Iowa State University

CyWi: An Open-Source Wireless Innovation Lab for SmartAg, AR/VR, and Beyond

Project Plan Document

Chenye Lim *Ryan Cullinan*

Jian Chew *Shay Willems*

Pawel Darowski *Tyler Beder*

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Problem Statement

Over the last decade, the experimentation of the Internet of Things (IoT) has been in full force because of the multitude of advantages it can bring to everyday life. Despite many years of research, we are still at the infancy of IoT and Industry 4.0 capabilities. IoT can be used for a wide range of products such as SmartAg, connected autonomous vehicles, smart grids, and AR/VR.

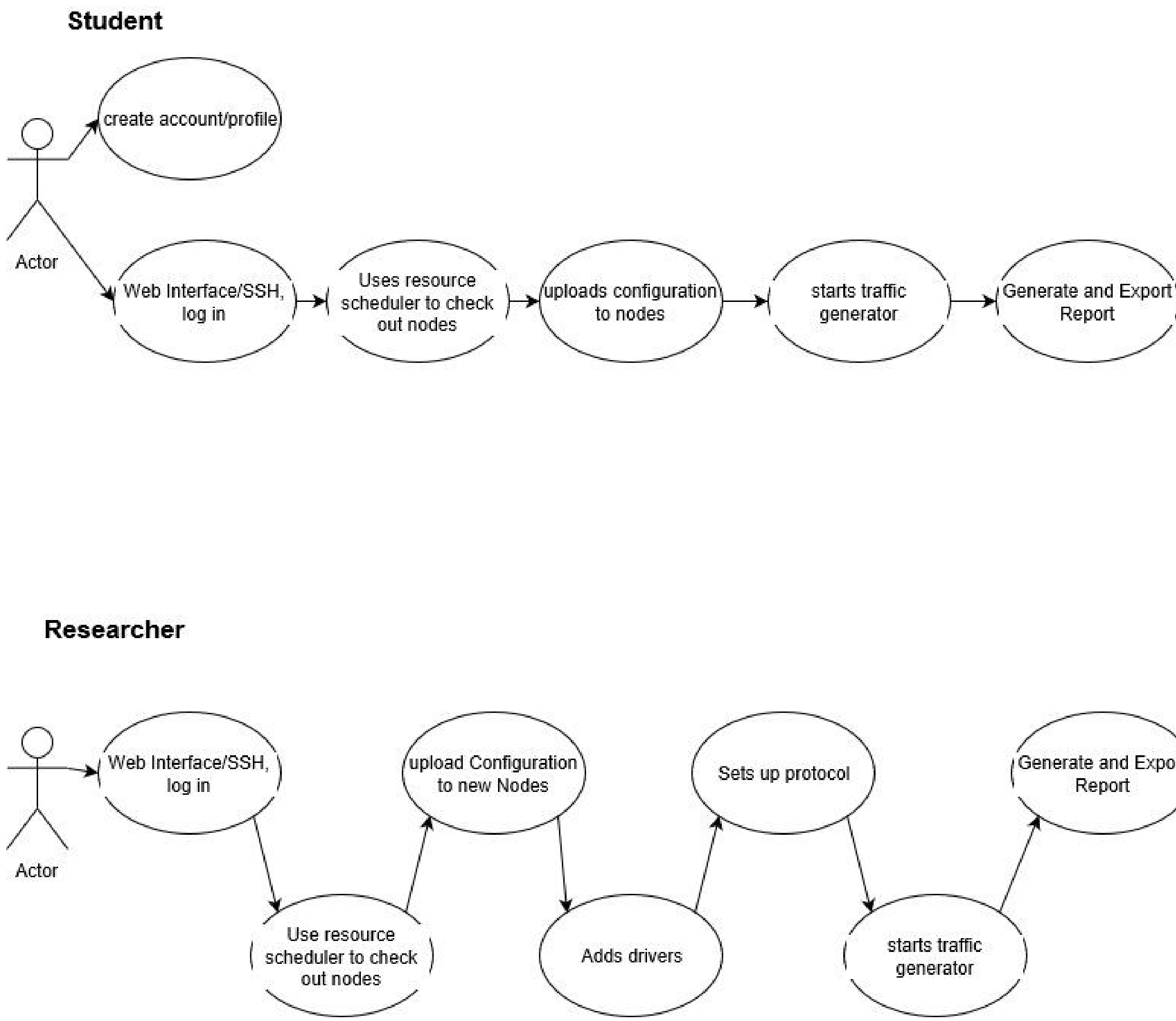

Figure 1: Use Case Diagrams

Iowa State University has decided to explore this field with the development of the CyWi lab. This lab will consist of a multi-node testbed located on the Iowa State campus and will be available to researchers and testers to run their experimentation code. This lab will feature the most bleeding-edge wireless innovation platforms as well as emerging wireless solutions. It will also feature 5G wireless for new learning, teaching, and researching across the globe.

Operating Environment

The CyWi's testbed will be located in 3050 Coover Hall at Iowa State University. This is a climate-controlled room with a keycard secured door. The only people allowed into the lab room are those with keycards: the professor/client, ETG, and a handful of researchers. Users will only have access via the remote web interface, never via physical access to the lab. One wall has windows facing west but the blinds will be closed so sunshine never touches our equipment. While it is not expected for the hardware to experience anything but optimal operating conditions, our web-based service will be exposed to the Internet so cyber attacks and DDoS are possible.

Intended Users and Intended Uses

The CyWi testbed is intended for two general types of users: students and researchers.

Students learn about wireless signals and protocols in their courses via lectures, assignments, and small projects. Theoretical knowledge is crucial. However, building upon that foundation with extensive lab experience configuring real-world hardware will improve students' understanding of the subject matter. Implementing wireless topologies such as mesh, star, and point-to-point could inspire future IoT developers. Comparing Zigbee and Bluetooth Low Energy performance, for example, over assorted ranges, signal strengths, and conditions will extend students' knowledge of technology strengths and limitations. CyWi will provide students the opportunity to experiment with a variety of popular, existing wireless technologies and to expand their understanding in a safe environment.

Researchers, on the other hand, will appreciate the cutting-edge communication technologies represented by the CyWi testbed. Access to powerful and configurable software-defined radios (SDRs) will allow researchers to study a wide spectrum of new heterogeneous networks and explore exciting innovative ideas. Researchers will evaluate performance monitoring and statistics after each experiment to determine feasibility of their chosen path. Emerging technologies such as 5G, SmartAg, augmented reality, virtual reality, and Internet-of-Things will generate opportunities for decades of continuous communications development. As Figure 2 shows, CyWi is particularly equipped to handle experiments of various throughput and latency specifications.

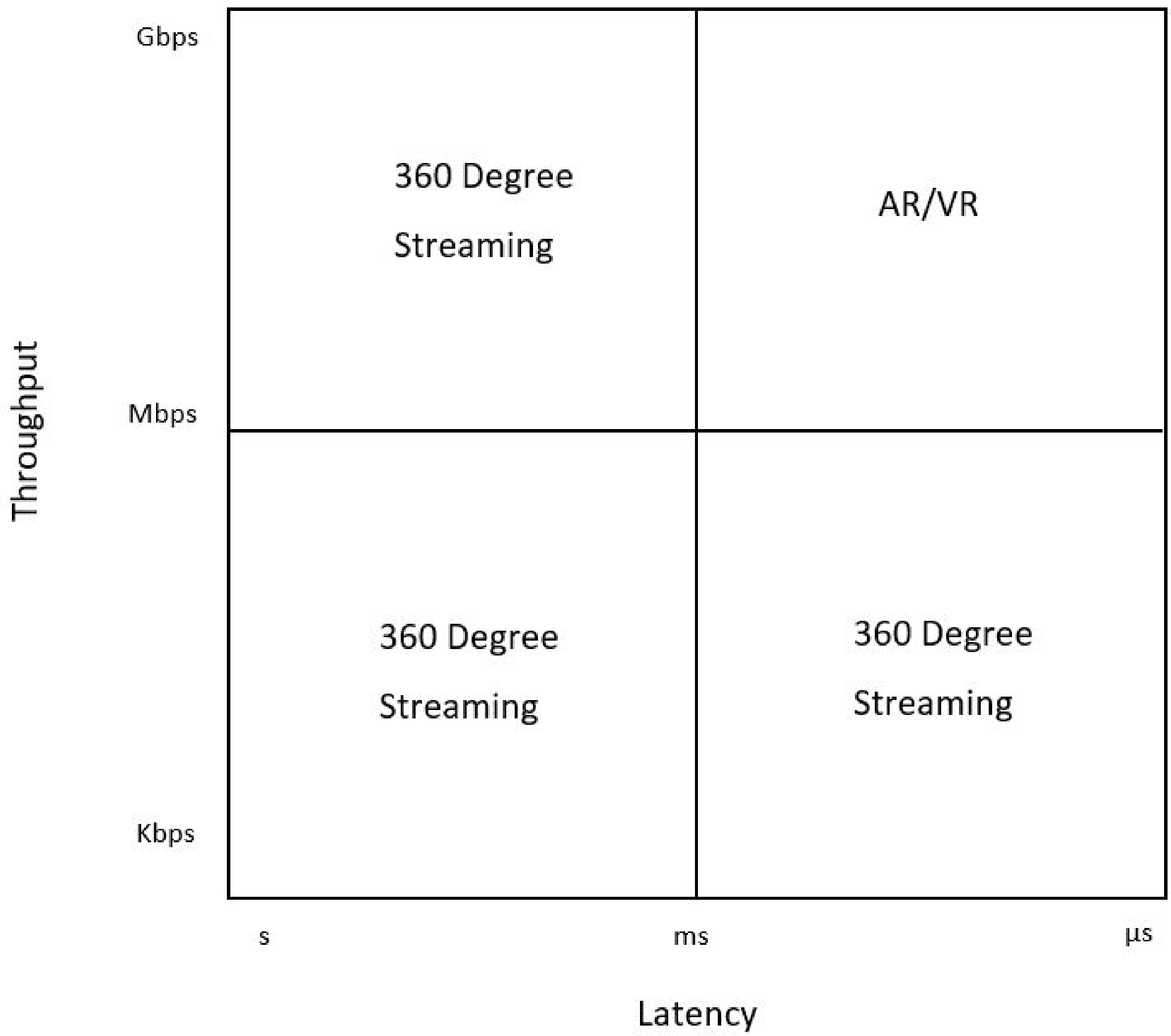

Figure 2: Bandwidth to Latency Relations

Assumptions and Limitations

Assumptions

- Power to the testbed will remain on 24/7/365.
- Air conditioning in the lab room will keep it at optimal computing conditions.
- No natural or manmade disasters will occur in or around the lab room.
- Any upkeep funding will continue after the project is finished.
- Internet access will remain up 24/7/365.
- Iowa State University will keep its accreditation in the coming years.

Limitations

- All software used must be open-source.
- The lab room only has space for only 110 total nodes.
- Two semesters is the maximum amount of time to spend on this project.

Expected End Product

The end product for this project will be a fully operational wireless communication system testbed. The testbed will be comprised of a grid of individual nodes equipped with various communication system hardware and software platforms. These nodes will be monitored and controlled by a server that can be access via a web platform that we will implanenting.

Related Work / Literature Review

For this project we looked into two different wireless testbeds, POWDER and ORBIT. Both of these testbed are hosted at Universities in the United State. POWDER, located at the University of Utah, is very similar to the testbed that we plan on creating. It is based around open source platforms, making more accessible for all types of wireless communication research. POWDER has cutting edge radio hardware and software enabling it use existing communication protocols. The testbed that we will create, unlike POWDER, will be able to run experiments on the newest 5G and MIMO protocols.

Acknowledgements

The CyWi team would like to give special thanks to professor Professor Hongwei Zhang . His technical assistance on the project will serve to be invaluable to us. Additionally we would like to thank Professor HongWei Zhang for securing the funding to make this project possible. Finally we would like to acknowledge the Iowa State Department of Electrical and Computer Engineering for providing the lab space in Coover Hall to create the CyWi testbed, and also we would like to thank ETG for their assistance in wiring the testbed.

III. Proposed Approach and Statement of Work

Proposed Approach

High-Level Block Diagram

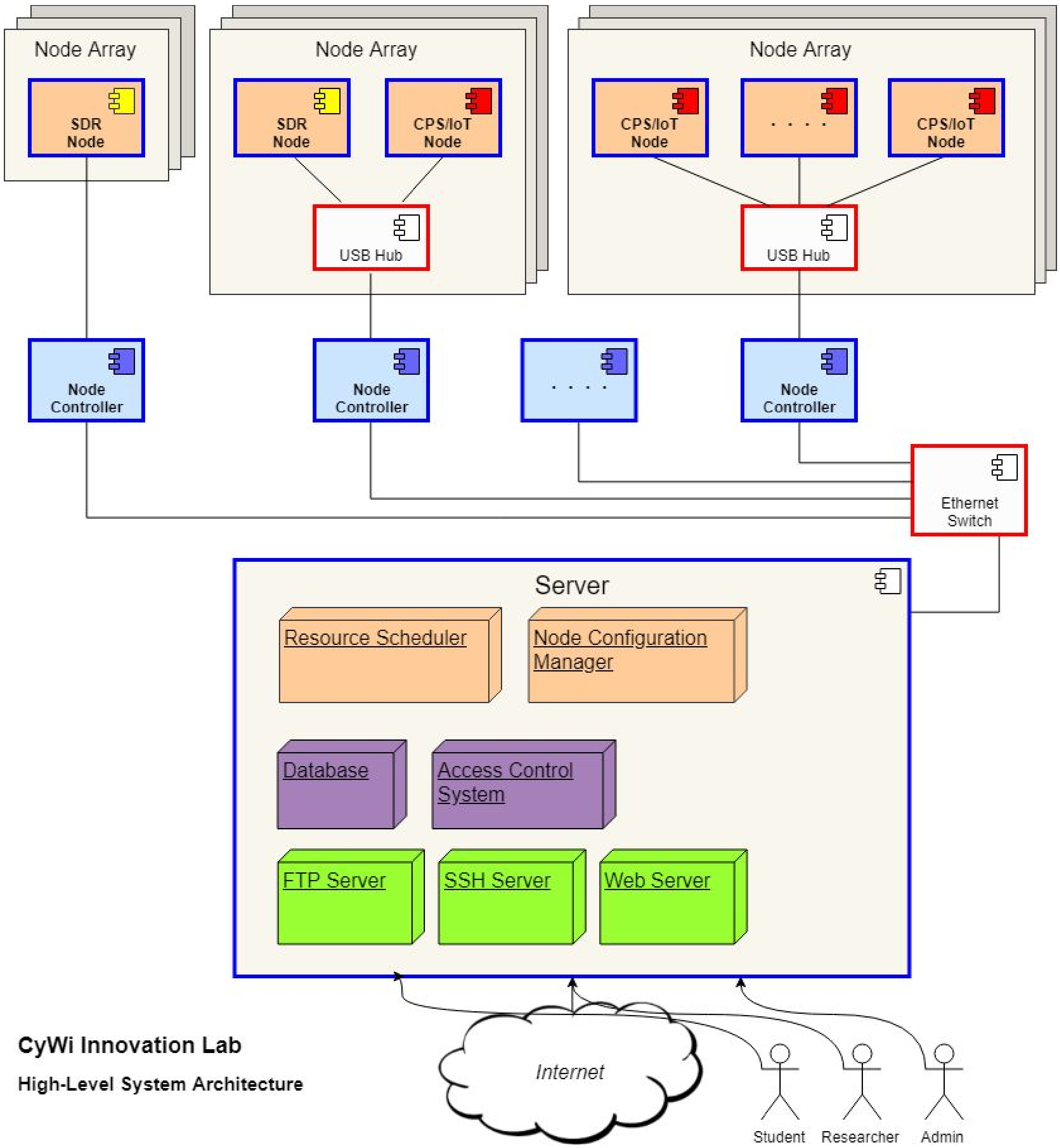

Figure 3: High-Level Block Diagram

Functional Requirements

The CyWi testbed is required to perform the following functions:

- Create user accounts.
- Allow user access via web interface and SSH.
- Securely store user profiles, experiments, and usage statistics in a database.
- Track resource availability.
- Reserve resources as requested by users.
- Create, configure, and run experiments.
- Allow the user to export experiment data.

Constraints Considerations

Restrictions that define the project limitations are:

- Lab room ceiling tiles are arranged in a grid of 11x10, which limits our maximum quantity of CPS/IoT devices to 110 CPS/IoT development kits.
- Powerful and configurable wireless devices, such as SDRs, are expensive. High costs limit the quantity of devices available to us and decreases the size of the testbed.
- Scheduling a time for six active students to meet is challenging and strains our ability to work together for longer periods of time.

Technology Considerations

One of the chief motivations for building the CyWi lab is to allow students and researchers to experiment with up-and-coming technologies. Therefore, the hardware selected for the testbed must be capable of supporting multiple modern standards such as 5G, SmartAg, CPS, IoT, and AR/VR. Finding one type of device that covers all of these would be difficult and expensive so we chose to focus on two classes of devices: software-defined radios (SDRs) and CPS/IoT development kits.

Including SDRs in the testbed allows us to offer our users a high level of control. An SDR's FPGA is fully customizable which allows researchers to have direct control over signal processing, removing the need for additional radio equipment. Since the testbed is designed to be used entirely remotely, this seems like the most elegant solution. The SDRs will be useful for experiments that require high bandwidth and low latency such as AR/VR-based models.

CPS and IoT have less stringent requirements when it comes to bandwidth and latency so a better option is to install a large number of affordable development kits with built-in support for Wi-Fi, Bluetooth Low Energy, and Zigbee. The next decade will see an explosion of CPS/IoT development so students and researchers will benefit from experimenting with wireless communication protocols designed for these applications.

Accessibility is another chief motivation of the CyWi lab and nothing is more accessible than open-source software. Not all development devices support open-source development software so this was a major consideration when deciding on which testlab devices to purchase. The Texas Instruments development kits support a variety of open-source real time operating systems (RTOS). For cellular research, we settled on Ettus USRP SDRs and the OpenAirInterface platform. The OpenAirInterface community is continuing to develop LTE and 5G solutions in an open environment.

Technical Approach Considerations

The CyWi team is approaching this large project with utmost seriousness. This testlab will remain at Iowa State University long after we have all graduated, and the return on investment for the funding that made it possible will be expressed in years of student and researcher hands-on experience.

Most of the team must undergo a steep learning curve when it comes to wireless technologies. For this reason, we are spending the first two months surveying CPS/IoT platforms and studying wireless technologies. Once we have a better understanding of the technology, we will be in a position to purchase devices that best suit our needs. We are also experimenting with other existing wireless testbeds such as Powder and ORBIT to determine which features we would like to implement and how to set our project apart from those testbeds.

All lab hardware will be installed by Iowa State's ETG. Once they finish, we will prepare each of the Node Controllers with a Linux distro and verify that the control plane has no issues. At this point we will begin specializing. Server administrators will be in charge of setting up access control, database, and each of the Internet-facing services including the Web interface. Powder has a clean user interface and is an open-source project so we look forward to borrowing some code from them; our client has suggested this and has signed off on it.

Some SDR and CPS/IoT profiles will also need to be constructed on the nodes. A couple team members will turn their attention on the node manufacturer documentation to determine the best way to proceed. Student users will appreciate a simpler profile, but researchers will expect a wide-open profile to allow them to reprogram FPGAs, write drivers, etc.

At this point we will be ready to begin system integration. Building interfaces between each component will take time but by then we will have experience in our respective positions. Together we will define and implement APIs across system components and end up with a cohesive testbed that's ripe for further demonstrations and testing.

Testing Requirements Considerations
As we get further into the project implementation, we will be testing components as they are getting built. We must be sure that each component works individually before system integration takes place. The services connecting to the Internet will be thoroughly tested, both from on and off campus. New user accounts will be registered and updated with new information. The database queries must be properly vetted to return the correct data. The Node Configuration Manager must be able to communicate with each of the Node Controllers and make quick configuration changes. The Resource Scheduler must be aware of each node's status and never over-subscribe a node; for this to happen, a solid finite-state machine must be implemented and tested. The Node Controllers must also have a recovery mechanism in place to keep downtime to a minimum. All of these systems will be thoroughly tested promptly after being built and again after system integration. Once each of the components are combined into one testbed system, we can begin demonstrating our product.

The last three or four weeks of this project are devoted entirely to demonstrating what the testbed is capable of. During this time, we plan to create experiments that show off all our supported wireless protocols and features. Bluetooth and Zigbee applications with the CPS/IoT nodes will have many possibilities such as building a mesh network and measuring its performance. For cellular network, we will experiment with using SDRs to generate custom signals. Implementing LTE between two SDRs will prove interesting and we will attempt to use a 5G stack to show that CyWi is capable. After each experiment, the report will be exported and looked over to verify a sanity check. This final stage of the project will serve a dual-purpose: we will be demonstrating our system while at the same time discovering and troubleshooting any potential bugs.

Security Considerations
In order to physically access the testbed, individuals will have go through the approval process similar to the other labs in Coover Hall. Since data will be stored locally on the server, limited data security will be required. Additionally, individuals that wish to access the testbed remotely will have to request access to the server.

Safety Considerations
There are a few safety considerations with the physical construction of the testbed. The testbed nodes will be hung from the ceiling and there will be a lot of electrical wiring involved with the testbed. Proper care will have to be taken to ensure that our hardware does not pose any risks to individuals using the testbed. To ensure proper installation of the electrical wiring and hardware, ETG will be contracted to perform the installation.

Possible Risks and Risk Management

With the proposed size of the testbed, when fully functional, it will require a considerable amount of power. Additionally there will be a lot wiring entwined into the testbed. There poses a risk for electric shock from potentially misusing/handling the hardware. In order to mitigate this risk the testbed is mounted to the ceiling, all live wiring will be properly shielded and out of reach.

Project Proposed Milestones and Evaluation Criteria

Milestone 1: Installation of all the hardware

This milestone will be composed of ordering all of the SDRs, TI products, and NUCs and installing them. This milestone will be considered complete if we have acquired all of the products and they are wired together in the designated room in Coover. This will be accomplished by March 22nd

Milestone 2: Completed Software

This will be the bulk of this project and it will include developing all of the necessary software for our test bed to run. This will include configuring all of the nodes and node controllers, implementing the node configuration manager, implementing the resource scheduler, and the web server. This milestone will be considered completed when the test bed is up and running and researchers are able to run experiments through it. This will be completed by December 6th.

Milestone 3: Developing Test and Writing Article

This milestone is for the purpose of showing that the test bed does indeed work and documenting the whole process. As we are developing this project we will be documenting the path we took and writing an article that will display the journey of making this test bed. We will also spend a month developing our own experiment that we will run through the test bed. This milestone will be considered completed with a documented article and a completed experiment that has been run. It will be completed by December 13th.

Project Tracking Procedures

We will track our progress by following the guidelines of our gantt charts. We have a gantt chart for the first semester and the second semester which are shown below.

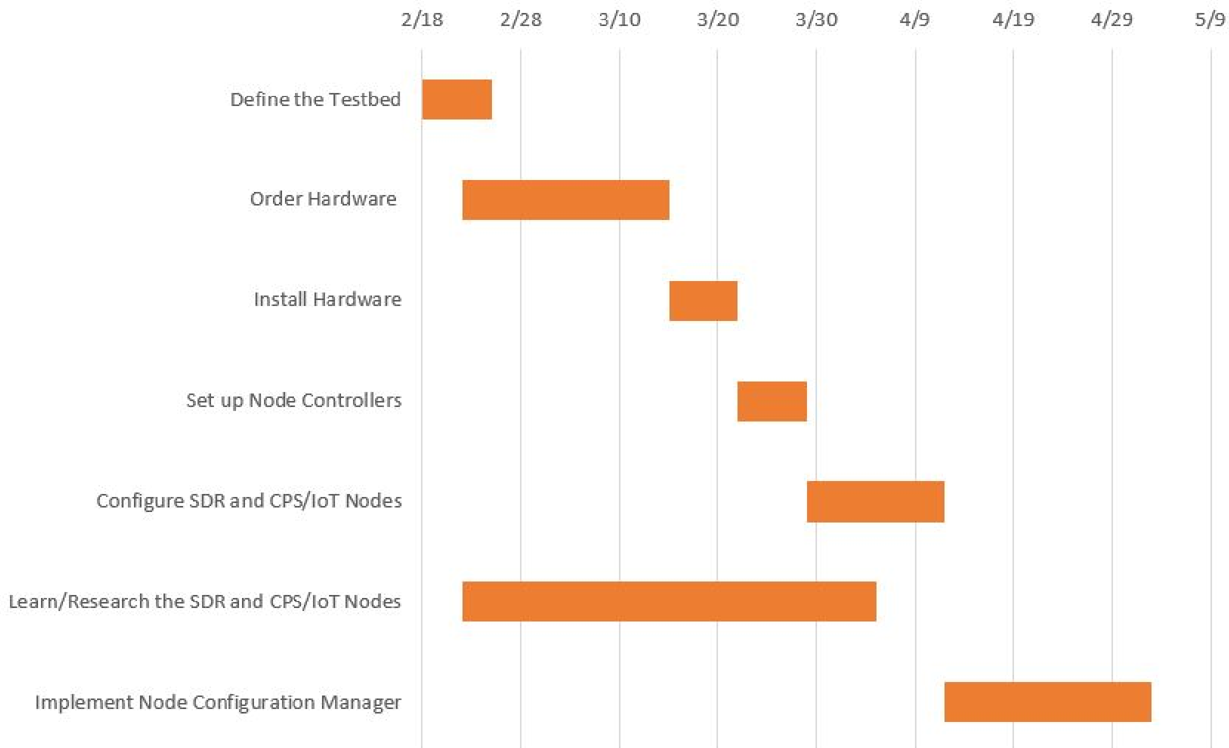

Figure 4: Semester 1 Gantt Chart

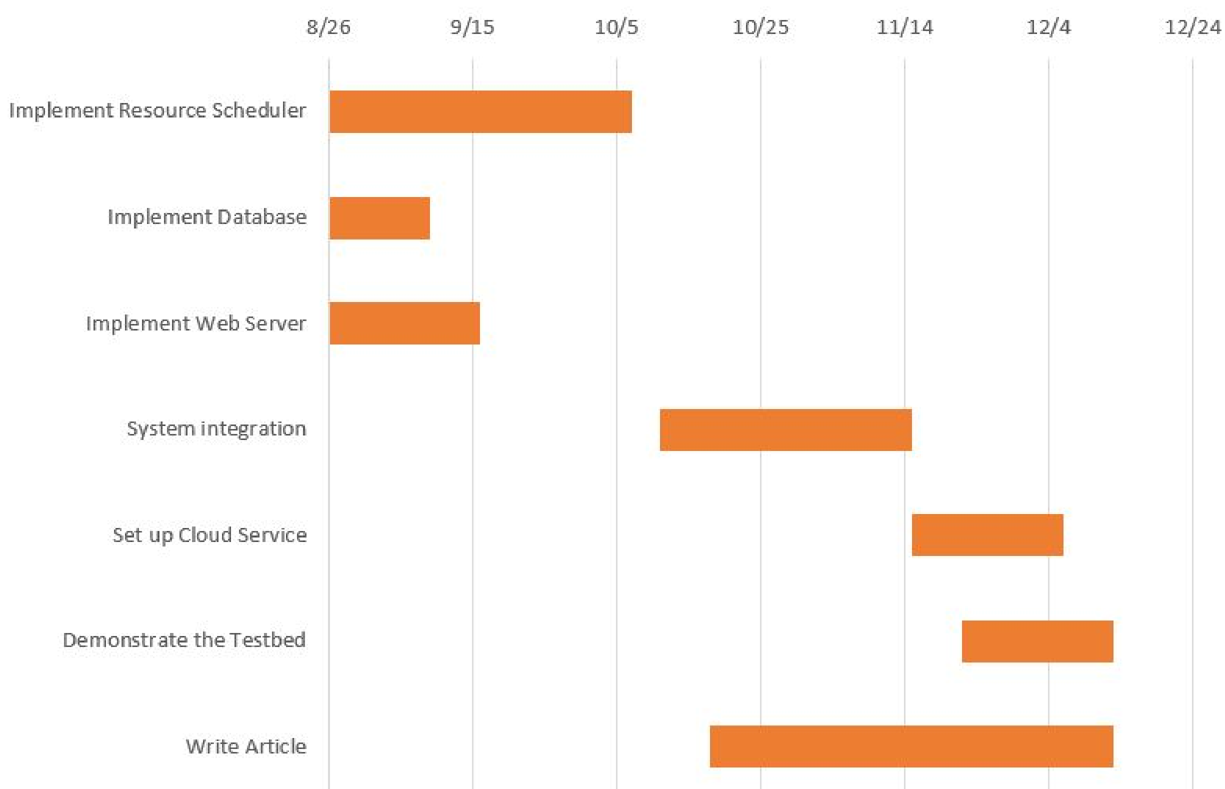

Figure 5: Semester 2 Gantt Chart

Statement of Work

Number and describe for each task that needs to be completed, 1) the task objective, 2) the task approach, and 3) the expected task results.

Define the testbed

- Approach: Researching technical needs of the testbed.
- Results: Determines what we need to order for hardware.

Order Hardware

- Approach: Communicate with professor as to what hardware we need.
- Results: To make sure we will be receiving the hardware we need in a timely manner

Install Hardware

- Approach: Assembling hardware in the lab.
- Results: Sets up the bigger part of the testbed.

Set up Node Controllers

- Approach: Determining what will make these nodes configurable to users.
- Results: The controllers will be responsible for reporting status and managing each node.

Configure SDR and CPS/IOT Nodes

- Approach: Determine how we need to set them up to make them configurable to the users.
- Results: Sets Nodes up for experimentation.

Learn/Research the SDR and CPS/IOT Nodes

- Results: We will know more about what configuration options to allow.

Implement Node Configuration Manager

- Approach:Using what we learned before, we make the list of FPGA and network layer configurations that will be available and write code that will set them up.
- Results: Nodes will be configurable.

Implement Resource Scheduler

- Approach: Use of scheduling algorithms, determining how it handles users requests whether it accepts or denies.
- Results: Manages which nodes are available for checkout, and to who.

Implement Database

- Approach: Determine how information will be stored and then made available to the user when an experiment is done.
- Results: We will have a database from which to pull experiment data from.

Implement Web Server

- Approach: Software for file transfer. Front End Design: software for SSH process and Web interface.

- Results: We will have a way of being able to move experiments onto the testbed.

System Integration

- Approach: Testing to make sure our different components work together.
- Results: Users will be able to put files on the testbed and get test results.

Set Up Cloud Service

- Approach: Determining how everyone will be able to get access to the testbed.
- Results: We will have a way for everyone to easily use the testbed

Demonstrate the Testbed

- Results: Shows that we have a functioning project

IV. Estimated Resources and Project Timeline

Personnel Effort Requirements

This section is just a draft of the early stage of the project. It will definitely get updated when we have a better idea on how long each of these tasks will take.

The table below includes the major tasks with description and also estimated hours for each task.

Task	Description	Estimated Hours
Weekly Report	Record past week's work and compile them into a report.	25 hours
Project Plan	Create a project plan and keep it updated throughout the project.	20 hours
Define the Testbed	Define exactly what the user experience will be and how these systems will fit together. Define explicit use cases.	10 hours
Order Hardware	Purchase SDRs, TI development kits, Intel NUC8s, server, and necessary networking equipment.	5 hours
Install Hardware	Physically install and connect all the devices.	10 hours
Set up Node Computers	Install Linux distro on each node computer and verify that they communicate with their wireless devices.	15 hours
Configure Wireless Devices	Install open-source software on each SDR and TI development kit as well as configure them on the private network.	30 hours
Learn/Research the SDR and	Learn how to use each of	100 hours

TI Devices	these technologies.	
Implement Controller Server	Implement the controller software on the server to allow it to configure the node computers. The controller server should be able to send files and commands to individual nodes. The node computers, in turn, will configure the wireless devices.	50 hours
Implement Resource Scheduler	Implement the resource scheduler to grant resources (access to certain nodes/wireless devices) to users per constraints.	100 hours
Implement Database Server	Implement a database on the server to store multiple tables for things such as user authentication, user statistics, node/wireless device status/availability, schedule reservation charts (if needed), experiment data.	30 hours
Implement Front-End Server	Create a launch site for researchers to interact with so they can login, request resources for a given time period, and gain access to the nodes/wireless devices.	50 hours
Interface Front-End, Resource Scheduler, Database, and Controller Servers (System Integration)	Implement interfaces between the servers so they can interact. Users should be able to login, query databases, checkout resources, configure wireless devices, run experiments, and export experiment data.	100 hours
Set up Cloud Service	Implement the cloud service	30 hours

	so that users can remotely access the testbed.	
Demonstrate the Testbed	Run some different kinds of experiments on the 'finished' testbed to demonstrate what it's capable of.	30 hours
Write Article	Article about how the testbed was created and how it works, etc. Possibly publish. Why it was made? Benefits? Audience: 1) users 2) developers	30 hours

Table 1: Major Tasks with Description and Estimated Hours

Other Resource Requirements

Every team member needs to have a computer that have a text editor with certain language compiler. To be able to test our user interface in the future, we need to have access to the internet. Besides that, we need access to the testbed lab in order to configure wired and wireless devices such as radios and server. And also, in the early stage of our project, we plan to take a more straightforward approach, by limiting most tests to be in wired connection. Furthermore, in order to further understand the nature of a wireless communication testbed, we need to register an account for access.

Financial Requirements

Total Budget	Undetermined
Cost of Hardware	**Price ($)**
3 x USRP X310	3 x 5,422 = 16,266
12 x USRP B210	12 x 1,216 = 14,592
50 x TI CC26x2R	50 x 39.99 = 1,999.50
8 x Intel NUC Kit	8 x 799.99 = 6,399.92

Total	39,257.42

Table 2: Expected Cost of the Project

The total budget of the project is currently undetermined because we have to check it with our academic advisor. The cost of the project is only made up of the hardware.

The project requires a few radios, each with different capabilities, such that the testbed can support as many experiments as possible. Moreover, it also requires a few computing devices which can run all the radios.

The external tools that we plan to use are all open-source. For example, OpenAirInterface is created by EURECOM, which can be used by the community, and Powder is created by University of Utah under the sponsor of National Science Foundation. Since we are planning to develop the code on our own and build upon open-source code, we expect to not spend any amount on software for this project.

Project Timeline

Name	Description	Timeframe	Start Date	End Date
Define the Testbed	Define exactly what the user experience will be and how these systems will fit together. Define explicit use cases.	1 week	2/18/2019	2/25/2019
Order Hardware (hardware & software platform research)	Purchase SDRs, TI development kits, Intel NUC8s, server, and necessary networking equipment.	3 weeks	2/22/2019	3/15/2019
Install Hardware	Physically install and connect all the devices.	1 week	3/15/2019	3/22/2019
Set up Node Computers	Install Linux distro on each node computer and verify that they communicate with their wireless devices.	1 week	3/22/2019	3/29/2019
Configure Wireless Devices	Install open-source software on each SDR and TI development kit as well as configure them on the private	2 weeks	3/29/2019	4/12/2019

	network.			
Learn/Research the SDR and TI Devices	Learn how to use each of these technologies.	6 weeks	2/22/2019	4/5/2019
Implement Controller Server	Implement the controller software on the server to allow it to configure the node computers. The controller server should be able to send files and commands to individual nodes. The node computers, in turn, will configure the wireless devices.	3 weeks	4/12/2019	5/3/2019
Implement Database Server	Implement a database on the server to store multiple tables for things such as user authentication, user statistics, node/wireless device status/availability, schedule reservation charts (if needed), experiment data.	2 weeks	8/26/2019	9/13/2019
Implement Front-End Server	Create a launch site for researchers to interact with so they can login, request resources for a given time period, and gain access to the nodes/wireless devices.	3 weeks	8/26/2019	9/20/2019
Implement Resource Scheduler	Implement the resource scheduler to grant resources (access to certain nodes/wireless devices) to users per constraints.	5 weeks	8/26/2019	10/11/2019
Interface Front-End, Resource Scheduler, Database, and Controller Servers (System	Implement interfaces between the servers so they can interact. Users should be able to login, query databases, checkout resources, configure wireless devices, run experiments, and export	5 weeks	10/11/2019	11/15/2019

integration)	experiment data.			
Set up Cloud Service	Implement the cloud service so that users can remotely access the testbed.	3 weeks	11/15/2019	12/6/2019
Demonstrate the Testbed	Run some different kinds of experiments on the ‘finished’ testbed to demonstrate what it’s capable of.	3 weeks	11/22/2019	12/13/2019
Write Article	Article about how the testbed was created and how it works, etc. Possibly publish. Why it was made? Benefits? Audience: 1) users 2) developers	2 months	10/18/2019	12/13/2019

Table 3: Project Checkpoints with Descriptions and Estimated Deadlines

The table above shows the overall timeline that can be broken down into **monthly** deadlines:

February

- The testbed should be clearly defined with the agreement between the students and the client(s)

March

- Required hardwares are ready to be installed in the testbed
- Each node is filled with its desired computer

April

- The functionality of SDR/TI machines are thoroughly studied
- Connections between each nodes are established

May

- Controller Server is readily to be deployed into the system
- Summer Break

August

- Semester II starts

September

- Database Server & Front-End Server are ready to be implemented

October

- Resource Scheduler is ready to be implemented

November

- Interface platform is created for the communication between Controller Server, Resource Scheduler, Database Server, and Front-End Server

December

- Finish Cloud Service setup
- Testbed is ready for demonstration

These are the major deadlines to be fulfilled throughout the project year. Alternatively, *Figure 4* and *Figure 5* can also be used as visual references for a brief timeline.

V. Closure Material

Closing Summary

Our project aims to provide an environment where researchers can run their wireless communication experiments at no cost, as well as Iowa State University students to access it for educational purposes. When the testbed is available, it will be opened to students for wireless networking experiments.

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