A Hardware Testbed for Renewable-Aware Resource Management at the Edge

Bachelor's Thesis

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I hereby declare that the thesis submitted is my own, unaided work, completed without any unpermitted external help. Only the sources and resources listed were used. The independent and unaided completion of the thesis is affirmed by affidavit.

Berlin, May 17, 2022

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Zusammenfassung

Abstract

Contents

Chapter 1

Introduction

Edge computing is a promising, emerging paradigm in the area of distributed systems and while still primarily being a theoretical concept, the rise of new domains like Internet of Things (IoT) establishes numerous areas of application [1]. Because of the decentralized nature of edge computing, new devices at the edge of the network are essential for many of these approaches. In some cases though, edge devices do not have access to the electrical grid and require on-site energy generation. Some examples include portable weather stations, smart watering and metering in autonomous farming or numerous sensors in smart city designs. Large-scale data centers already profit from integration of on-site renewable energy generation and are able to achieve significant cost reductions while also reducing their greenhouse gas emissions [2]. In its current state however, renewable energy generation is rather volatile and unable to supply sufficient uninterrupted power on its own [3], resulting in a problem for edge devices without a connection to the electrical grid. If devices under these circumstances aim to operate self-sufficiently and maximize uptime, their resources need to be managed dynamically, relative to current on-site renewable energy production.

To allow for dynamic resource management, matching the system's energy consumption to the on-site production, numerous approaches for power management pose a viable option. Power management, in this case energy proportional computing, can generally be pursued on a hardware- and software-level [4]. On a hardware-level, dynamic voltage and frequency scaling (DVFS), the dynamic adjustment of both voltage and frequency to reduce dynamic power consumption, is vital for this intention as the CPU traditionally consumes the most power in a system.

Recent Research in the area of energy-aware resource management in edge/fog computing utilizing DVFS for power management mainly relies on simulations to predict a real-world outcome [5, 6, 7]. Most simulators make the assumption that computational load can be adjusted in a way that energy consumption perfectly matches the energy production [8, 9, 10, 11]. While the reasoning for using simulations as opposed to real hardware testbeds may be justified and opportune for most research projects, it remains unclear how close these assumptions are to reality and how this may change the accuracy of the predictions and consequently research outcomes.

1.1 Testbed Requirements

This bachelor's thesis proposes a hardware testbed for renewable-aware resource management in edge computing, capable of dynamically adjusting its computational load relative to the on-site renewable energy production. In order to examine the assumption of energy-aware simulators, that computational load is adjustable so that energy consumption is matched to production, this thesis proposes to compare simulations derived from real-world data to this physical hardware testbed. To provide the necessary data to compare the simulations to, a testbed with the following properties is required.

1. Renewable energy is produced and consumed respectively.
2. Excess energy produced, can be stored and retrieved if the production fails to provide sufficient power.
3. $$\frac{P_{\text{load}}}{P_{\text{idle}}} \geq 2.$$
   Adjusting the consumption to current production is more meaningful, in regard to energy savings, if the quotient between the power consumption under load and idle is as high as possible. In order to work properly with the data provided, the lower bound 2 was chosen.
4. The current energy production and resources' power draw can be measured in Volts and Amperes respectively. The amount of stored power can be measured.
5. Resources can be managed dynamically. This is necessary for adjusting the consumption depending on the current production of renewable energy.

1.2 Thesis Outline

This thesis is divided into 6 chapters.

Chapter 2 introduces the fundamental concepts discussed in subsequential chapters. First, edge and fog computing paradigms and their necessity for future information and communications technology (ICT) are presented. Second, the respective use cases of physical and simulation testbeds in edge and fog computing environments are outlined. Third, dynamic resource management, and specifically energy proportional computing for our use case, techniques are presented and DVFS, as the main technique for our physical testbed, along with its implementation in the Linux kernel, will be outlined.

Chapter 3 first reviews related research in the area of energy-aware resource management utilizing DVFS. The utilization of simulations in all presented papers leads to the described problem which is subsequently outlined. Then, these simulations are presented and aforementioned problem is demonstrated.

Chapter 4 presents the hardware testbed. First, all hardware components used and their conformity with the requirements listed in section 1.1 are presented. Second, the assembly of the individual components and their relations to each other are described. Third, the setup of the software, necessary to ensure functionality of the components, data transmission and operability, is presented. Fourth, the implementation of DVFS, customized for this testbed, is outlined.

Chapter 5 evaluates the testbed by assessing the accuracy of its capability to adjusting its computational load relative to the on-site energy generation. An error analysis is conducted and reviewed in regards to collected data by the testbed. The subsequent consequences for conducted research in the area of energy-aware resource management is discussed.

Chapter 6 concludes the thesis by summarizing the main points and contributions.

Chapter 2

Background

2.1 Edge Computing Paradigms

2.2 Testbeds in Edge Computing Environments

2.3 Dynamic Resource Management

2.3.1 Dynamic Voltage and Frequency Scaling

Chapter 3

Related Work

3.1 Energy-Aware Resource Management with DVFS

3.2 Energy-Aware Simulators

Chapter 4

Testbed

4.1 Hardware Components

4.2 Hardware Assembly

4.3 Software Setup

4.4 Implementation of DVFS

Chapter 5

Evaluation

Chapter 6

Conclusion

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