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Master Thesis Informatics

Measuring Framework for Energy Consumption and Performance on Edge Computing Devices

Author:	Emanuel Oscar Lange
Supervisor:	Prof. Dr. Michael Gerndt
Advisor:	Dr. Shajulin Benedict
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Abstract

Internet of things is an emerging field in computer science which focuses on among other things sensors and embedded systems (so called edge devices), which are connected to the internet. There is a rising necessity to give these devices more compute power. Basic algorithms such as filtering and pre-processing are needed due to an increase in devices and the amount of data they send over the network. But embedded devices often running on limited performance and battery life. Measuring the performance and energy consumption of multiple devices and aggregating these statistics could help in identifying more efficient solutions for existing applications. This thesis would focus on developing a framework to collect the necessary information on edge devices and aggregate them on a compute node in the edge or cloud layer.

Contents

1 Introduction

Internet of Things (IoT) is a loosely defined conglomerate of devices that are connected to the internet. Oracle defines IoT as a “network of physical Objects (Things), that are equipped with sensors, software and other technology to connect them with other devices and systems over the internet, so they can exchange data” [1].

1.1 Growth of IoT

Oracle expects the number of devices to rise up to 22 billion by 2025 [1]. IoT Analytics estimates the current number of active endpoints (2021) to be around 12.3 billion and to grow up to more then 27 billion by 25 [2].
Meanwhile network technology is also growing with 5G being one of the more recent developments. It promises to support a lower latency and higher bandwidth connection then the last framework with “(...) transmission speeds of more than ten Gigabit per second (Gbit/s)” [3]. Addition-ally, the widespread adoption of glass fiber cables increases the cable connection speed.
One would hope that these two evolutions align too reign in the new era of IoT. But especially another development is resulting in bandwidth problems. Artificial Intelligence is being implemented in more and more use cases and especially the field of deep learning requires huge amounts of data. One of the biggest applications is in regards to video and picture analysis. Cameras in general support higher and higher resolutions with 4k video streams. The ex-vice president of HPC, ML and AI at IBM Sumit Gupta estimates the amount of data an autonomous vehicle produces per hour to be about 15 terabytes [4].

1.2 Shifting Compute Power

One solution to combat this problem is called Edge Computing. The compute power is shifted from huge cloud clusters to the edge devices. For example, cameras nowadays can filter their recordings to the interesting parts where a movement was recorded instead of broadcasting all the time.
This process comes with its own challenges though. Besides security concerns, the energy consumption and efficiency of these devices is more difficult to manage. The energy concern is important because these devices are sometimes limited in battery life but also the rising importance of a more climate friendly technology. This thesis will focus on different methods to measure energy consumption in edge devices, aggregate them on an edge or cloud node and analysis them.

2 Goals and Objectives

The main goal of the thesis is to build a framework that creates an easy solution to check energy consumption of one's edge devices. This problem can be divided into three sub problems. First the energy consumption itself needs to be measured on an edge device. This form of measurement should be able to support the most common pieces of hardware used in IoT devices, such as Arduino, esp32 and Rasberry Pie.
Secondly this data needs to be sent and recorded on some edge node. Again, the most common pieces of network should be supported.
Thirdly an edge device needs to collect and aggregate data. Some simple forms of analysis like grouping together data should be possible.
If there is enough time, one can look at predictive algorithms for energy consumption and/or ex-tending the supported hardware/software. This heavily depends on the effort needed in the first three parts.

3 Approach

The two most prevalent ways two measure energy consumption are Energy Profilers and Power Monitors.
Energy Profilers estimate the used power by using metrics such as CPU utilization, CPU frequency and temperature. While not as accurate as the Power Monitors they don't require any specialized hardware.
The important question now is in which direction the thesis should go? There are additional pros and cons to each approach.

3.1 Energy Profiler

The main problem with the Energy Profilers is the limited runtime information available on chips used in edge devices.
The simplest formular to use would probably be

$$\begin{aligned} PowerConsumption = (1 - CPU_{Utilization}) \cdot Idle_{PowerConsumption} \\ + CPU_{Utilization} \cdot Average_{PowerConsumption} \end{aligned}$$

as explained here [5].
The idle power consumption and average power consumption are static for each chip.
Average power consumption references the power draw of a processor running at the standard specified frequency. If possible,this could be refined by dynamically sampling the frequency.
The CPU utilization can be retrieved depending on the chip used.
For Arduinos there is one main loop, so the utilization is either 100
Rasberry Pies have a multitude of options based upon the OS. For example, for Linux there is a library called sysstat.
For ESP32 there is a FreeRTOS command called vTaskGetRunTimeStats.
These measurements only measure the application running on the chip and not the attached devices like the camera itself for example.
Also, the framework would have to be specifically designed for certain chips and OS-versions to retrieve the needed information. This problem could be alleviated by writing extendable interfaces for system specific functions.

3.2 Power Monitor

These are a lot more accurate than the before mentioned Energy Profilers. They also have the benefit of being able to measure the entire systems power consumption.
The basic idea would be to use a power meter to gather power draw of a device/system. Hook the meter up to a chip, for example an Arduino. This Arduino is then sending the information to another device.

4 State of the art

Energy profilers are pretty common for compute setups but not IoT applications. For example, the Intel Power Gadget [6]. These programs estimate the power consumption of the CPU during usage.
There exists an energy profiler for IoT applications from the company simplicity studio [7]. But it is only developed for testing your applications while developing and the chip being hooked up to your pc.
The field of power monitors is more developed for IoT in the sense that more projects exist. One project [8] is using a raspberry pie to evaluate the power consumption. There is also a method just using an Arduino without additional hardware [9], this method is very limited in the supported voltage. Lastly there are some commercial options available for smart homes, for example the EMPORIA ENERGY gen 2 Emporia vue smart Home Energy Monitor. It supports hooking up multiple devices in the home and sending the collected energy statistics via wireless LAN to your phone.

5 Expected Results and Discussion

The main idea is to explore the feasibility of this concept. There are a lot of hurdles to overcome. The ecosystem of IoT is very diverse, which increases the difficulty for this concept. Additionally other factors such as production cost, running cost and physical size of the product play a huge role in this field. As the amount of edge devices, even for smaller projects can be huge. And the space requirement especially for the external power monitors can make the application of this framework unfeasible.
But the final discussion should focus on an important aspect of this growing field IoT that has a huge impact on the success, namely how efficient are these devices and how efficient can they be.

6 Potential Further Research

As mentioned before there are some possible research options if there is enough time. The frame-work could be extended to support more hardware and software. The analysis part of the project can be improved to for example predictive analysis. The actual user experience can be improved with a visual component for the data representation.

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