s	84%	10%	5%	1%	80kg
Galaxy S4	2%	18%	1%	0%	21.55kg
Nokia Lumia 1520	74%	13%	9%	1%	37kg

TABLE 5. Selling rate of smart phones.

Smart phone	2014 units	2015 units	2016 units	2017 units	2018 units	2019 units	2020 units
Apple	191,425.8	225,850.6	260,275.4	294700.2	329,125	363,549.8	397,974.6
Samsung	307,596.9	320,2197	6,096,797	8,991,397	11,885,997	14,780,597	17,675,197
Microsoft	185,660	204,460	223,314	242,168	261,022	279,876	298,730

based solutions in the next 5 years [62] (Depicted by Figure 7). It was also predicted by Cisco Internet Business Group that there will be almost 7 devices connected to Internet for every person in 2020.This exhibits the remarkable effect IoT is going to have on ICT industry but notable concerns of energy efficiency and carbon footprints need to

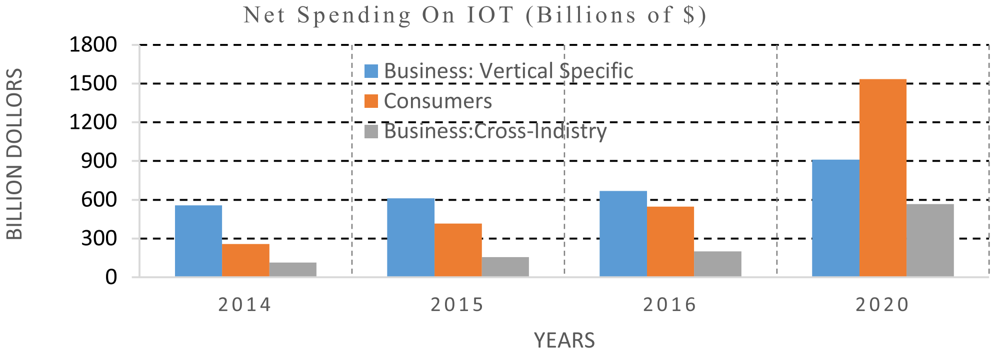

FIGURE 8. Economic impact of IoT.

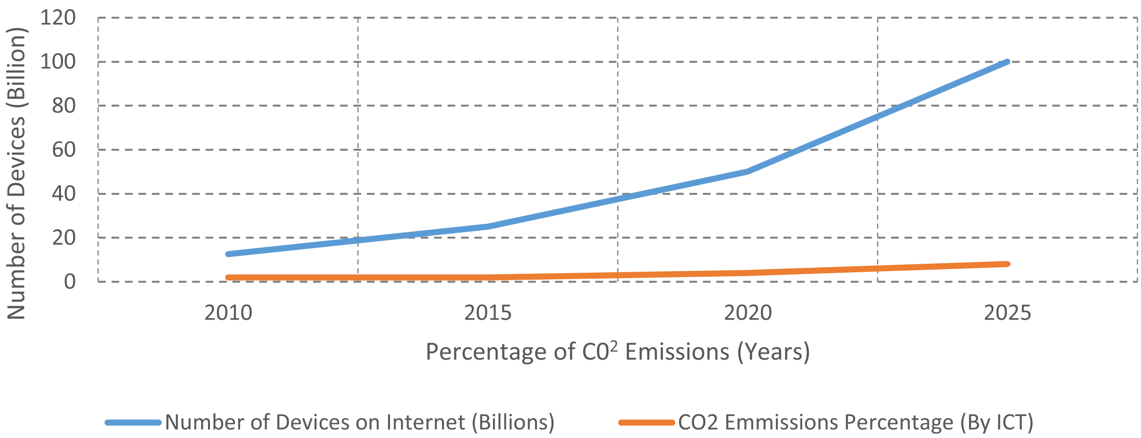

FIGURE 9. CO_2 emission predictions.

be addressed for IoT to become an extensive technology. IEEE Green ICT Initiative reports that 2% of total CO_2 emissions presently are caused by ICT Industry and it is going to double in the next 5 years (depicted in Figure 7 and Figure 9) [63] if sufficient measures are not taken. Many industrial corporations and technology giants are paying attention to these issues and are coming up with some viable solutions [97] but technology of such significance needs divergent strategies. Detailed CO_2 emissions of different materials is provided in Table 3 and Table 4. Moreover, we have already described and critically evaluated a number of models proposed by researchers to tackle these two serious issues. We have provided some suggestions to problems that need to be researched to develop more generic solutions for energy concerns in the IoT network.

- More research is needed to develop a common architecture for IoT because it will help in developing more generic solutions for energy efficiency.
- Recyclable material for the development of sensors needs to be thoroughly investigated.
- There is a need for a comprehensive research to devise Policies for creating awareness among the users and providers for efficient deployment of IoT solutions.

According to [65], for each 85 kWh electricity consumptions, one tree is needed to neutralize the carbon footprints generated by that electricity and according to [66] in 2007 18PWh energy was consumed by ICT industry. So, if we go deep into calculations, we will need hundreds of billions of trees to save our environment from CO_2 emissions generated by only 2% electricity consumption. Alternatively, carbon footprints can be minimized by devising divergent mechanism which makes for a viable long term solution. Smart phones are very important component of the IoT. Currently, there are billions of smart phones built. These smart phones can play a very important role in the green IoT. We investigated and explored several ways which could be deployed to achieve energy efficiency and green IoT. Our forecast clearly indicates some alarming situations and if appropriate actions are not taken now, the results could be disastrous.

VII. CONCLUSION

In this paper, the major challenges of energy efficiency and carbon footprints in the IoT network have been discussed and different solutions to solve these problems have been critically evaluated. Furthermore, a detailed taxonomy of methods to achieve Green IoT has been provided in this paper. Five principles have been proposed to realize the concept of Green IoT. The impact of IoT on economy is going to be paramount and it is predicted to revolutionize the entire ICT industry. The need of research for a generic architecture, recyclable material and policy making to achieve Green IoT has been highlighted. IoT can undoubtedly change the course of technological advancements in the world if focused and dedicated work is put in the right direction. The world awaits the wonders it can unfold.

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