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Green computing for Internet of Things

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***Abstract*— Cloud computing services are used to meet the ever-growing demand for IoT. Data centers are increasingly becoming one of the largest consumers of energy to provide the infrastructure for the IoT paradigm. The demand for energy increases in the future as more innovations emerge, and technology follows new practices resulting in green computing being adopted. Green computing strategies reduce energy consumption by IoT devices without degrading their performance. This paper will evaluate numerous aspects of green computing for IoT computing analyzing critical concepts, challenges, and remediation.**

***Index Terms*—Internet of Things (IoT), cloud computing, edge computing, energy consumption.**

I. INTRODUCTION

Internet of Things (IoT) brings together smart objects integrated into a heterogeneous network for monitoring and decision making process. It involves large scale sensor data harnessed using computing resources. Green computing enables an eco-friendly way of using resources and other practices. It involves designing and doing away with various elements used for computing to reduce harm to the environment. Companies have started to invest in computing devices made of recyclable materials. The aim of green computing is an eco-friendly usage of computing resources and economically viable methods. Figure 1 shows the IoT device statistics by year. IoT devices connect to different networks, and their growth has been continuously increasing as the organizations progress towards digital transformation. They also have an impact on global spending and revenue generated from the IoT market. These added devices also introduce network security issues that must be addressed appropriately [1].

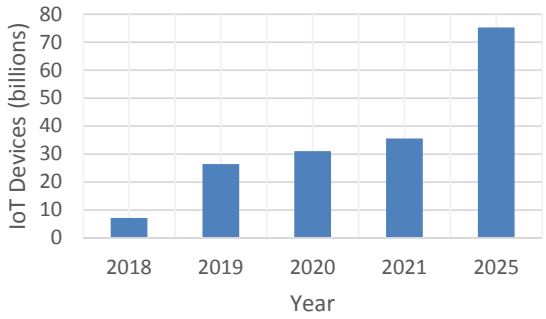

Figure 1: IoT statistics

II. BACKGROUND

Green computing

Green computing is designing and usage of resources that are eco-friendly and maintain computing performance without degradation. The resources used for computing are recycled after its usage, and the company manufacturing these devices should consume less energy and readily be biodegradable. The majority of IoT devices are energy-efficient sensors, which has resulted in heavy usage of them by industrialists. These sensors also benefit IT advancement using wireless networks efficently. Data centers provide data storage and processing capabilities for big data. Cloud computing platforms are challenged with the rise in the number of IoT devices. These IoT devices require low latency and mobility, which has resulted in edge computing for real-time services. Fog computing is a distributed computing paradigm whose purpose is to interconnect the network devices at different levels of computation. They provide low latency response to IoT devices, which centralized cloud computing architecture fails to deliver. Green computing is focused on the maintenance of computing capabilities and, at the same time, reduce the consumption of energy and be eco-friendly. There have been technological improvements in the manufacture of computer CPUs, becoming more energy efficient from one generation to the other. But, an increase in the number of computing devices that are used has made it essential to address green computing needs. Green computing has been adopted in cloud computing to lower energy use and reduce the usage of hazardous materials in devices [1, 2].

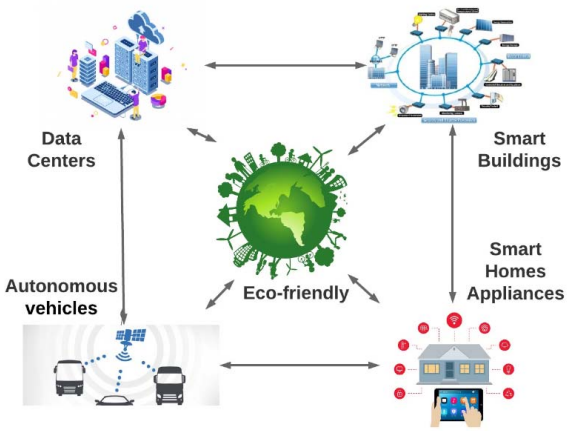

Figure 2: IoT green computing

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Internet of things

IoT is an interconnection of devices building a smart world. It is a paradigm that impacts both society and technology. IoT technology involves building infrastructure for smart objects interconnection based on evolving information and network services. The data gathered from the devices need to be processed for analysis, and the data privacy policy must be ensured. In building a smart city, IoT is characterized by efficient use of energy since the number of sensory devices and the linkage add-ons to facilitate communication with each other. Green computing has to focus on the reduction of energy consumption to meet the sustainability of the smart city and also be eco-friendly [3].

IoT has become a significant component in today's world that interconnects devices that are important in making decisions. The majority of these devices are sensors and equipment that facilitate the exchange of data through various networks enabling the device to device information sharing. This has resulted in the emergence of edge computing to achieve low latency response and alleviate resource congestion on the centralized data centers. It transfers all the device data computation to an edge data center near to them. The distributed infrastructure also balances network congestion created during transmission of data [3].

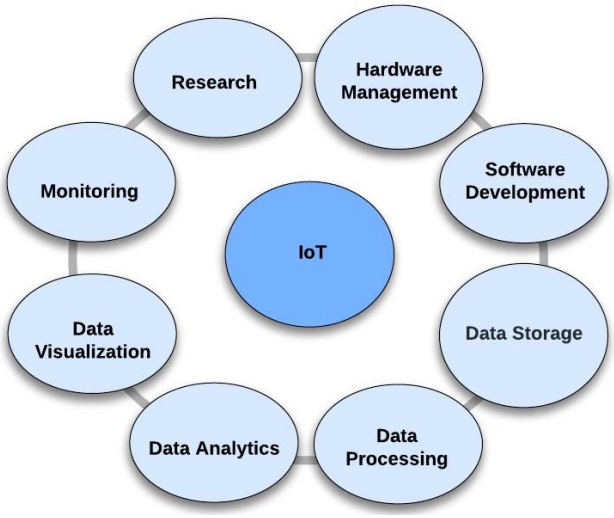

Figure 3: IoT applications

IoT applications are dependent on the internet for communication, embedded hardware manufactures, and management of IoT devices, cloud computing for storage and processing. Finally, the presentation layer for the interpretation of data which form different applications layers of IoT [4], as shown in Figure 3. The architecture layer of IoT comprises of the perception layer consisting of sensors and actuators. The network layer enables interconnectivity and communication between devices for transmission of data. The application layer includes tasks such as display of processed data and other abstract services. Figure 5 shows various layers and their components classified based upon their energy consumption [5].

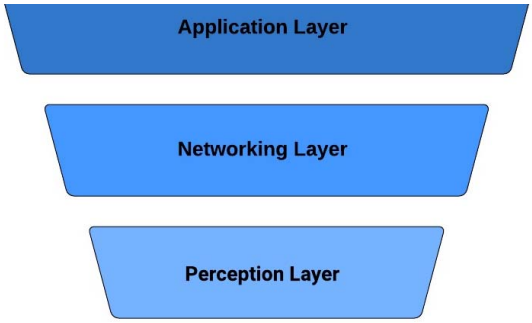

Figure 4: IoT architecture layer

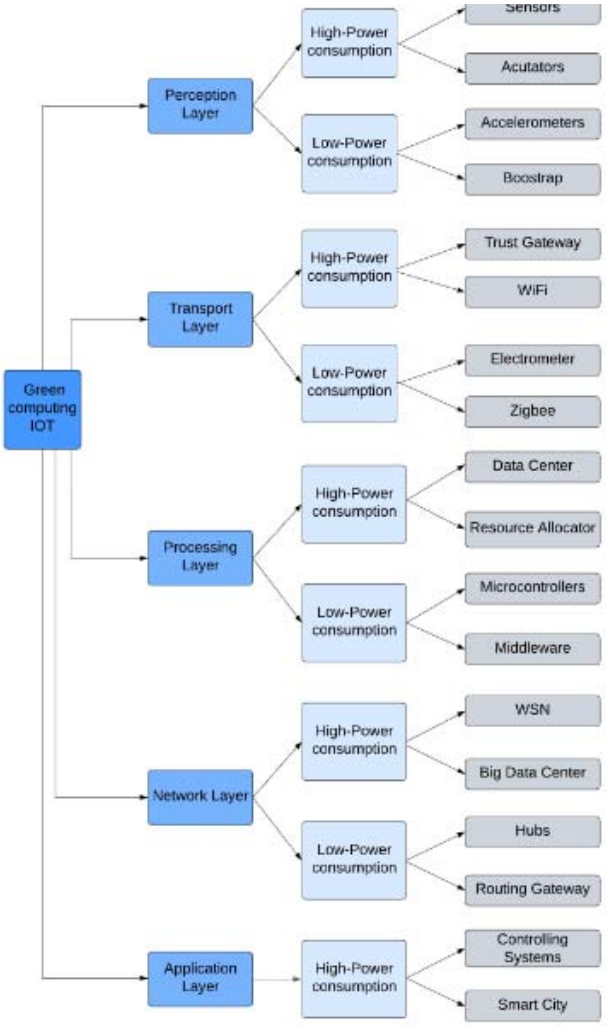

Figure 5: IoT classification based on power consumption

Cloud computing

Cloud computing has resulted in the emission of CO2 due to the energy consumption from the data centers. Various practices have been adopted to lower the energy consumption by data center machines by using hardware virtualization and energy-

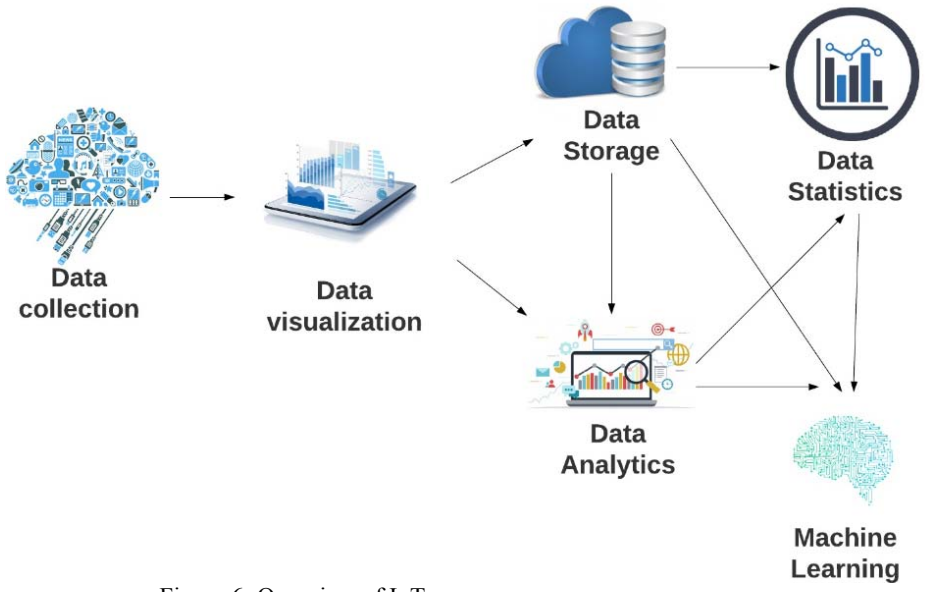

Figure 6: Overview of IoT

Conversant strap in software applications. The energy consumption is predicted to rise with the continuous usage of cloud computing services and the data centers which host them. It is for this energy concern that there is a need to rethink how data centers adopt green computing, and the equipment been used [6]. An overview of IoT data been collected from devices, processed, and analyzed, is shown in Figure 6.

Edge-IoT

An increase in the rise of mobile devices has resulted in mobile edge computing (MEC) for low latency responses. MEC provides mobile computing, network congestion control, and storage capacity to the edges of the networks. MEC lowers the usage of mobile energy and supports latency-critical applications. The development of the 5G network has been motivated by the gains of MEC, which combines both wireless communications and mobile computing to offload network computation. Wireless sensor networks are responsible for sending data by indoor devices, at the front end of Wireless Mesh Sensor Networks (WMNs), edge devices are deployed to reduce the network congestion helping users to tailor their needs through MEC [6].

III. Application of Green Computing in IoT

There are many government regulations to promote green computing. IoT edge computing has developed and benefited many industries. The various technological domains using green computing are:

Autonomous vehicles

The automobile industry is investing in autonomous vehicles for driverless cars, which will have to analyze and make decisions on data that pertains to their surroundings for movements and directions. These vehicles need to transmit Data to the manufacturers so that they can track their usage and also get the required maintenance alerts. The data will be transmitted through networks resulting in congestion. To achieve low latency when accessing the network, it is necessary for the manufacturers to device new effective computing ways [7].

Edge computing aides the autonomous vehicles in transmitting and sharing the data between them. Edge data centers that are located at nearby geographical proximity helps in making the flow of data seamless. They also enable less usage of energy for sensors used in these autonomous vehicles. Since there is a shift towards the adoption of autonomous vehicles, the risk of carbon emissions is reduced, which will be a step forward towards the eco-friendly approach [7].

Smart cities

The data collected from sensors, which includes traffic, infrastructure, and home appliances, are used by city leadership to address the challenges witnessed in these cities. The data collected from these sensors are massive and requires extensive computing capabilities to process and analyze them; also, the response back to these devices should be in real-time, resulting in less usage of energy [7].

Industries

Industries such as oil drilling, can utilize IoT edge computing to gather data on a variety of environmental factors without relying on pre-collected historical data. Thus by adopting edge computing in industries, there will be lesser energy consumption in production [7].

IV. Advantages of Green Computing

Green computing brings various benefits; some of them are:

Eco-friendly
Green computing reduces the negative impact of the manufacturing and disposal of computing devices in a manner that is eco-friendly and ensures environmental sustainability.

Resource utilization
The data centers use resources such as computers for processing the collected data, the equipment used to make computer components should be biodegradable and also do not degrade on performance [8].

Low latency and Cost saving
Edge computing enables the allocation of resources in a manner that is efficient in energy consumption and reduces response latency. It also increases the lifetime of the devices saving on cost [8].

Improving on compliance
Green computing also enhances the compliance and regulation of the companies in meeting the business demands set by their customers and other stakeholders, also improving their image.

V. CHALLENGES FACING GREEN COMPUTING IMPLEMENTATION

Green computing awareness
*P*eople lack knowledge about green computing and its impact. Studies show that only 28 % of people are aware of CO2 emissions and the consequence it has on the environment [8].

Equipment cost
Companies will have to incur a fee by adopting green computing. People believe that using traditional methods; they can save as opposed to using modern energy-efficient means. However, recently companies are considering energy consumption and CO2 footprint of hardware equipment so that they can control emissions.

Performance degradation
There are concerns regarding the materials used for making eco-friendly equipment resulting in performance degradation. Hence it is required to educate people regarding the usage of biodegradable devices and their performance.

VI. SOLUTIONS TO THE CHALLENGES

People awareness
Many people are unaware of the various principles surrounding green computing. People should be made aware of conserving the environment by conveying the message regarding the energy consumption of devices they use and how they can be recycled.

Data centers
Data centers are an essential component of today's cloud computing industry. The energy consumed by these data centers should be reviewed frequently, and measures should be taken to use biodegradable hardware components [8].

Virtualization
Virtualization creates multiple simulated environments on a physical host abstracting the hardware. It allows for efficient management of resources and monitoring them. It enables resource sharing and low energy utilization [8].

Recycling equipment
People discard unwanted hardware, which should be biodegradable so that it is eco-friendly. A lot of computer parts could cause harm to the environment. Thus, by using recyclable material, we can reduce the impact of these materials on the environment.

VII. RESEARCH IMPLICATION

This paper provided a comprehensive insight into green computing for the internet of things. Green computing will require adopting practices that can reduce energy consumption and as well does not degrade the performance of the devices. Companies must focus on the energy-efficient design of IoT devices and create awareness among the people. It requires a change in policies and needs collaboration among organizations to promote green practices. This paper presents challenges and the potential solutions that can help in green computing. Researchers could provide insights into the best practices that should be followed for the integration of green computing in IoT. Green computing will not only be beneficial for the IoT but also promotes a cleaner environment.

VIII.CONCLUSION

Green computing for IoT remains the best consideration in building a sustainable ecosystem. Embracing green computing practices will contribute to making recyclable devices and reduce energy consumption across computing infrastructure. Green computing will, therefore, be an excellent solution for supporting the growth of IoT being eco-friendly.

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