ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Project Proposal for ECE 445
Vehicular Edge Computing System

Team #38

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March 26, 2024

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1 Introduction

1.1 Background

The intelligent transportation system has received great interests from the academia and industry. The growing volume of data to be processed and the goal of short response time requires the development of edge computing system[1].

1.2 Problems

1.2.1 Energy Consumption

Energy-saving is always the issue being emphasized in computing server, as for the most of the computing devices, it consumes a significant amount of energy for computing and cooling. For example, as for the traditional cooling systems, such as fans or air-conditioners, the devices at a data center can consume over 40% of the total energy needed[2]. In presence, with the rapid development of Artificial Intelligence, the electrical energy required has the tendency to rise explosively in the following years. Elon Musk predicted that even maybe in the next year, AI will run out of electricity[3]. In order to ensure the electricity provision, it's in an urgency to find solutions to reduce energy consumption for electronic devices. In this project, we want to take the step to find proper way to save more energy for edge computing systems.

1.2.2 Immobility of edge servers

The general idea of deploying edge computing systems is to locate the them at fixed points near the user end, which covers a fixed service region[1]. But it encounters the problem of low utilization rate for some reasons. For one thing, the time duration of a car being served by a certain edge server is limited, which fundamentally stop the server from accomplishing time-consuming work, like deep learning problems. So the server either not provide the service at all, which makes the server idle, or transfer the data to the next server where the car is going to approach, which is also sophisticating.

1.3 Solutions

1.3.1 Propose

Considering the problem above, we aim to deploy the edge server on-board the vehicle, e.g. a car. There are two main advantages in this way. First, we propose that making use of the movement of the vehicle, the server can be cooled down greatly by the wind. It saves a lot of energy compared with the case if we put the server inside a building and traditionally installing a refrigerator regarding the large amount of heat produced by the server. Second, the service coverage is dynamic so that statistically, the average utilization rate of a server rises. That's because there should be a server station having no way but to stay at a particular location to serve the area with a lower vehicle flow rate.

1.3.2 Scheme

Now that the server is put on-board, we need to design a shelter with a ventilating structure to make it stable enough, immune to rain, and realize effective wind cooling. In order to improve the performance of the server and save more energy, we want to design a control module of adjusting the CPU utility according to the cooling effect. Also, as the server cannot be accessed in wires, we need to add a wireless communication module to make it accessible to the nearby base station.

1.4 Visual Aid

1.5 High-level requirements list

1. Energy saving:

The cooling system can save 40% of the electricity, compared with the traditional temperature-only based cooling system, i.e. using fan or air-conditioner only.

2. Cooling effectiveness:

The peak server temperature can be consistently controlled under 75°C regardless of the speed of the car.

3. Computational performance improvement:

The computing intensity can be dynamically adjusted with the help of the wind cooling to improve the overall utilization and performance of the server. The server on-board vehicle can accomplish more than 10% work load compared with the server deployed indoors.

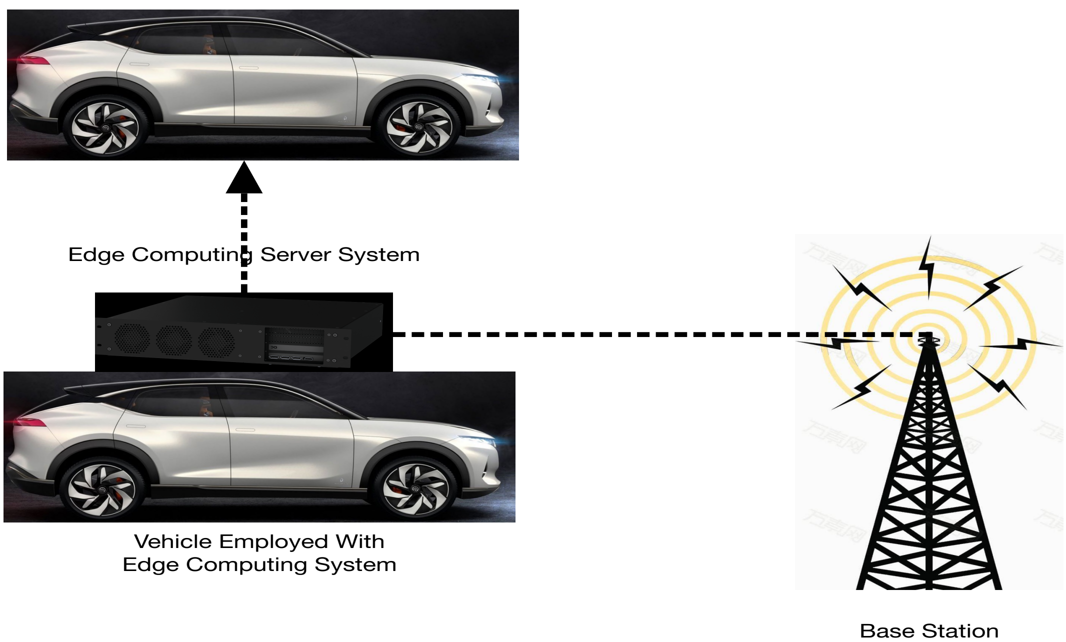

Figure 1: Visual Aid

2 Design

2.1 Block Diagram

2.2 Subsystem Overview

Our design is divided into three main systems, which are the server, the shelter of the server, and the peripherals.

2.2.1 Server

This block just includes the server itself. The server will be modelled as if it's in practical use, so that we can test whether the cooling system is functioning well or not. We will enhance its ability of wireless communication, so that it can get access to the user ends and also the nearby base station at any time to transmit and receive data.

2.2.2 Shelter

This block is the shelter of the server. It has three functionalities. The basic functionality is to carry and fix the server on the vehicle. Second, it functions as a cooling system, including air path and phase-change material. The air path utilizes the wind to cool the server when the vehicle is running. Third, it can protect the server from rainy or snowy weather conditions. We'll design a waterproof shelter to help to drain the water away the server (the inner space of the shelter).

2.2.3 Peripherals

This block includes a micro-controller, the speed sensor, potential electronic devices needed for water-cooling, and a WiFi. Also there's a Li-ion battery to provide energy to the devices above. The speed sensor detects the speed of the wind to get more information about the air passing. The micro-controller receives the data from the sensor to make decisions to control the water-cooling part. The WiFi transmits and receives data between the server and the base station.

2.3 Subsystem Requirements

2.3.1 Server

This block includes the software part of the server. The server will be configured as if it's practically used in edge computing.

• We will configure Ubuntu in the server, deploy Docker based on Ubuntu, which is popularly proposed in edge computing, and run deep learning algorithm to make the server work under certain intensity.

• Under this condition, we will settle the server on-board a moving platform, and test

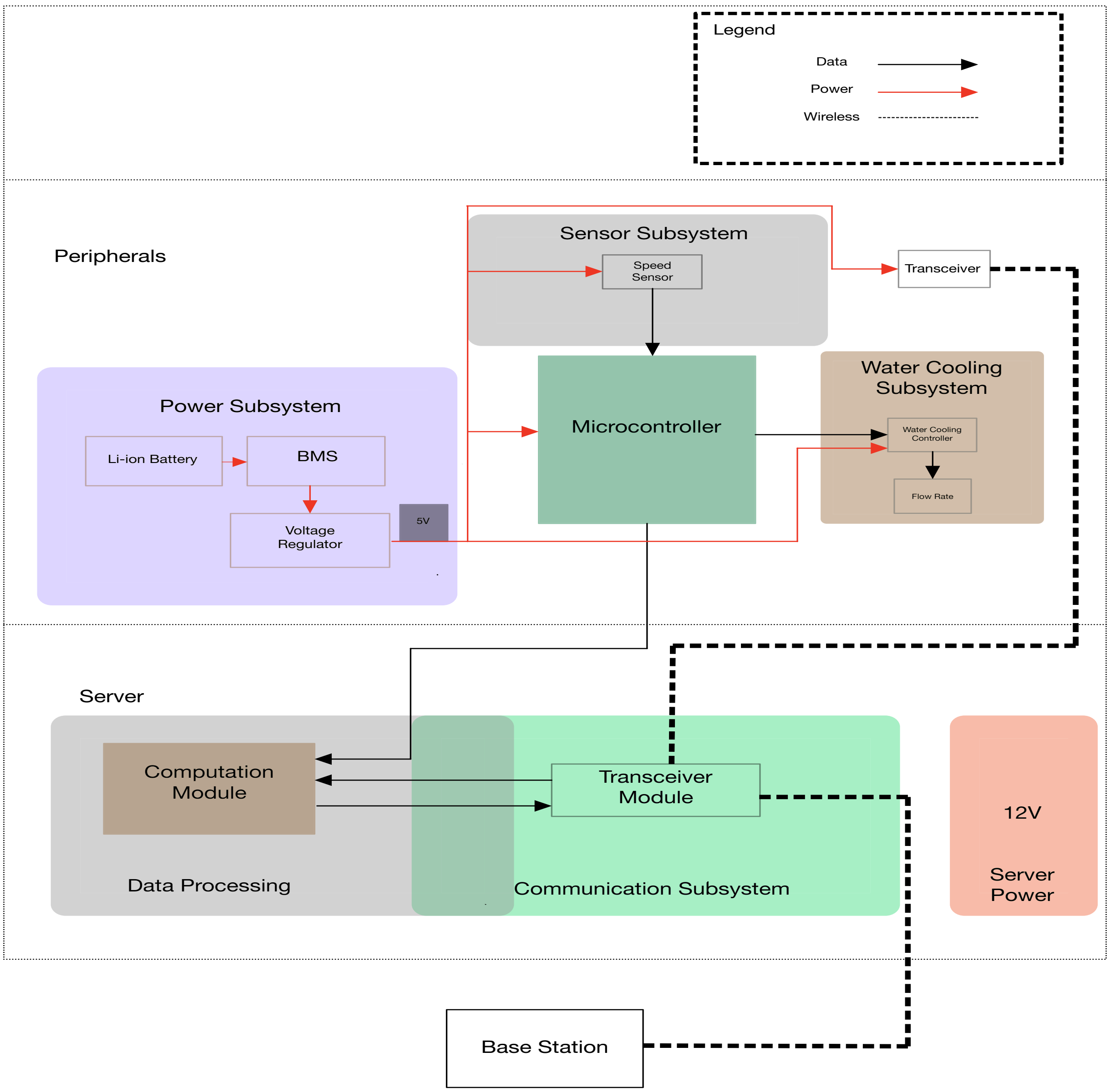

Figure 2: Block Diagram(1)

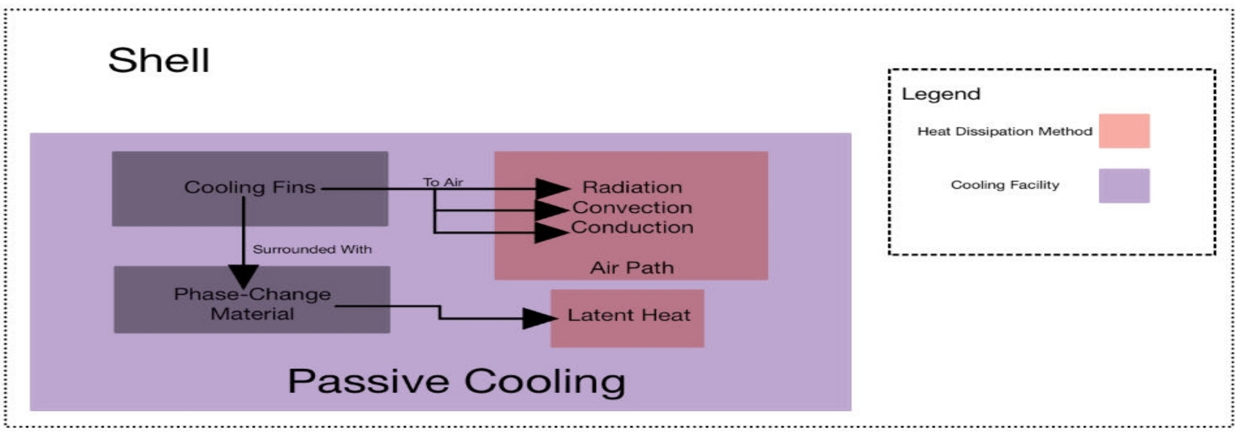

Figure 3: Block Diagram(2)

whether the cooling system is functioning well or not, i.e. effectively cool the server under the safe temperature.

• We will enhance its ability of wireless communication, so that it can get access to the user ends through the Internet. In Linux OS, we install a driver for USB wireless network card. The USB wireless network card will be further described in the subsystem of peripherals.

• The CPU computational intensity and the operation condition of the fans(embedded in the server) is adjusted according to the temperature of CPU. There's a block of code to control the hardware resources of the server. The document in "/etc" directory in Linux is modified.

2.3.2 Shelter

The shelter has a little larger dimension than the server to fit it. It is fixed at the roof of the vehicle to carry the server with the larger side of it aligned with the direction of the vehicle. The roof of the shelter is waterproof, and it needs to has the design of inclination to expedite the water draining and avoid a thick snow cover. One of the side of the shelter, like the one towards the roar of the vehicle, needs to protect of the potential wires from rain or snow. This side should not be sealed so that the user can plug and unplug wires and battery conveniently. Inside the shelter, it has an air pathway along the direction of the vehicle to let the wind to cool the server effectively. We need to design a pathway structure and test it to reach the best cooling performance. Cooling fins are set at the edge of the air pathway, and also, we design to add phase-change materials surrounding the fins to enhance the cooling ability.

2.3.3 Peripherals

• The wireless communication subsystem: transceiver. It gets energy from the Li-ion battery. It adopts wireless connection with the base station with reliable accessibility through certain protocols. And it is wired to the server to make data connection with it. We need to figure out the specific components of this part needed and the proper wireless protocol.

• The micro-controller. It connects the server to transmit data, like those from the speed sensor; and it receives data of instruction from the server.

• The sensor subsystem: a speed sensor. It gets energy from the Li-ion battery. By sensing the speed of the wind, it connects to the micro-controller to transmit data.

• The water cooling subsystem: water cooling controller. It complements the wind cooling system by using the water collected from rain. This part may not be used in the end, and we need to figure out its components.

• The power subsystem: Li-ion battery. It must be able to supply to the rest of the system continuously at 5V.

2.4 Tolerance Analysis

For the given server shelter with dimensions of 1m x 60cm x 60cm, we can perform a basic thermal analysis to estimate the airflow required to prevent overheating.

Assumptions:

• The server generates a uniform heat load, which we will assume is 400 W (a typical value for a small server).
• The shell is made of a thermally conductive material (like aluminum).
• The ambient temperature is 25°C.
• The target maximum internal temperature is 75°C to ensure electronic components operate within safe temperatures.

Heat Transfer Calculation:

Using the formula $Q = \dot{m} \cdot c_p \cdot \Delta T$, where:

- Q is the heat power (Watts),
- $\dot{m}$ is the mass flow rate of air (kg/s),
- c_p is the specific heat capacity of air (approximately 1005 J/(kg·K) at room temperature),
- ΔT is the temperature difference (K).

We need to solve for $\dot{m}$, given that $Q = 400$ W and $\Delta T = 50$ K (from $25°C$ to $75°C$):

$$\dot{m} = \frac{Q}{c_p \cdot \Delta T}$$

$$\dot{m} = \frac{400\,\text{W}}{1005\,\text{J/kg} \cdot \text{K} \times 50\,\text{K}}$$

$$\dot{m} = \frac{400\,\text{W}}{50250\,\text{J/kg}}$$

The volumetric flow rate of air required is:

$$\dot{m} = \frac{400}{50250}\,\text{kg/s}$$

We can also convert this mass flow rate to a volumetric flow rate using the density of air (which is approximately $1.225\,\text{kg/m}^3$ at sea level and at $25°C$):

$$\dot{V} = \dot{m} \cdot \frac{1}{\rho}$$

The calculation is done only in an ideal way. However, under certain condition of the server operating, the flow rate of air required will change. We'll use the experimental data to do the mathematical analysis later.

3 Ethics and Safety

We admit that we must try our best to guarantee the safety during our project, and the safety of the practical application of the design of the project. We consider some potential safety problems that needs serious attention in our project.

• We know that the edge server can help to process the data from other cars and we will spare no effort to protect the safety of data with the methods including encryption algorithm to protect user privacy.

• Our project is related to vehicle so we must pay attention to the driving safety. We must ensure that the computing system does not interfere with the vehicle's electronic systems, which could affect navigation, communication, or other critical functions.

• Also, we make sure that any modifications do not negatively impact the vehicle's safe running or emergency handling.

• Since our server is fixed on the car, we must make sure that the fixation is reliable.

Throughout the whole project, we will adhere the IEEE code of ethics. We will ”uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities”. We will ”treat all persons fairly and with respect, to not engage in harassment or discrimination, and to avoid injuring others”. We will ”strive to ensure this code is upheld by colleagues and co-workers”[4].

References

[1] L. Liu, C. Chen, Q. Pei, S. Maharjan, and Y. Zhang. “”Vehicular Edge Computing and Networking: A Survey”.” (2020), [Online]. Available: https://doi.org/10.1007/s11036-020-01624-1 (visited on 07/25/2020).

[2] X. Zhang, T. Lindberg, N. Xiong, V. Vyatkin, and A. Mousavi. “”Cooling Energy Consumption Investigation of Data Center IT Room with Vertical Placed Server”.” (2017), [Online]. Available: https://doi.org/10.1016/j.egypro.2017.03.581 (visited on 05/01/2024).

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