An Exploration of Turing Pi Based Edge Cloud with Docker/Kubernetes

Design Document

Team: SDMAY23-19

Client: Dr. Akhilesh Tyagi
Advisor: Dr. Nicholas Fila
Team Members:
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Executive Summary

Development Standards & Practices Used

Practices: Agile development, CI/CD integration, Automated Scaling with Kubernetes.

Standards: RESTful APIs and HTTPs protocols.

Summary of Requirements

- The senior design product shall implement a scalable message service.
- While the Turing Pi is online, the senior design product shall use an open source distributed event streaming platform.
- The senior design project shall have three compute modules available at any given time.
- The service landing page should maintain smooth performance scalable to 30,000 requests per second.
- The messaging service shall propagate messages to user groups within .75 seconds.
- If the messaging service is under 90% load or greater, then the service shall propagate messages to user groups within 2 seconds.
- The service shall be available to United States users 98.99% of the month.
- The messaging service shall encrypt user messages in transit.
- The senior design product shall use the Hypriot operating system.
- The senior design product shall use Docker as its containerization platform.
- The senior design product shall use Kubernetes as its orchestration platform.
- The senior design product shall use CI/CD pipelines for building and testing code.
- The turing pi product shall be placed inside a mini ITX case.
- The senior design product shall use a minimum of three raspberry pi compute modules.
- The senior design product shall implement a simple graphical user interface.

Applicable Courses from Iowa State University Curriculum

- CPR E 288
- ComS 309
- SE 317
- CPR E 319
- CS 252
- SE 319

New Skills/Knowledge acquired that was not taught in courses

- Turing Pi cluster board

- Kubernetes
- Docker
- Kakfa

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List of figures/tables/symbols/definitions (This should be the similar to the project plan)

1 Team

1.1 Team Members

Bryce Carter, James Gibbs, Theodore Tayib, Chee Hau Fong,Kyoungken Lee

1.2 Required Skill Sets for Your Project

This project requires skills with full stack development, DevOps, cloud, and hardware understanding.

1.3 Skill Sets covered by the Team

The skills required for this project are meant to be learned because it is an exploratory design endeavor. Nevertheless, all members have full stack experience. Derrick Brandt has cloud and DevOps experience. Theodore Thayib and James Gibbs have hardware understanding.

1.4 Project Management Style Adopted by the team

We have adopted an agile project management style.

1.5 Initial Project Management Roles

Bryce Carter	Individual Component Design
Kyoungkeun Lee	Goal Setting and Motivation
Chee Hau Fong	Testing
James Gibbs	Team Lead
Theodore Thayib	Client Interaction

2 Introduction

2.1 Problem Statement

Docker, Kubernetes, and cloud platforms are causing a paradigm shift in the software engineering profession. It would benefit students to have the ability to investigate the capabilities of this new era. An exploratory senior design project could allow students to confront their information gap through research. Additionally, it could allow them to document their findings in building a miniature cloud platform with Turing Pi, Docker, and Kubernetes.

2.2 Intended Users and Uses

Intended users are students, including Iowa State University, who are interested in affordable power-efficient cluster machines and beginners for edge computing/kubernetes/Docker.

2.3 Requirements & Constraints

Functional requirements:

1. The senior design product shall implement a scalable message service.
2. While the Turing Pi is online, the senior design product shall use an open source distributed event streaming platform.
3. The senior design project shall have three compute modules available at any given time.

Non-functional requirements:

1. The service landing page should maintain smooth performance scalable to 30,000 requests per second.
2. The messaging service shall propagate messages to user groups within .75 seconds.
3. If the messaging service is under 90% load or greater, then the service shall propagate messages to user groups within 2 seconds.
4. The service shall be available to United States users 98.99% of the month.
5. The messaging service shall encrypt user messages in transit.

Resource requirements:

1. The senior design product shall use the Hypriot operating system.
2. The senior design product shall use Docker as its containerization platform.
3. The senior design product shall use Kubernetes as its orchestration platform.
4. The senior design product shall use CI/CD pipelines for building and testing code.

Physical Requirements:

1. The turing pi product shall be placed inside a mini ITX case.
2. The senior design product shall use a minimum of three raspberry pi compute modules.

UI Requirements:

1. The senior design product shall implement a simple graphical user interface.

2.4 Engineering Standards

The senior design product shall use GraphQL messaging protocol.

> The users will benefit from performance increase, a key factor in user enjoyment of messaging services.

The messaging service shall use HTTPS encryption protocols.

> Security of the application is important enough to warrant a modern standard. Failure to use HTTPS is simply unacceptable in the modern era.

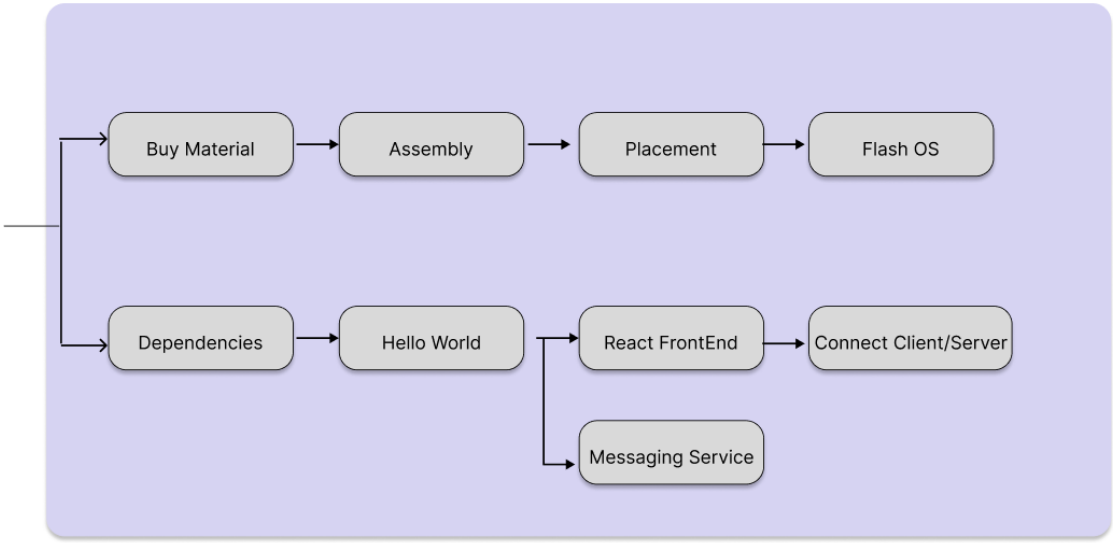
3 Project Plan

3.1 Project Management/Tracking Procedures

This project shall use an agile approach. User stories and short sprints will provide us the flexibility needed to properly implement the requirements. Additionally, We will use Git for version control and GitLab for remote repository management and work tracking.

3.2 Task Decomposition

We have decomposed the major tasks into 9 steps and turned them into a diagram according to the project's timeline.

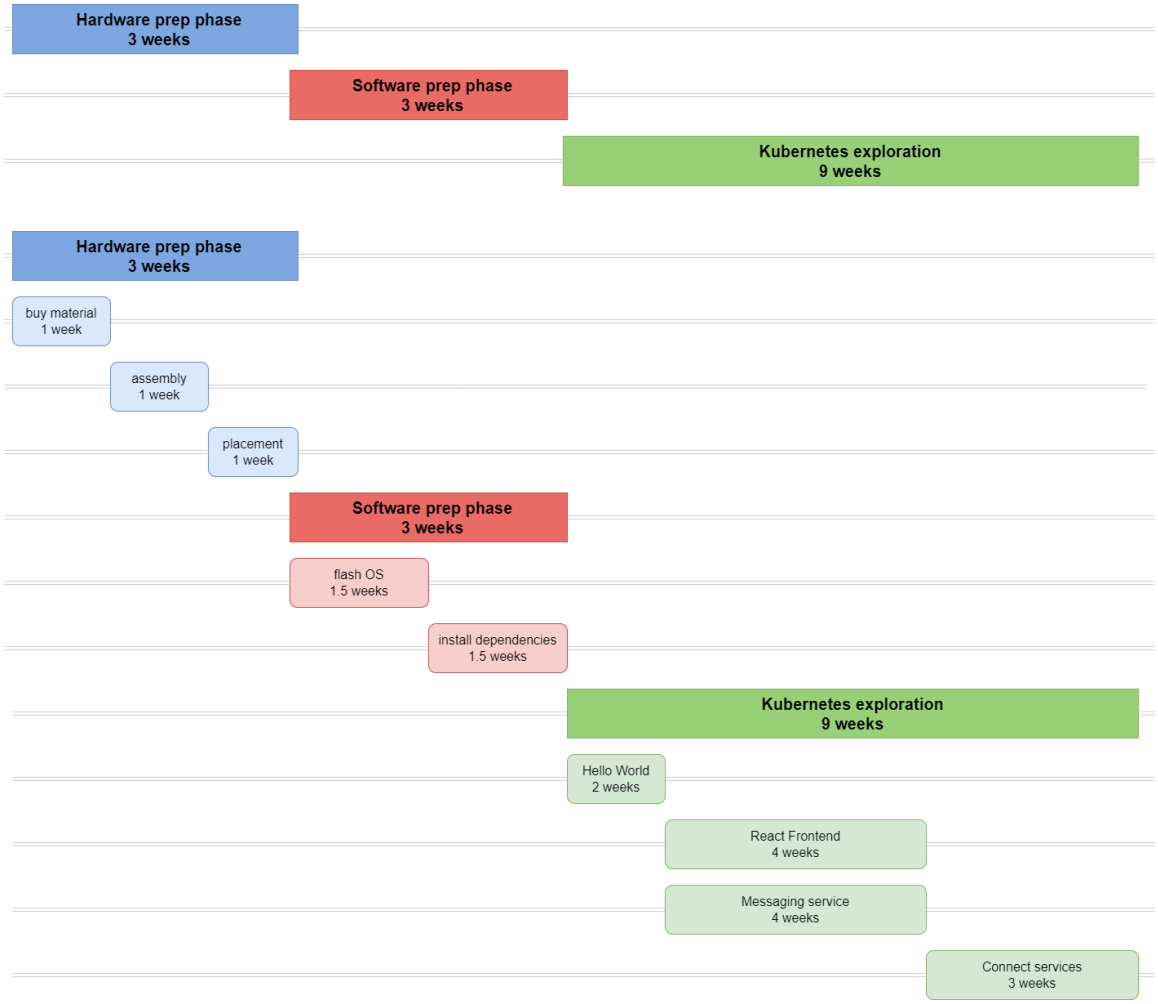


3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

The project has three major milestones: Flashing the Hypriot OS onto the raspberry pi compute modules; creating the simple frontend for the messaging service; connecting the front end and the backend.

3.4 Project Timeline/Schedule

The project has three broad phases. These phases are further broken down below.



3.5 Risks And Risk Management/Mitigation

Please find the risks and their mitigation in the table below.

Risks		Probability	Consequence	Mitigation Plan
Supplier risk	Out of Stock	High	Schedule Delays	Order early
	Delivery Delay			
Health & safety	Personal Injury	Low	Harmed Students	Don't rush the hardware assembly

Project Complexity	Information Silos; Asymptotic Performance	Moderate	Productivity Impact; Scope Reduction	Focus on simple design; document document document
Schedule risk	Whiffed estimates	High	Schedule Changes	Agile methodology

3.6 Personnel Effort Requirements

Task 1: Three persons: 5 hours

Task 2: Three persons: 5 hours

Task 3: Three persons: 5 hours

Task 4: Three persons: 7 hours

Task 5: Three persons: 7 hours

Task 6: All team: 10 hours

Task 7/8: Two teams of three each: 20 hours

Task 9: Two teams of three each: 20 hours

3.7 Other Resource Requirements

N/A

4 Design

4.1 Design Context

4.1.1 Broader Context

We are designing mainly for ourselves, as this is an exploratory project meant for a senior design team to learn about these important technologies. We have also spent time considering a broader context where our project might place itself.

Area	Description	Examples
Public health, safety, and welfare	How does your project affect the general well-being of various stakeholder groups? These groups may be direct users or may be indirectly affected (e.g., solution is implemented in their communities)	Our project does not affect the health or well-being of the public directly. Indirect effects would be the result of surprises born from the technology.
Global, cultural, and social	How well does your project reflect the values, practices, and aims of the cultural groups it affects? Groups may include but are not limited to specific communities, nations, professions, workplaces, and ethnic cultures.	Exploration into burgeoning technology is braided with the university experience for many students. This project is a good reflection of a research university's values.
Environmental	What environmental impact might your project have? This can include indirect effects, such as deforestation or unsustainable practices related to materials manufacture or procurement.	This project will have minimal environmental impact attributable to energy used to power electronics.
Economic	What economic impact might your project have? This can include the financial viability of your product within your team or company, cost to consumers, or broader economic effects on communities, markets, nations, and other groups.	This project will have minimal economic impact on Iowa State University. The project has a low likelihood of having an outsized impact economically pending exceptional outcomes.

4.1.2 Prior Work/Solutions

Docker and Kubenetes are the premier products on the market. These technologies have been used in the industry for some time and documentation on them is extensive. Docker containerization is utilized by developers for many projects and works great with other applications like Jenkins, Jfrog, and Gitlab. Using edge computing, containerization, and cloud orchestration allows for better asynchronous functionality and distributed computing. Which is perfect for implementing a messaging service that updates information continuously and has many devices requesting as well as sending information. This project is not looking to create some entirely new solution but to see what can be learned from existing products.

https://kubernetes.io/

https://www.docker.com/

https://turingpi.com/

4.1.3 Technical Complexity

This project involves working with several complex open-source software products, including Docker, Kubernetes, and Redis, and integrating them with our proprietary system to deliver the final product. While Docker and Kubernetes have become popular tools in recent years, Redis is a newer addition to the project that we will need to master. As there are no classroom-based resources available for learning these technologies, the technical complexity of the project is significant. The challenge of integrating multiple complex components without any existing education resources makes this project highly demanding from a technical standpoint.

4.2 Design Exploration

4.2.1 Design Decisions

1. Use of Turing Pi hardware

   The usage of the Turing Pi platform is essential to meeting the client's vision.

2. Use of Kubernetes for orchestration

   Kubernetes is an industry standard container orchestration platform. This exploration of the platform will enable future students to be better prepared for current and future job opportunities.

3. Use of Redis for event streaming

   Redis was chosen as the event streaming solution due to its superior performance in data processing and storage. This technology is well-suited to meet the needs of the project.

4.2.2 Ideation

We ideated using a technique titled "lotus blossom." This led us to new potential pathways. We considered the use of RabbitMQ as an alternative to Apache Kafka. We also considered what might happen if we used Docker Swarm instead of Kubernetes. Besides the Turing Pi, we had to consider a barebones motherboard-less option where we sync up everything ourselves. Unrelated to our main design decision, we talked about what version control system we should use, and how we were going to use CI/CD in this project.

4.2.3 Decision-Making and Trade-Off

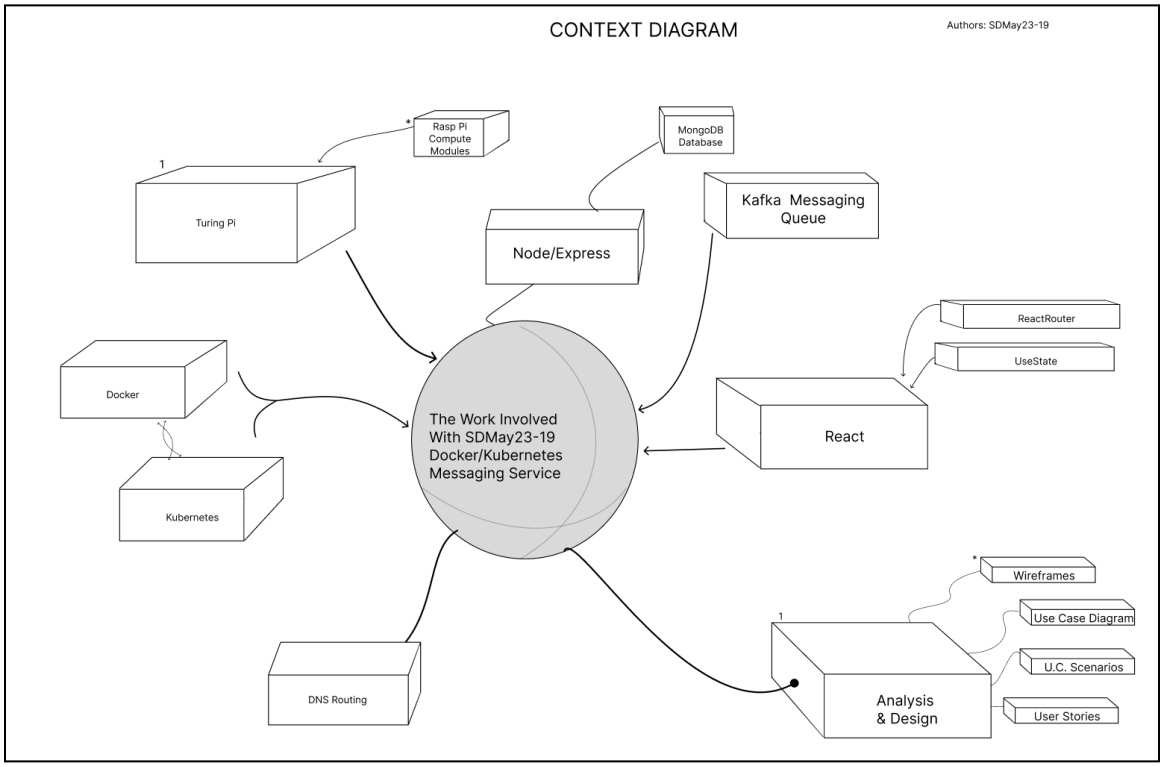
Selection Criteria	Criterion Weight	Messaging Service	AI Image Recognition	Ecommerce
Complexity	.2	4	8	4
Kubernetes Applicability	.3	8	2	5
Previous Experience	.5	8	2	3

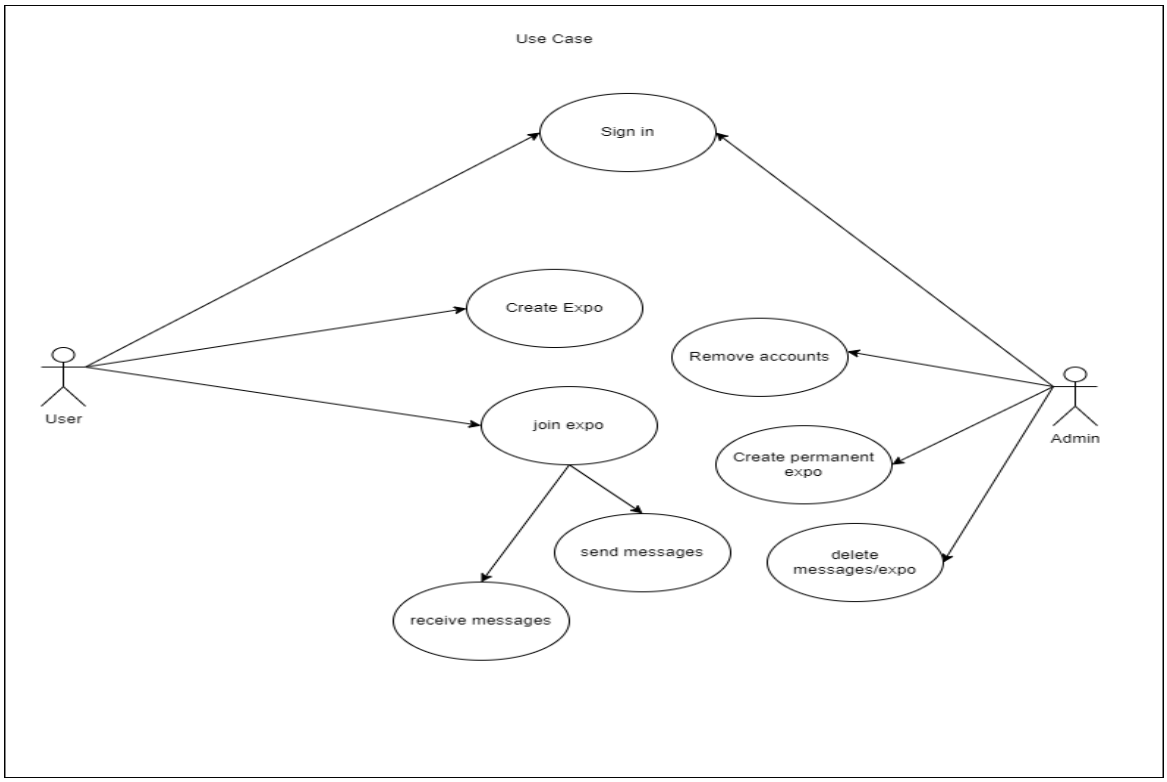
4.3 Proposed Design

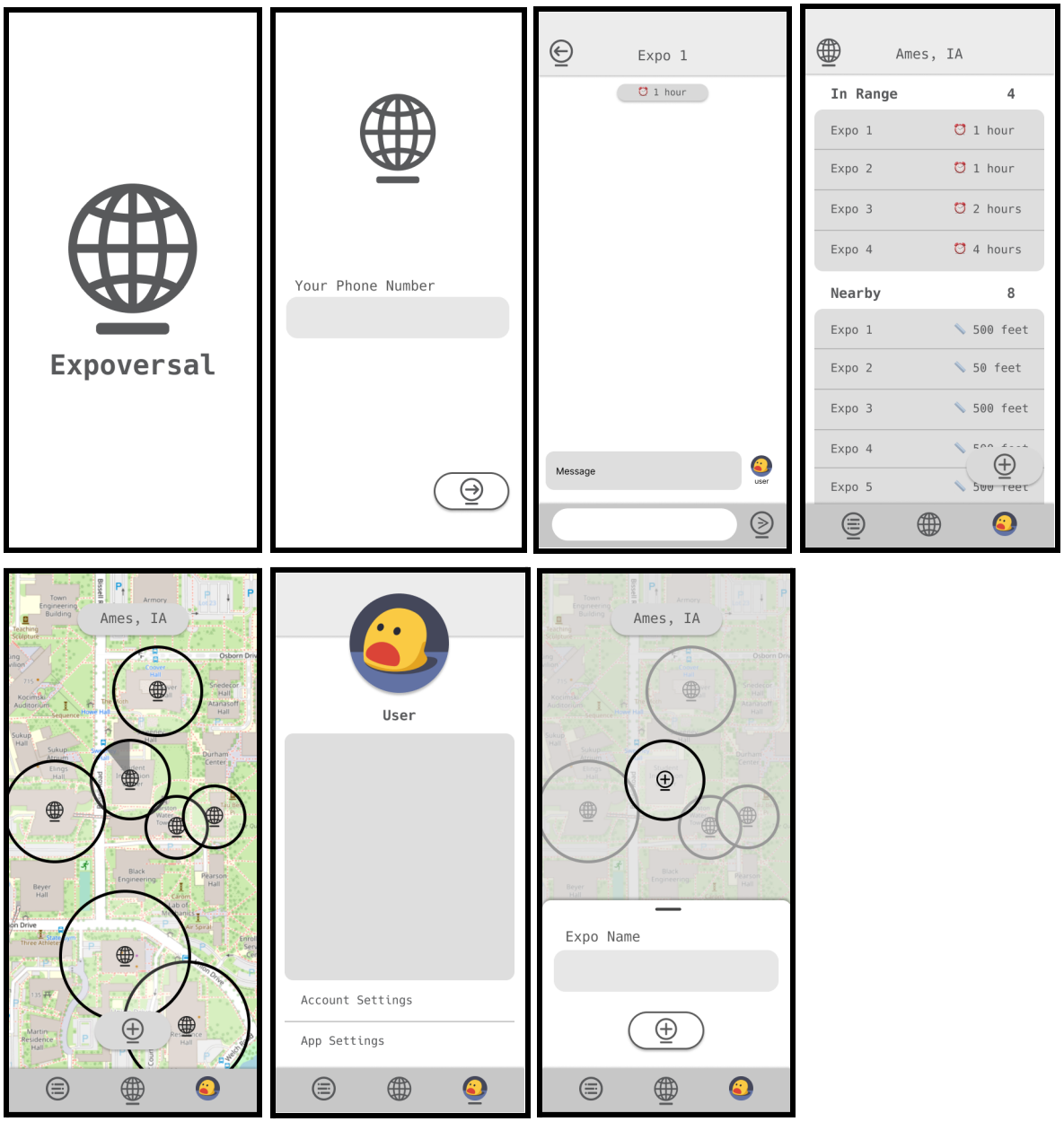
4.3.1 Overview

The project involves an online messaging service where users can enter chat rooms and communicate with one another on campus. The current design involves creating more than one chat channel that is region locked.

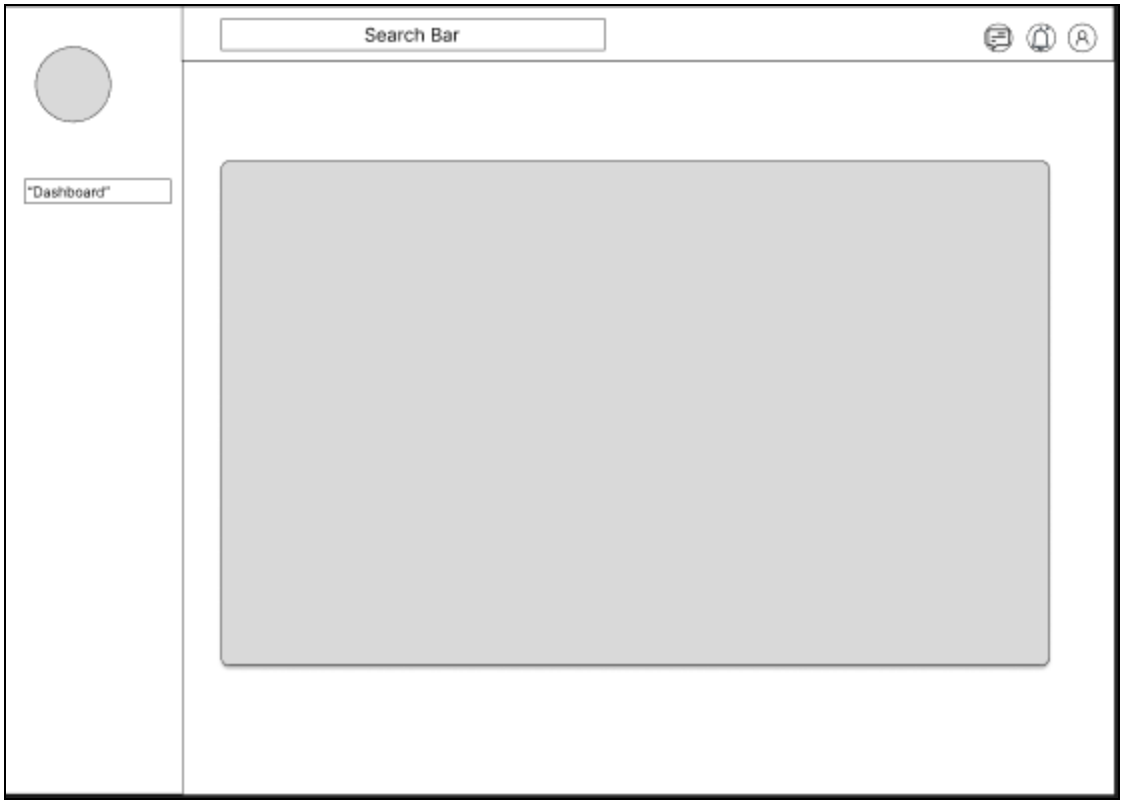
4.3.2 Detailed Design and Visual(s)







Web Application Side:



4.3.3 Functionality

Users who are on Iowa State campus would be capable of accessing our application. From there, they could enter chat rooms based on their location on campus. Once inside the chat room, the users may talk with anyone else also in that region's space. Any messages sent into the chat are propagated to others in that chat room.

4.3.4 Areas of Concern and Development

The design of the application satisfies the requirements and meets the user needs fairly. The application's design is complex enough to utilize the technologies the project is meant to investigate which is the goal of the design. The main concern for the system's current design will be how scalable it can be. Scalability is a primary functionality of the services/technologies in the system.

4.4 Technology Considerations

Since this is an exploratory project for Turing Pi, Docker, and Kubernetes, there are only a few considerations to be made. For hardware, we have decided to use Turing Pi 2 since Turing Pi has been discontinued, and it also allows us to have more options and better and newer hardware for our compute modules. For the compute modules, we mainly considered the price, memory, storage, and connectivity. Ultimately, we chose CM4104016, which has 4GB RAM, 16GB of eMMC storage, and wireless connectivity like Wi-Fi and Bluetooth.

For our event streaming platform, we have considered two different platforms. They are RabbitMQ and Apache Kafka. RabbitMQ is one of the most commonly used message brokers, allowing applications

and services to communicate data without requiring uniform exchange protocols. On the other hand, Kafka is generally used to create real-time streaming data pipelines and adaptive applications. It combines communications, storage, and stream processing to enable storing and analyzing historical and real-time data. Both event streaming platforms are open source and can process millions of messages simultaneously. However, we decided to use Kafka as it is more efficient than RabbitMQ with the same hardware.

4.5 Design Analysis

We have gotten a development environment set up inside of docker. Additionally, we have gotten some preliminary wireframes set up, as seen above. Not seen above is an itemized list with hardware we need for the project.

5 Testing

Testing is an **extremely** important component of projects, whether it involves a circuit, a process, power system, or software.

5.1 Unit Testing

The project shall use JEST. JEST is a simple Javascript testing framework. It's fast and safe, reliably running multiple tests in parallel. It also allows for mocking, as well as easy to comprehend exceptions when tests fail. We'll be able to use it with both our react frontend, and express backend.

5.2 Interface Testing

React can interface with JEST described above. This allows us to test the front end interfaces. Our backend can be tested with JEST because it is javascript based.

5.3 Integration Testing

Our critical paths involve backend containers orchestrated by kubernetes. We plan on testing this with K6, a technology that measures Kubernetes metrics, a key technology required in the project. Contract testing will be used to test individual services and then integration and component testing will be used to test kubernetes orchestration and kafka channels.

5.4 System Testing

K6 will be used to load test the kubernetes deployment,

5.5 Regression Testing

New additions are ensured not to break through CI/CD pipeline integration.

5.6 Acceptance Testing

User acceptance testing phase after sprints.

5.7 Security Testing (if applicable)

N/A

5.8 Results

The tests are designed to assist in our goal of exploring the functionality of the technologies being used. While it is important to ensure behavior of the end product, our capstone project focuses on diving into technologies Kubernetes and Docker. The focus is on education, so testing will help us toward that end.

6 Implementation

The implementation phase of the project involved building the Turing Pi hardware and implementing all container and orchestration systems. The team also worked on web development and application software during this phase. The container and orchestration systems were linked with the messaging service, resulting in the completion of the cloud platform hosted on the Turing Pi.

To start the implementation phase, the team first focused on building the Turing Pi hardware. This involved setting up the hardware components, including the Raspberry Pi Compute Module 4, and configuring the system to support the necessary software components. Once the hardware was set up, the team proceeded to implement all container and orchestration systems. They started with the installation and configuration of K3s, which replaced the previously planned Kubernetes platform. The team also switched from using Apache Kafka to using Redis for event streaming.

In addition to the container and orchestration systems, the team also worked on web development and application software during the implementation phase. They developed a basic web interface to interact with the cloud platform and also implemented various software components, including the messaging service and the database system. Once the container and orchestration systems were linked with the messaging service, the cloud platform hosted on the Turing Pi was fully functional.

7 Professional Responsibility

7.1 Areas of Responsibility

Area of Responsibility		
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence.	Perform services only in areas of their competence; Avoid deceptive acts.
Financial Responsibility	Deliver products and services of realizable value and at reasonable costs.	Act for each employer or client as faithful agents or trustees.
Communication Honesty	Reports work truthfully, without deception, and are understandable to stakeholders.	Issue public statements only in an objective and truthful manner; Avoid deceptive acts.
Health, Safety, Well-Being	Minimize risks to safety, health, and well-being of stakeholders.	Hold paramount the safety, health, and welfare of the public.
Property Ownership	Respect property, ideas, and information of clients and others.	Act for each employer or client as faithful agents or trustees.
Sustainability	Protect the environment and natural resources locally and globally.	Balance human needs and the environment.
Social Responsibility	Produce products and services that benefit society and communities.	Conduct themselves honorably, responsibly, ethically, and lawfully to enhance the honor, reputation, and usefulness of the profession.

7.2 Project Specific Professional Responsibility Areas

Area of Responsibility	Rating	Reasoning
Work Competence	High	The research conducted by this project will be used to influence teaching of future and emerging technology at Iowa State and thus must be of the highest quality.
Financial Responsibility	Medium	This project must also balance the financial needs of the university.
Communication Honesty	High	Documentation is essential to inform stakeholders of research conclusions.
Health, Safety, Well-Being	Low	Exploratory programs must put the well-being of users first.
Property Ownership	High	Ownership of hardware used by the university must be respected.
Social Responsibility	Medium	Exploratory programs must respect the public good.

7.3 Most Applicable Professional Responsibility Area

The most applicable area of responsibility is work competence. The members of the team must all work together to bring this exploration to life. The scale is too large, so it is important that work competence responsibilities are honored and kept.

8 Closing Material

8.1 Project Evolution

Since our previous design document, our project has evolved in several ways. We initially planned to use Kubernetes as our container orchestration tool, but after further research and evaluation, we decided to switch to k3s. k3s is a lightweight Kubernetes distribution that is optimized for edge computing and has a smaller footprint than the full Kubernetes stack. We found that k3s was a better fit for our project requirements and offered faster deployment and better performance.

We also made changes to our database and messaging components. Initially, we planned to use Apache Kafka as our messaging system and MongoDB as our database. However, we decided to switch to Redis for messaging and PostgreSQL for the database. We found that Redis offered better performance and scalability for our messaging needs, while PostgreSQL provided more advanced features and better support for relational data.

Another significant change in our project was the hardware we were using. Instead of the CM4104016 Raspberry Pi Compute Module 4, we received the CM4104000 model, which has minor differences but requires additional storage space. We needed to use an SD card for additional storage, which added an extra step to our setup process.

Unfortunately, due to delays in receiving the hardware, we were not able to fully explore and familiarize ourselves with the Turing Pi 2. This delay impacted our project timeline and required us to adjust our plans accordingly.

Overall, our project has evolved to include k3s, Redis, and PostgreSQL, and we had to adapt to changes in hardware and timeline. Despite these challenges, we are confident that our project will still meet our functional and non-functional requirements and deliver value to our stakeholders.

8.2 Discussion

The main focus of this project is exploring the technologies changing the face of software engineering. Docker, Kubernetes, and the cloud alter what it means to run “at scale.” The results and lessons learned will come from our experimentation next semester when we implement our design.

8.3 Conclusion

In conclusion, this project was an exploration of using the Turing Pi hardware platform for building an edge cloud solution using Redis as a messaging service and K3s as a container orchestration system. The project design underwent several revisions and changes during its development, including the decision to switch from Apache Kafka to Redis as the messaging service and from Kubernetes to K3s as the container orchestration system. The use of the Turing Pi hardware platform was essential to meeting the client's vision, and the exploration of the Kubernetes and Redis systems will enable future students to be better prepared for current and future job opportunities.

The implementation of the project was challenging, requiring a deep understanding of complex software products and their interactions. The team was able to successfully build the Turing Pi hardware platform and implement the container and orchestration systems, web development and application software. The final result was a cloud platform hosted on the Turing Pi that can deliver the promised end product.

This project has provided valuable insights into the complexities of building an edge cloud solution using open-source technologies. The team has gained valuable experience in hardware assembly, software development, and system administration. The project has also highlighted the importance of continuous learning and adaptation in the face of evolving technology. Overall, this project has been a valuable learning experience for the team, and we believe that the skills and knowledge gained will be beneficial in our future careers..

8.3 References

S. Cass, "Home Clustering Made Easier: Learn Docker and Kubernetes with the Turing Pi," in *IEEE Spectrum*, vol. 58, no. 11, pp. 16-18, November 2021, doi: 10.1109/MSPEC.2021.9606504. Available at: https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9606504

8.4.1 Team Contract

Team Members:

1) _____Bryce Carter_____ 2) _____Chee Hau Fong_____

3) _____James Gibbs_____ 4) _____Kyoungkeun Lee_____

5) _____Theodore Thayib_____

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:

The Team shall hold meetings weekly on Tuesday from 5:30 pm to 6:30 pm over Discord. *Subject to change by supermajority consensus.*

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):

The Team shall prefer Discord, the instant messaging social platform, as the communication method. *Subject to change by supermajority consensus.*

3. Decision-making policy (e.g., consensus, majority vote):

Decision-making procedure:

(a) Consensus vote for small choices for members present
(b) Polls for large decisions with team lead as tie-breaker

4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):

Record keeping procedure:

(a) Meeting Agenda Kept in Google Drive
(b) Meeting Minutes Kept in Google Drive
(c) Meeting Agenda Posted in Discord Channel #meeting-records
(d) Meeting Minutes Posted in Discord Channel #meeting-records

(a) Decisions made for small choices are entered into a Team Decisions document with a justification statement. Example: We chose this route for **x** reason.
(b) Large decisions are entered into the Team Decisions documents as a screenshot of the poll.

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:

Expectations shall include (1) **on time** and (2) **prepared** unless extenuating circumstances prevent the member.

2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:

Expectations shall include (1) **equal effort** and (2) **completion of work** unless extenuating circumstances prevent the member.

3. Expected level of communication with other team members:

Expectations shall include (1) **24 hour reply time** and (2) **response in discord demonstrating up-to-date knowledge** unless extenuating circumstances prevent the member.

4. Expected level of commitment to team decisions and tasks:

Expectations shall include (1) **equal consideration of ideas** and (2) **trust in team decisions** unless extenuating circumstances prevent the member.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):

    Bryce Carter:Individual Component Design

    Kyoungkeun Lee: Goal Setting and Motivation

    Chee Hau Fong: Testing

    James Gibbs:Team Lead

    Theodore Thayib: Client Interaction

2. Strategies for supporting and guiding the work of all team members:

    Standard Operating Strategy:

    (a) Analyze the problems inherent with the work
    (b) Estimate the time commitment of the work
    (c) Delegate the work

3. Strategies for recognizing the contributions of all team members:

    Standard Operating Strategy:

    (a) Start meetings with shoutouts for great work

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.

    Bryce Carter: Experience with development operations, and working with different teams in an industry environment.

    Kyoungkeun Lee: Experience with embedded devices and basic knowledge of operating systems and I/O systems.

    Chee Hau Fong: Experience with APIs and CI/CD

James Gibbs:Experience with docker and kubernetes

Theodore Thayib: Experience with docker, APIs, javascript (react), backend (flask)

2. Strategies for encouraging and supporting contributions and ideas from all team members:

Standard Operating Strategy:

(a) Encourage others to give input if they haven't had a chance to talk much.

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)

Standard Operating Strategy:

(a) Member in command has responsibility for maintaining respectable group dynamics

Goal-Setting, Planning, and Execution

1. Team goals for this semester:

The Team goals include:

(a) Completing all assignments and turn in on time
(b) Finishing project design and implementation
(c) Creating teamwork

2. Strategies for planning and assigning individual and team work:

Standard Operating Strategy:

(a) Discussing as a team about assigning work based on member's individual skills
(b) Rewarding how much they achieve according to weekly goal
(c) Sharing progress with team members weekly

Exceptional Conditions Strategy:

(a) Give an optional week break every 4 weeks
(b) Impromptu team meetings
(c) Assigning specific tasks

3. Strategies for keeping on task:

    Standard Operating Strategy:

    (a) Progress reports on weekly meeting
    (b) Asking help if stuck and being available to team
    (c) Meeting minutes for keeping track and feedback

    Exceptional Conditions Strategy:

    (a) Stricter Agile/Scrum documentation
    (b) More consistent reminders
    (c) More consistent progress reports

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?

    Misdemeanor Procedure:

    (a) Ask if everything in their life is going okay
    (b) Ask if there is anything we can do to help
    (c) Reduce complexity, within reason, for next task

2. What will your team do if the infractions continue?

    Major Transgression Procedure:

    (a) Notify Professor
    (b) Notify student that professor has been notified

****

a) *I participated in formulating the standards, roles, and procedures as stated in this contract.*

b) *I understand that I am obligated to abide by these terms and conditions.*

c) *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*

1) Bryce Cater DATE 9/23/2022

2) James Gibbs DATE 9/23/2022

3) Chee Hau Fong DATE 9/23/2022

5) Kyoungkeun Lee DATE 9/23/2022

6) Theodore Thayib DATE 9/23/2022