OPTIMIZING BATTERY CONSUMPTION OF EDGE IOT DEVICES

by

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DEDICATION

I dedicate this project to myself. A special feeling of gratitude to my loving self for enduring the mental stress over the course of the past three years. GGs only. We do not go again.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF ABBREVIATIONS

ABSTRACT

Recent advances in the world of IoT have significantly improved what one can do with the help of personal gadgets such as smartwatches and other edge devices. This improvement has lead to the inclusion of additional functionality like fall detection, temperature and motion sensing etcetra. Although this in itself is not a bad thing, however, this does pose the problem of increased energy consumption on devices which are already constrained by limited battery. We present our study which discusses the possibility of optimizing energy consumption for edge IoT devices by reducing communication cost of applications by determining an optimal chunk size. We present a metric **energy-per-byte** or **EPB** which helps determine the optimal chunk size for respective edge devices. We evaluate our approach with the help of two case studies using different edge devices and applications, and we achieve considerable energy optimization depending on the app functionality and the hardware involved.

I. Introduction

In the past couple of years, IoT has made significant progress. From personal devices such as smartwatches and environment like smart homes, to industrially scaling projects like smart cities and smart, autonomous cars. There has been an extensive application of IoT edge devices to an extent that today, a considerably significant amount of people possess at least one such device —be it your smart car or a smartwatch that you regularly or routinely use.

Recent advances in the world of IoT have increased the amount of use cases that these personal devices such as smartwatches have. But having additional functionality also poses the problem of increased energy consumption on devices already constrained by limited battery. For example, a device logging sensor data, say temperature, in real-time is bound to use more energy if it starts logging data from a motion sensor as well.

This work studies the possibility of optimizing energy consumption for edge IoT devices by aiding the programmer in setting parameters that would ultimately lead to lesser energy consumption. We aim to focus on optimizing the communication cost of applications by determining the optimal chunk size, with which the data should be transferred. It also involves a case study comparing energy consumption of native app and the same app running in a container environment such as Docker (cite here).

There has been an extensive amount of work on energy optimization —both without and in an IoT setting. Xiao et al. [1] compared 3G and Wi-fi while Balasubramanian et al. (cite here) compared GSM, 3G and Wi-Fi with respect to energy consumption. However, neither of them compared energy consumption of respective data transfer technologies for throughput efficiency for the same task.

Gupta et al. (cite here) made a measurement study of energy consumption when using VoIP applications with Wi-Fi connection in smartphones and showed that power saving mode in Wi-Fi together with intelligent scanning techniques can reduce energy consumption. Xiao et al. (cite here) measured energy consumption for video streaming on mobile apps and concluded that Wi-Fi is more efficient than 3G. There are other measurement studies as well which compare different modes of communication but none of them discuss energy consumption differences for different packet sizes.

The work that seems the most related to ours is by Friedman et al. (cite here) where they measured power and throughput performance of Bluetooth and Wi-Fi usage in smartphones. They concluded that power consumption is generally linear with the obtained throughput, and Bluetooth uses less energy than Wi-Fi. However, this study also showed that different hardware and different software have different results and there is no generic trend. They also concluded that an upper bound does exist, bottlenecked by the receiver, after which the sender expends more power retransmitting packets. This dependency of energy consumption on software is also discussed by Flinn and Satyanarayanan (cite here) who point out that "*There is growing consensus that advances in battery technology and low-power circuit design cannot, by themselves, meet the energy needs of future movile computers* "(cite here). This observation has been confirmed by recent advances in green software engineering, which demonstrated how the source of energy leaks can be software-related as well (cite here).

Our work on the other hand, considers multiple constraints in real-world IoT setting. Firstly, the transmission is not always continuous. The data may be communicated in regular or irregular intervals. Secondly, the amount of data to send depends on the amount of data collected by the sensors which may vary based on different applications. Thirdly, since the transmission may not be continuous, if the app demands it, based off energy consumption data from different chunk sizes, an optimal communication interval can be set to reduce the amount of buffering required (if needed). Lastly, unique apps on different devices with different operating systems will have their own optimal throughput efficiency for energy consumption. Given the hardware configuration of such a device, our tool can determine the optimal chunk size for data transfer with respect to energy consumption.

I.0.1 Contributions

This thesis has the following contributions. It:

- proposes a method to estimate energy consumption of edge IoT devices
- proposes a new approach to reduce energy consumption with the help of optimal chunk size
- presents a new metric called Energy-Per-Byte or EPB
- discusses a case study to compare energy consumption between native, Lingua Franca and container version of the same app.
- evaluates the effectiveness of this approach on two real-world applications of different domains.

The organization of the rest of the thesis as as follows. In chapter II, we will provide background information about edge IoT devices, energy usage and estimation, containers and middleware accessor frameworks. In chapter III, we briefly summarize the related work and chapter IV will discuss our methodology in detail. In chapter V, we will discuss our evaluation and results, and provide our reasoning. Chapter VI, will discuss the case study of energy cost comparison between native, Lingua Franca and Docker version of the same application and finally in chapter VII, we will conclude our thesis and discuss possible future work.

II. Literature Review

Over the past few years, Internet of Things or IoT, has had a significant impact in our lives. It plays an important role whether it is a smartphone or a smarthome environment or just something as handy as a smartwatch. Different types of data is collected and exchanged among interconnected sensors/devices through modern communication network infrastructure connected by million of IoT nodes [2, 3, 4, 5, 6]. This direction of computing has already overtaken the traditional methods based on stationary computing [7]. As a paradigm, IoT expresses that most physical devices, such as smart phones, smart watches and other embedded devices are interconnected with each other. These devices communicate with data centers and exchange information —all while adhering to their routine tasks [4].

Following various popular technologies these days, such as smart homes, smart grid and smart healthcare, IoT has become one of the essential components of people's home and workplace existence. It will continue to impact the daily life of people and its not just limited to technology. IoT has been reported to be one of the most important technologies that will impact US interests in 2025 [4]. The number of interconnected physical devices has already transcended the human population for a couple years now. In 2012, there were 9 billion interconnected physical devices [7]. This rapid increase in the number of mobile devices suggested that conventional centralized cloud computing would struggle to satisfy the Quality of Service (QoS) for many applications. However, with the introduction of 5G technology, edge computing becomes a viable and key solution to solve this issue [8, 9, 10]. The edge computing platform allows edge nodes to respond to service demands which results in reduced bandwidth consumption and network latency. Figure 1 shows a basic edge computing architecture.

Edge computing based IoT helps solve some critical issues and improves

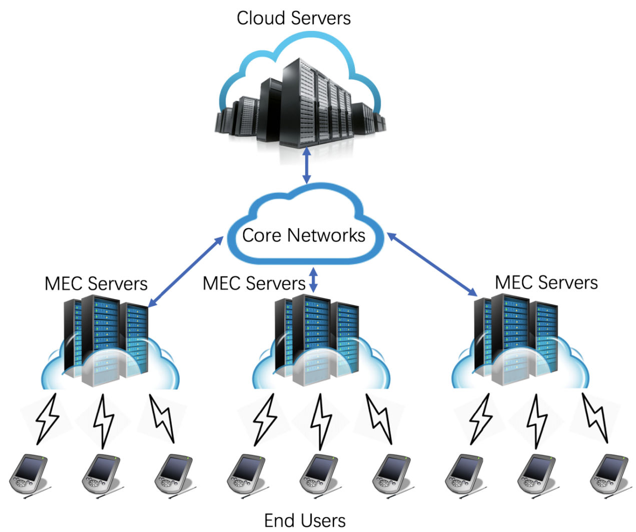

Figure 1: The basic edge computing architecture

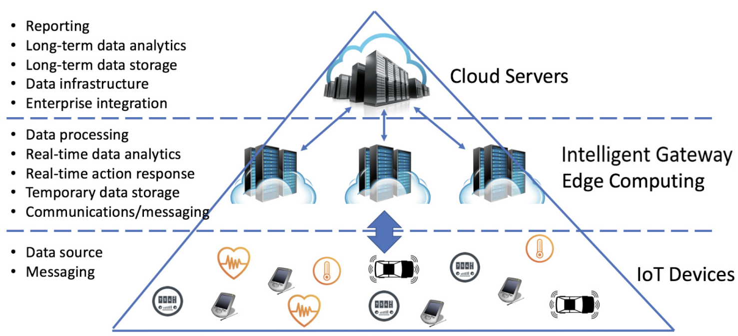

Figure 2: Edge computing based IoT architecture

performance. Not to mention, IoT and edge computing share some characteristics which is further clarified by figure 2.

It further illustrates that IoT devices are end users for edge computing and IoT can benefit from both cloud and edge computing. The latter helps with faster response times and provides a tolerable computational capacity and storage space. Nowadays, the physical end user devices such as smart phones are considered edge devices. They may have an exclusively local component of an application but most generally, some sort of data is communicated with the cloud server, with or without the help of a gateway device.

One of the restricting factors among IoT edge devices is limited battery life (among limited storage and other things).

III. Related Work

IV. Methodology

V. Evaluation

VI. Case Study

VII. Conclusion

APPENDIX SECTION

APPENDIX A

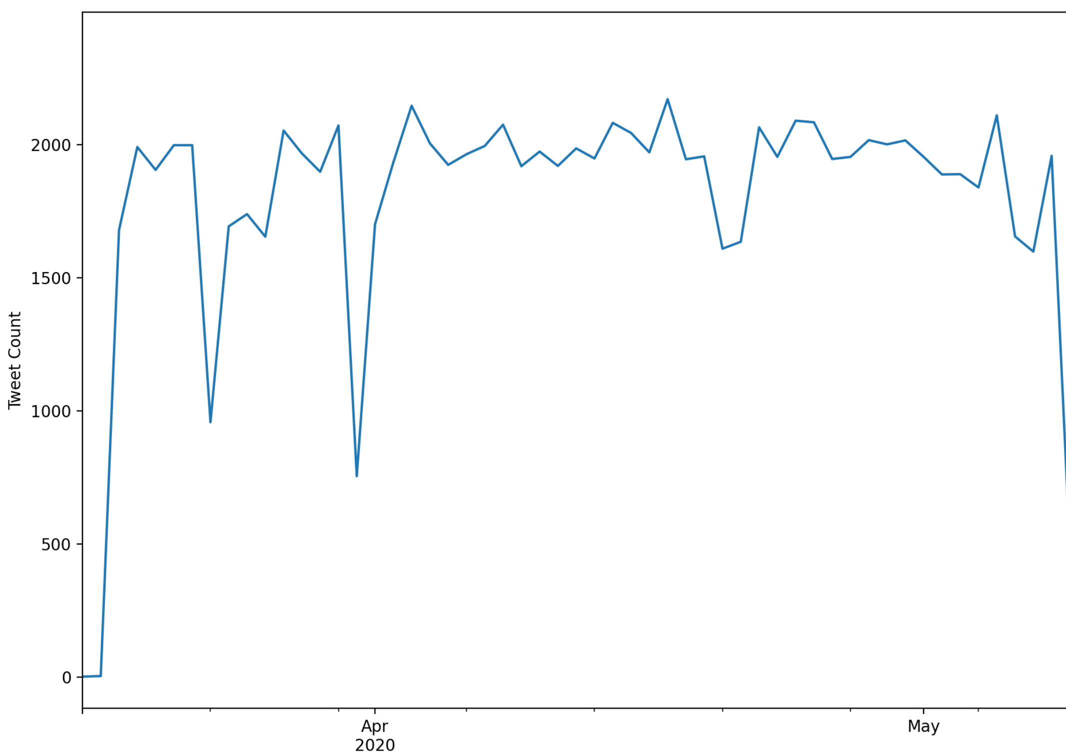

Figure A.1: First figure of appendix A. Captions of figures and tables in the Appendix section should not show up in the table of contents.

Table A.1: First table of appendix A. Captions of figures and tables in the Appendix section should not show up in the table of contents.

Dataset name	Number of records	Number of users
Dataset A	248	20
Dataset B	464	28
Dataset C	348	7
Dataset D	419	5
Dataset E	854	15

Table A.2: Second table of appendix A. Captions of figures and tables in the Appendix section should not show up in the table of contents.

Dataset name	Number of records	Number of users
Dataset F	1000	10
Dataset G	2000	20
Dataset H	3000	30
Dataset I	4000	40
Dataset J	5000	50

APPENDIX B

Table B.1: First table of appendix B. Captions of figures and tables in the Appendix section should not show up in the table of contents.

Column 1	Column 2	Column 3
1	2	10000
3	4	20000
5	6	30000

Table B.2: Second figure of appendix B. Captions of figures and tables in the Appendix section should not show up in the table of contents.

Column 1	Column 2	Column 3
A	B	10000
C	D	20000
E	F	30000

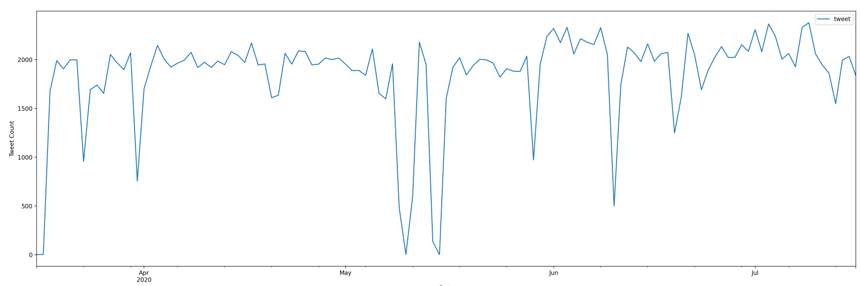

Figure B.1: First figure of appendix B. Captions of figures and tables in the Appendix section should not show up in the table of contents.

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