A Solar-Powered Fleet Tracking System for Rural IoT Applications

(Technical Paper)

Impact of the Internet of Things on the Environment

(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Introduction

Former Google CEO, Eric Schmidt, said the proliferation of the Internet of Things (IoT) means "The internet will disappear. There will be so many IP addresses … so many devices, sensors, things that you are wearing, things that you are interacting with that you won't even sense it. It will be part of your presence all the time. Imagine you walk into a room, and the room is dynamic. And with your permission and all of that, you are interacting with the things going on in the room" (Smith, 2015). The IoT consists of all network-connected objects, from fitness trackers to smart home sensors. Over the last twenty years, the number of IoT devices has grown exponentially. Some predictions ten years ago stated the IoT would reach 1 trillion nodes by 2020 (Evans, 2011), while data from 2019 showed this figure reached 26.7 billion (Maayan, 2020). Such technology has the potential to solve many problems, by allowing sensors and communications to exist in the background of our daily lives as well as reach the most remote locations. Meanwhile, the ubiquitous nature of the IoT means its effects will impact the entire world, regardless of whether individuals choose to purchase and install such devices.

One application that the IoT has revolutionized is asset-tracking. In contexts that involve large-scale asset movement, such as car manufacturing, school or city bus systems, or even the new scooters available to rent at virtually every street corner, asset loss is costly so it saves companies significant amounts of money to track these assets using sensors. The IoT enables this tracking by allowing roaming sensor nodes to track the assets and occasionally transmit their GPS locations. However, until recently these asset trackers have either required the asset to possess a power source or be battery-powered. In the former, the applications of the sensor devices are severely limited and the assets' locations cannot be tracked when the asset is powered off. In the latter, the added battery component introduces the extra cost of both the battery and its replacement every few years. For my capstone project, my team is developing a “self-powered” fleet-tracking device, that uses harvested solar energy to power a GPS and transmitter module to send GPS data wirelessly to a central node for display on a laptop.

With regards to environmental impact, IoT devices are marketed as being sustainable because of their low power consumption and ability to decrease energy usage in various applications, such as in buildings or manufacturing. Most Science, Technology and Society (STS) research regarding the IoT has been about the social impacts of being surrounded by always-on, always-listening electronic devices (Choi, 2014). The only environmental research has been to claim that the IoT can be used to benefit the environment, such as reducing electrical waste in companies (Gu, 2017). However, there has been little research done about the detrimental effects of the IoT on the environment. These effects are potentially more substantial given this planet's current trend towards global warming. My STS thesis will seek to determine whether the effects of the IoT on the environment are positive or negative, by weighing the manufacturing and electronic waste costs of the IoT versus the environmental benefits of sensing to reduce human energy consumption.

Technical Topic (Capstone)

One of the largest impacts of the Internet of Things (IoT) is its ability to bring the benefits of electronic technology to communities that lack access to the electric grid. Recent research in energy harvesting technology has vastly improved the capability of circuits to harvest and store solar, thermal, and vibrational energy (Blaauw, 2014). Meanwhile, research in ultralow-power circuit design has introduced techniques to reduce the power consumed from data sensing, processing, and transmission. The combination of energy harvesting and low-power circuits has led to the development of “self-powered” systems. These systems use the energy harvested from their environments to power sensing, data processing, and data transmission. The goal of this capstone is to expand the applications of self-powered IoT systems to fleet and asset tracking by developing a solar-powered fleet tracking device that encrypts and transmits its GPS location to a central node for decryption and visualization. Such a system is useful in situations involving frequent movement of valuable objects, such as school buses, manufactured cars, and farm vehicles.

The project deliverable will be two roaming solar-powered nodes attached to vehicles that send encrypted GPS data to a central node that decrypts and visualizes the data on a laptop, summarized in Figure 1. The fleet tracking project has several important sub-systems. For the energy harvesting, the system significantly improves upon prior art by deriving all of its energy from the sun, with onboard storage in the form of a rechargeable battery. Existing technology either requires a constant power supply, such as access to the vehicle's battery, or a single-use battery, which needs replacement after a fixed amount of time. Battery replacement poses an inconvenience when a user has thousands of widely dispersed nodes that need periodic maintenance. Additionally, the project's design allows for long-range wireless communication without cellular or Internet service, an important feature for a design meant to reach remote or rural parts of the country that lack reliable network connections; this is done using LoRa (long range) communication technology, a low-power, high-range communication protocol developed for IoT applications that has a demonstrated range of 3-10 miles. Finally, the IoT's reliance on wireless communication makes it vulnerable to security attacks and data breaches. As a result, this project encrypts the GPS data before transmitting it wirelessly, to ensure the asset location data remains protected even if intercepted by a malicious entity. The Advanced Encryption Standard (AES) is used for this encryption, as it is the current U.S. standard for all encrypted data.

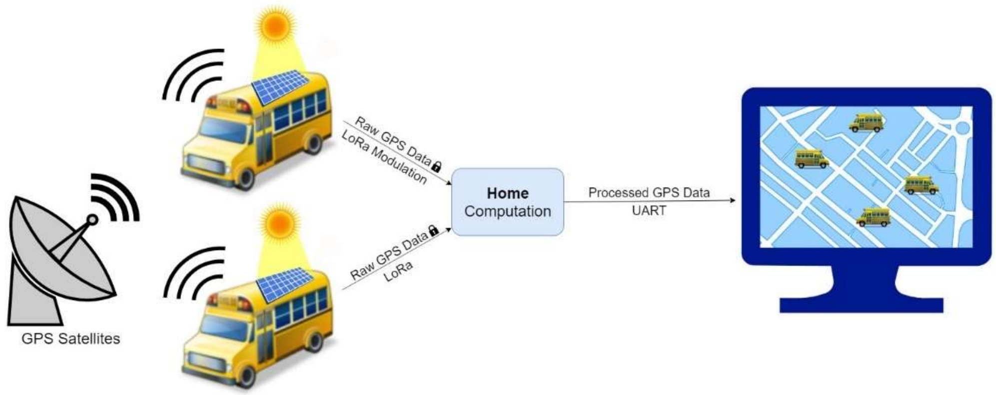

Figure 1. Fleet tracking system with two roaming nodes sending encrypted GPS data to a central node for decryption and visualization.

Thus, this capstone project aims to develop two solar-powered fleet-tracking nodes that send data to a central hub for data display. By using solar power and LoRa technology, this system can be deployed in remote, off-grid locations without constraints arising from powering the system or maintaining the system through battery replacement. More broadly, this project seeks to expand IoT technology to benefit off-grid communities that lack access to reliable energy or cellular connection. In this way, the IoT brings the valuable applications of electronic technology to areas that lack access to the electric power grid.

STS Topic

As the number of Internet of Things (IoT) devices grows exponentially, it becomes important to quantify the IoT's effects on the environment, as these will grow exponentially alongside the IoT. Many IoT applications claim to reduce user energy consumption, through techniques like monitoring building energy efficiency or detecting pipe leaks. Meanwhile, the IoT boom has added a tremendous amount of electronics to the world, electronics that upon reaching their lifetime and ceasing to be operational, all have to be disposed of. My STS thesis will define the social forces that push IoT development, and quantify the resulting impacts of the IoT on the environment.

The IoT is a complex system involving many entities, comprising of:

1) Technology companies developing IoT devices and systems, who wish to push their products on consumers to make money.
2) Users, including everyone who is voluntarily or involuntarily affected by IoT systems
    a) Individual consumers, who purchase and install IoT devices to use in their lives.
    b) Business consumers, comprising of large companies who purchase and install large-scale IoT systems to assist their business and manufacturing.
    c) Passive users, who are not consumers of IoT systems but are nevertheless affected by the IoT's widespread social and environmental impacts.
3) IoT devices, created by technology companies and marketed to individuals and businesses to be sold and installed; once installed, they collect data and perform the tasks for which they were designed.
4) Network connections, such as the Internet, whose data rates and distance ranges define how the technology companies design and market the IoT devices.
5) The environment, a passive actor affected by the choices the aforementioned entities make.

The interactions between these entities, with a focus on the effects of the interactions on the environment, are summarized in Figure 2.

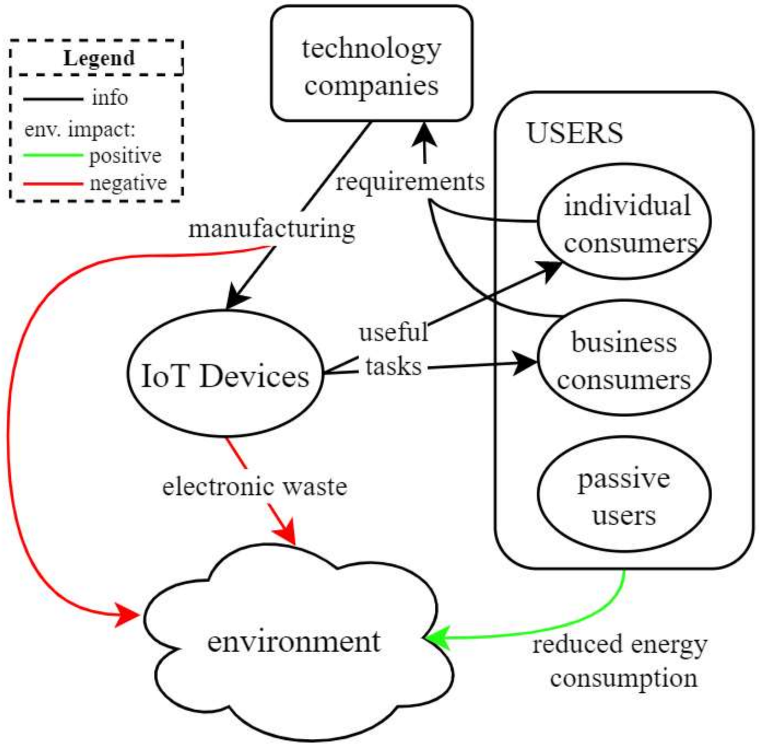

Figure 2. Interactions among entities involved in IoT system.

I will quantify the effects of the IoT on the environment using actor-network theory (ANT), co-production, and technological momentum. At the heart of determining the impact of the IoT on the environment are the interactions between the environment and IoT devices, the network, consumers, and technology companies, modeled using ANT (Cressman, 2009). While critics of ANT claim it is too broad in scope, this broadness allows the use of ANT as a framework, rather than a theory for the analysis of the proposed topic, by analyzing the relationships between the entities listed above, in particular the impacts of these relationships on the environment.

Additionally, the proliferation of IoT devices is a combination of co-production (Jasanoff, 2004) and technological momentum (Hughes, 1969). While IoT devices are designed using co-production, with companies and consumers determining what to build, technological momentum has caused these devices to affect even those who do not explicitly initiate contact with the devices, the “passive users.” For example, background sensors such as smart buildings and traffic cameras have permeated throughout our society and become ubiquitous, affecting the building or road users who have had no input into the sensor development or deployment.

Understanding the effects of the IoT on the environment is important because these effects will grow alongside the number of IoT devices, which are already growing exponentially. Unlike most sustainability efforts, the IoT is not something individuals can choose to “opt-out” of; IoT sensing systems will be in the background recording data, so before their installation it is important to gauge whether, for the sake of sustainability, these systems should even be developed.

Research Question and Methods

The proposed research question is: is there a way to quantify the impact of the IoT on the environment, and if so, is the IoT truly beneficial for the environment and thus for society? The IoT’s environmental impact is a multi-faceted issue when taking into account society's role in the proliferation of IoT; it will be a combination of technological momentum, co-production, and actor-network theory. While technology companies determine what IoT devices are produced and large companies will oversee the installation of IoT devices into the workplace, ordinary people will have to live with the consequences of these devices being installed throughout their lives. Meanwhile, people's demand of more devices, such as security sensors or smart homes, will drive what is produced by technology companies. Overall, will the energy reduction from smart energy systems overcome the production and energy costs of manufacturing, installing, maintaining, and disposing of IoT devices?

I will use a combination of discourse and network analysis to research for my project. Previous literature will be crucial to determine what IoT technology already exists, particularly to reduce energy consumption. I will also examine studies about electronic waste and its impacts on the environment. Finally, I will examine interactions among all the actors in the IoT social system to understand where the effects on the environment are coming from. These interactions will then be quantified using prior research on energy reduction and electronic waste numbers to arrive at a conclusion about the IoT's impact on sustainability efforts and the environment.

Conclusion

As the Internet of Things becomes a dominant presence in technology and society, it is important to research its capabilities while being aware of its effects on the global sustainability effort to mitigate climate change. For my capstone project I am developing a self-powered fleet tracking system. This system involves two roaming nodes sending GPS location data to a central node attached to a computer, which then displays the GPS points on a map. The purpose of this system is to track large devices that do not always have a reliable energy or network sources, such as manufactured cars or school buses travelling to remote areas. For my STS thesis, I aim to quantify the effects of the IoT on the environment to determine whether these effects are positive or negative. I intend to use a combination of actor-network theory, co-production, and technological momentum. Both projects take a deep dive into IoT systems and examine how they work technologically, socially, and environmentally, with the broader goal of expanding human capabilities and knowledge about IoT technology.

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