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Research Article

Energy-Efficient Communication Protocols for Massive IoT Deployments: Green IoT

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ABSTRACT

The Internet of Things (IoT) is a rapidly growing technology that connects billions of devices, generating significant energy consumption. However, this energy consumption is a significant concern for the environment. Green IoT aims to reduce this energy consumption by incorporating strategies such as designing energy-efficient data centers, transmitting data from sensors, and implementing energy-efficient policies. These strategies can help create a sustainable environment for IoT devices. A case study of smartphones is provided to illustrate the importance of adopting green IoT practices. By focusing on energy-efficient data centers, data transmission, and policies, IoT devices can contribute to a more sustainable and environmentally friendly future.

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1. Introduction

The Internet of Things (IoT) is a revolutionary technology that connects daily life objects using sensors like Radio-frequency identification (RFID). It has been projected to revolutionize the world similar to the Internet itself, with an exponential increase in RFID sales. However, energy consumption concerns are expected due to active RFIDs needing battery-powered energy (Orgerie et al., 2014). To make IoT green, various strategies must be implemented to fulfill the energy hunger of billions of devices.

The mechanism of IoT consists of several elements such as identification, sensing, communication, computation, services, and semantics. Identification ensures that required data or service reaches the correct address, while sensing collects information from different resources and sends it to data centers for analysis. Communication in IoT uses Wi-Fi, Bluetooth, microcontrollers, microprocessors, Field Programmable Gate arrays, and many software applications (Mohd Aman et al., 2021). Services can be related to identity, information aggregation, collaborative, or ubiquitous. Semantics deals with intelligent knowledge gathering to make decisions. To make 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. The current era is considered fully Internet-based, and our dependence on the Internet and devices is rapidly increasing. IoT is revolutionizing our daily life activities by tracking different scenarios and making intelligent decisions to improve our lifestyles and protect our environment. There are numerous applications of IoT in daily life, such as smart homes, food supply chains, the mining industry, transportation, garments, and smart cities.

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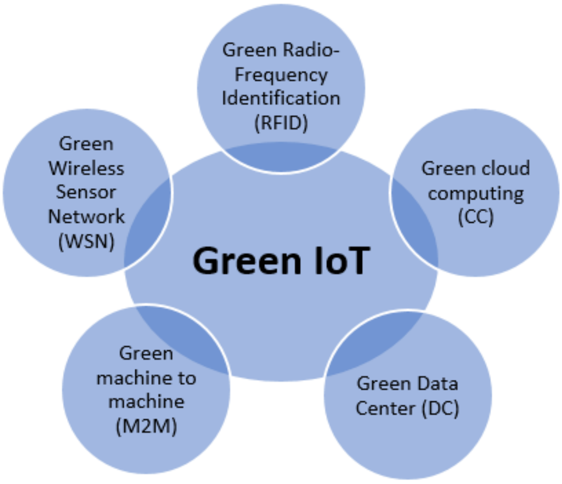

Fig. 1. Green IoT concept.

However, IoT technologies come with challenges, such as security and privacy, which experts need to work on to gain trust among users. By 2025, the National Intelligence Council of the US predicts that by 2025, daily life objects will be part of the Internet, resulting in billions of devices connected to the Internet. This requires huge processing and analytics capabilities, which consume a lot of energy resources. Additionally, the emission of CO_2 due to ICT products is increasing rapidly, damaging our environment. To address these critical problems, the Green IoT is an important topic.

This paper illustrates the concept, necessity and advantages of Green IoT. Along with that, the conceptual changes in networking as a result of green technology are described in Fig. 1.

2. Related literature

The rapid development of smart and IoT technologies has revolutionized various aspects of life, aiming to simplify processes, improve efficiency, and enhance life quality. However, this rapid development must be carefully monitored and evaluated from an environmental perspective to minimize harmful impacts and ensure smart utilization of limited resources. The 4th International Conference on Smart and Sustainable Technologies in Split and Bol, Croatia, highlighted the complex effects of IoT technologies on societies and their potential impact on sustainability. The conference focused on four main areas: IoT technologies in Sustainable Energy and Environment, IoT-enabled Smart City, e-health, and Transportation and Low Carbon Products (Nižetić et al., 2020). A study shows that in order to enable huge IoT applications, fog computing is a potential technology that will provide computational and storage services in future 6G networks. Nonetheless, energy-efficient methods for compute and storage services are required due to energy constraints in fog nodes and Internet of Things devices. The vast IoT and 6G-enabling technologies are examined in this essay, along with the opportunities and challenges of creating energy-efficient fog computing solutions for the Internet of Things. Future prospects and unresolved issues are also covered (Malik et al., 2021).

To understand the concept of Green IoT, research concludes that The Internet of Things (IoT) is revolutionizing communication through sensor actuators, enabling the collection and distribution of critical data. However, the use of resources presents challenges, leading to the search for green IoT that prioritizes energy efficiency. One such component is Radio Frequency Identification (RFID) applications, which can address energy use issues by integrating new solutions for Green IoT technology. This paper explores the impact of RFID applications on green IoT, focusing on challenges, environmental consequences, and benefits, including performance, safety, and advantages and disadvantages (Yusoff et al., 2021).

3. Green IoT

Green IoT focuses on energy efficiency in IoT principles, aiming to reduce the greenhouse effect caused by existing applications or eradicate it in IoT itself. To implement Green IoT, various strategies are proposed, including a framework for energy-efficient optimization of IoT objects, Green RFIDs, Green Datacenters, Green Sensor Networks, and Green Cloud Computing. IoT is an emerging technology that is changing the way we see the IT industry, but it also presents challenges such as large-scale consumption of energy resources. To address this issue, a critical literature review of models proposed for energy-efficient deployment of IoT is presented, categorizing them based on the technologies used in them (Arshad et al., 2017).

Green IoT is a hot research topic in the ICT industry, as traditional energy resources are decreasing rapidly and the use of energy is increasing exponentially. However, system models explicitly designed for Green IoT were not discussed. Comparisons of energy consumption of cloud and PC computing over various scenarios were deduced, with situation-wise choice being the best option.

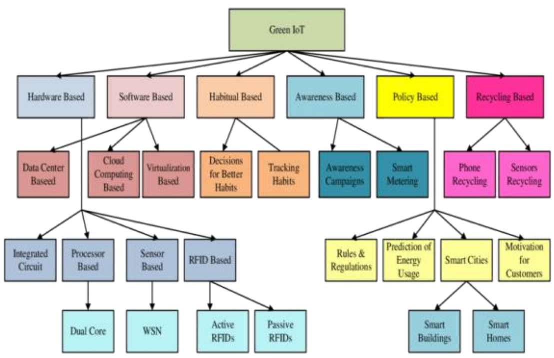

Fig. 2. Green IoT taxonomy(Arshad et al., 2017).

Green Technologies to implement IoT while maintaining Quality of Service (QoS) across various domains were elaborated in Fig. 2, emphasizing the importance of data centers and cloud computing. Strategies to conserve energy using Smart Buildings via data collected through IoT were discussed, but comparative analysis of energy conservation was not discussed. Wireless sensor networks (WSN) are a vital component in IoT deployment, and further research is needed to explore alternative energy storage methods.

4. Software-Based Green IoT Techniques

Energy efficiency is a crucial aspect of IoT, as it helps to reduce energy consumption and improve the overall performance of the system. Data centers play a pivotal role in an energy-efficient IoT network, but implementing energy efficiency in these centers is essential for their viability. Various architectures have been proposed to achieve this, such as e-CAB, CMOSDEN, and CMOSDEN. Sensors consume unnecessary energy when they are idle but powered on, and an energy-efficient scheduling algorithm has been proposed to conserve energy usage. However, the requirement of an embedded server may generate energy overheads due to the need for an extra server in case of server failure. Virtualization can also help decrease energy consumption within architectures, with a virtualization framework using Mixed Integer Linear Programming (MILP) showing 36% less energy consumption. Gemini, an optimization model for green and scalable IoT, has shown promising results in achieving energy efficiency. However, it needs to be implemented on a large-scale network to achieve valuable results. The medical industry is increasingly using IoT for real-time patient data storage, and using cloud storage and Access Points (AP) can help reduce energy consumption. Smartphones, with their strong sensing power, are a driving force in the technology industry, but energy efficiency remains a significant challenge. A novel solution, propounded in, records data in different applications, contexts, locations, and times to predict energy consumption in smartphones. However, more research is needed to develop efficient data mining techniques for predicting energy efficiency for a broader IoT network. Fig. 3 shows green IoT sensor nodes.

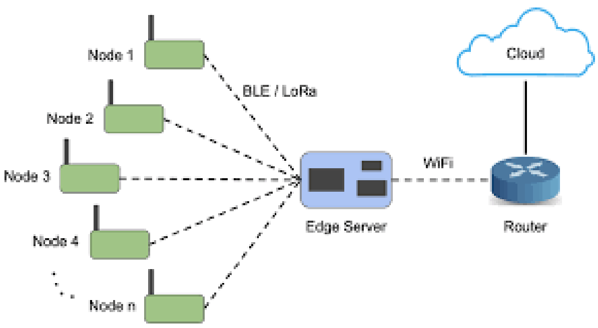

Fig. 3. Green IoT sensor nodes.

The consumption of energy during arbitration in RFID systems is a challenging issue that needs to be resolved. A solution to this problem involves using multiple slots per node of a binary search tree to reduce collisions among tag responses. Compressed sensing (CS) is an emerging theory that can efficiently sample and reconstruct data and reduce energy consumption in WSN and IoT. Wireless smart sensor networks (WSSN) can be useful in implementing IoT and developing energy-efficient ways for them. Medium Access Control (MAC) is used to limit extra communication between nodes, increasing the lifetime and decreasing energy consumption. A Programming Language named EPDL was designed to help non-experts write energy policies for a smart environment like IoT.

Overhearing problems in RFID can be addressed by calculating communication periods in advance and putting tags to sleep when not in use. The ICT industry must design mechanisms that consider efficient energy consumption, as the ratio between green and non-green nodes in a network can vary significantly.

5. Hardware-Based Green IoT Techniques

The Internet of Things (IoT) has revolutionized the way we communicate and interact with devices, transforming the way we consume energy. Active RFID, a key component of IoT, has been optimized for energy efficiency, but advancements in passive RFID and Wireless Identification and Sensing Platform (WISP) can lead to more efficient and low power computation. However, some energy-expensive commands in series could cause communication delays between sensor nodes and interrogators, leading to serious energy overheads.

Fig. 4. Green IoT based recycling process.

The design of Integrated Circuits (IC) in an IoT network is vital for energy conservation. Green Sensors on Chip (SoC) improves the design of IoT networks by combining sensors and processing power on a single chip, reducing traffic, e-waste, carbon footprint, and overall energy consumption. However, the use of recyclable materials can also help conserve more energy. The Time Reversal Technique reduces power consumption by powering sensors from radio frequency signals, simplifying sensor nodes and minimizing work done at the sensor-end. Base stations (BS) are introduced to communicate with sensors for data processing, but communication delays between sensor nodes and BS can cause severe energy overheads. CoreLH, an energy-efficient dual core processor for IoT, reduces energy consumption by assigning tasks based on resource requirements, as presented in Fig. 4.

A hierarchical architecture using a novel service discovery protocol reduces energy consumption by introducing Cluster Heads (CHs) and Area Routers. However, CHs require constant battery supply to ensure quality. Smart Passive Sensors can further decrease energy consumption and wastage. Discontinuous Reception/Transmission (DRX/TX) is a mechanism that allows devices in IoT like sensors to switch off when they are idle to conserve energy. A three-stage optimized DRX/TX scheme focuses on energy saving and Quality of Service (QoS) for IoT in LTE-A networks. Policies and strategies based on real-time data from IoT devices can help save energy on a large scale. These strategies can be used to identify different parts of a building where occupants' behavior and energy consumption vary and to make decisions to save energy. City Explorer, a home automation solution, minimized energy consumption by 20% when applied to real-life scenarios.

6. Conclusion

The Internet of Things (IoT) is a crucial technology that is expected to significantly impact the ICT industry in the coming years. Analysts predict that 24 billion of the 34 billion devices connected to the Internet in 2020 will be IoT-based, with nearly $6 trillion spent on IoT-based solutions in the next five years. The ICT industry is predicted to have nearly 7 devices connected to the Internet for every person in 2020. However, concerns about energy efficiency and carbon footprints need to be addressed for IoT to become an extensive technology. The IEEE Green ICT Initiative reports that 2% of total CO2 emissions are caused by the ICT industry, and it is predicted to double in the next five years without sufficient measures. To address these issues, researchers have proposed several models to develop more generic solutions for energy concerns in the IoT network. These include developing a common architecture for IoT, investigating recyclable materials for sensor development, and devising policies for the efficient deployment of IoT solutions. Additionally, smartphones play a significant role in green IoT, and if appropriate actions are not taken, the results could be disastrous.

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