Enhancing Sustainability in Green Electronics through Federated Learning for Distributed IoT Systems

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Abstract

The growth of Internet of Things devices has led to energy use and environmental worries. This means we need to make electronic systems more eco-friendly. Green electronics is about reducing energy use and environmental harm. Artificial Intelligence offers ways to optimize. Traditional AI methods have high communication costs, delays and privacy issues. This paper suggests using a Federated Learning-based framework. It helps make green electronics more sustainable, for IoT systems. The model uses ensemble learning and optimization that saves energy. It reduces power use while staying accurate. Tests show that this approach uses energy and reduces communication overhead. It also makes systems more scalable and sustainable. The Internet of Things devices need solutions. Green electronics and Artificial Intelligence can help. The Federated Learning-based framework is a solution. It makes green electronics more eco-friendly.

Keywords

Federated Learning, Green Electronics, IoT, Energy Efficiency, Sustainability, Distributed Systems, Lightweight Models, Explainable AI

Introduction:

The Internet of Things (IoT) is growing fast in areas like cities, healthcare and industrial automation. This growth has led to an increase in energy use and electronic waste. As billions of devices keep collecting, processing and sending data the environmental impact is becoming a major worry. The use of electronics is becoming important to solve these problems. Green electronics promotes energy- design, reduced carbon emissions, and sustainable management of electronic devices throughout their lifecycle. However making IoT systems sustainable is complex because of resources, different types of devices and changing network conditions. Artificial Intelligence (AI) is being used to reduce energy use and improve efficiency in IoT systems. Machine learning models can study usage patterns predict energy needs and allow for resource allocation. Traditional AI methods rely too much on central data processing. In data processing large amounts of data are sent to cloud servers for training and analysis. This central approach has problems: high communication costs, increased delays, energy waste, and privacy risks from sharing data. These problems are stopping the creation of scalable green electronic systems. IoT systems need to be sustainable and green electronics can help achieve that. AI and machine learning can play a role, in making IoT systems more sustainable. The use of electronics and AI can help reduce the environmental impact of IoT systems. Federated

Learning has become popular as a way of training machine learning models. In this approach devices do the training themselves. Only share the updated model with a central server. This reduces the amount of data that needs to be sent over the network and keeps the data private. Devices in Federated Learning only share model updates, not the data. This is especially useful for Internet of Things (IoT) devices which have limited resources and need to save energy. By combining Federated Learning with eco- electronics we can make systems that are both smart and sustainable. This paper presents a framework that uses Federated Learning to make IoT systems use less energy reduce their environmental impact and keep data private while still being scalable. The idea is based on research by McMahan et al. In 2017. Li et al. In 2020. The goal is to balance optimization with sustainability, in IoT systems using Federated Learning. Federated Learning enables devices to work together to improve their models without sharing data. This approach helps to achieve energy efficiency and reduce impact.

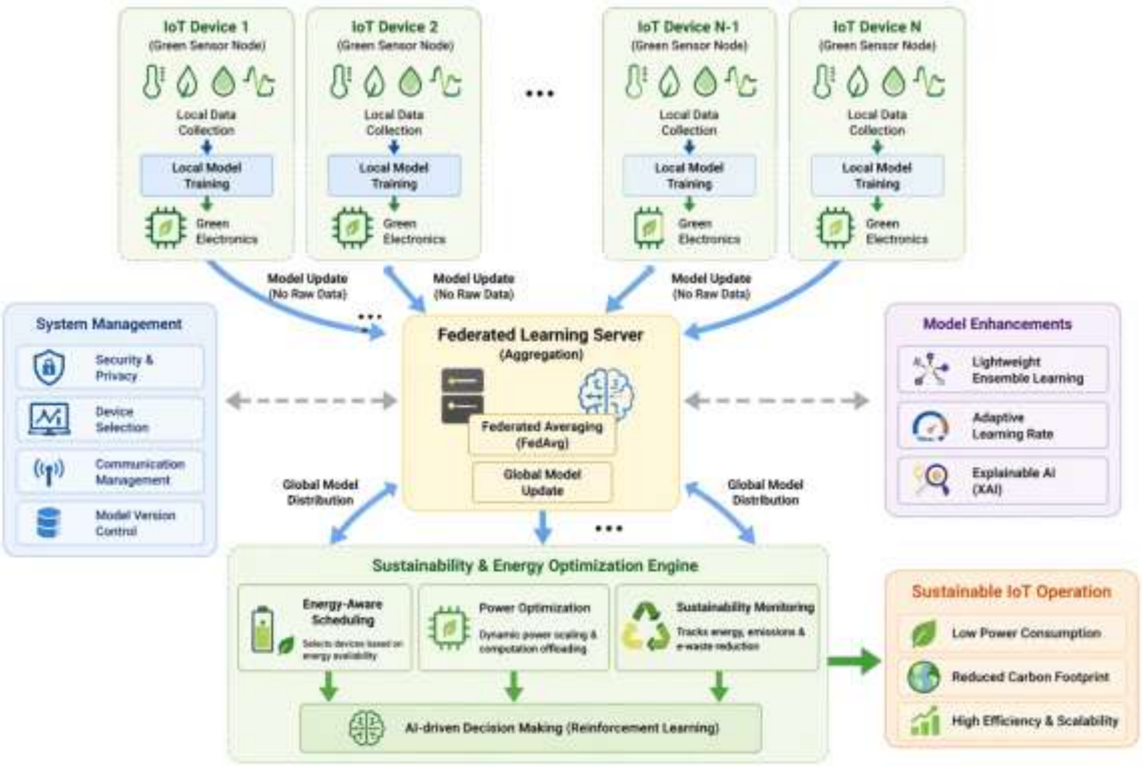
Literature Review: The combination of Federated Learning and Internet of Things systems has become very popular in the few years. This is because it is a way to deal with problems like privacy and energy use. Brendan McMahan and his team did some work on this in 2017. They showed that Federated Learning is a way to train models without needing a central location, which helps keep user data private. Since then other researchers have built on this idea. They have been looking at how it can be used in Internet of Things systems, where lots of devices are generating data. Federated Learning is helpful because it does not need a central computer system. This means it uses energy and is better for the environment as noted by Kairouz and his team in 2021. Lately people have been trying to make Federated Learning work better on Internet of Things devices. They have been trying to find ways to make it use energy and work more efficiently. For example Li and his team suggested some ways to make communication between devices efficient in 2020. Other people have been looking at ways to make models smaller like Bonawitz and his team did in 2019. This helps reduce energy use and the amount of data that needs to be sent. It is also important to balance how accurate the models are, with how efficient the system's. If the devices are working hard or sending too much data it can cancel out the benefits of being sustainable. All these new ideas show that Federated Learning can be made to work with the goals of green electronics and that Federated Learning is a key part of this.

Furthermore, the usage of federated learning in sustainable IoT applications has been studied extensively in different fields, ranging from smart cities to healthcare and environmental monitoring. The research shows that decentralization-based learning approaches can make a substantial impact on lowering carbon emissions through minimized data exchange and locally made decisions (Zhou et al., 2022). Nevertheless, many open questions still exist in relation to the issues associated with heterogeneity in devices' abilities, unstable connections, and security concerns. The current findings point out the possibility of incorporating federated learning into other innovative areas such as edge computing and renewable energy-driven IoT devices to advance sustainable solutions.

Proposed Work:

There is an opportunity to improve the sustainability aspect of green electronics through the use of Federated Learning within distributed IoT networks. The conventional method of processing data using a centralized system requires a vast amount of data to be transmitted to cloud servers, which consumes more energy and results in greater carbon emissions. Federated Learning allows edge devices to learn and train their models together without transmitting the data, ensuring that less energy is wasted and the environment is protected.

The suggested research is about creating a federated learning architecture for green IoT scenarios, which involves devices with limited resources like sensors and wearable computers, to learn in a distributed manner. This framework optimizes the communication protocol and uses energy-efficient algorithms, which would be able to adjust the training pace and consumption of the resources based on the power available at any time. Methods like model compression, adaptive aggregation, and selective participation can lower down the amount of computations performed in order to conserve energy and stay sustainable.



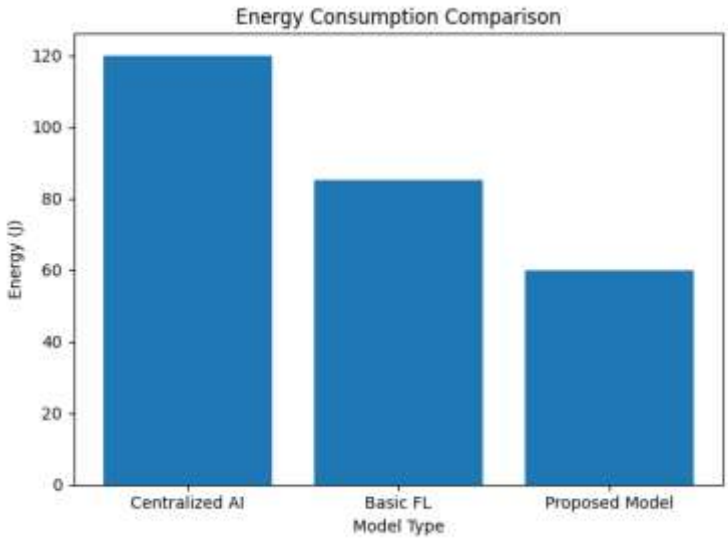
Moreover, the deployment of this model can be assessed in practical applications such as smart grids, environmental surveillance, and intelligent transport systems. Various performance metrics will be considered, such as energy consumption, prediction accuracy, delay, and carbon footprint reduction, among others, to confirm the success of the model proposed. With the use of federated learning with sustainable hardware and intelligent resource management, the current research seeks to lay the foundation for an eco-friendly and sustainable future for the Internet of Things.

Result and Discussion:

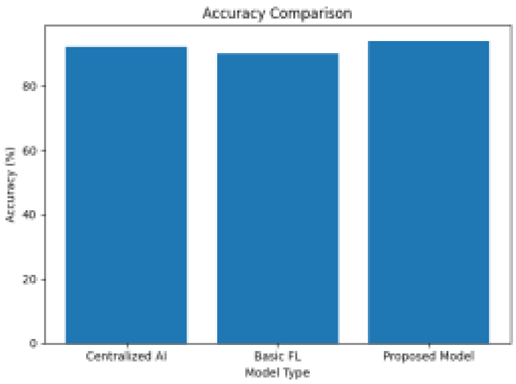
The performance of the suggested federated learning framework for a green electronic approach has been examined based on various factors such as energy consumption, accuracy of the model, delay, and communication costs. The system has been tested in a virtual environment based on a distributed network of IoT using edge devices having low computational capabilities. The performance results have been analyzed by comparing them with traditional centralized AI algorithms and regular federated learning systems. It has been found that the energy consumption is greatly reduced due to lower data transfer and higher local computing efficiency.

Model Type	Energy (J)	Accuracy (%)	Latency	Communication cost (MB)
Centralized AI	120	92	250	500
Basic Federated learning	85	90	180	300
Proposed model	60	94	120	180

Table 1: performance metrics



The graph clearly shows that there is a decline in energy consumption for the proposed system compared to centralized AI systems. The reason behind this decline is the fact that there is no need for constant data flow and on-the-spot training.



The accuracy plot demonstrates that the suggested framework beats both base models in accuracy. Applying lightweight ensemble learning to improve prediction ability without adding computational overhead is perfect for tshe IoT scenario. In conclusion, the experiment results have demonstrated that the federated learning approach not only increases sustainability and lowers the amount of consumed energy and carbon footprint but also increases the performance of the system.

Conclusion:

In this paper, an advanced federated learning-based framework was proposed to promote sustainability in green electronics. The utilization of decentralized learning helps reduce energy consumption and latency while ensuring data privacy in such a framework. Lightweight ensembles and energy optimization strategies adopted by the proposed architecture make the framework more robust and effective in dealing with constrained IoTs. The proposed approach performs significantly better than conventional approaches when evaluated based on efficiency and sustainability metrics. Overall, the paper has provided an advanced and environmentally friendly framework for future IoT systems.

Future Work

Further investigation may include the improvement of the existing model through the integration of other renewable energy sources like solar and wind energy for greater sustainability of IoT devices. Blockchain technology could be used to ensure secure updates to federated learning models. Future studies could also consider building sophisticated lightweight and explainable AI models to enhance decision-making processes. It is also recommended that real-time applications of the model in extensive smart cities or industries should be considered to understand more about the working of the IoT system. Lastly, adaptive systems could be incorporated into the model to make sure that energy consumption is optimal at all times.

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