Experimental Exploration of 5G-and-Beyond Wireless Systems and Rural Broadband

DESIGN DOCUMENT

SDMay23-24
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Executive Summary

Development Standards & Practices Used

- 3GPP (3rd Generation Partnership Project) - The name of the standard for 5G as a whole and the name of the body who creates the standard
- O-RAN (Open-Radio Access Network)
- Restructured Text (Sphinx) - The coding language for making documentation tied to our GitHub
- IEEE 802.X (Wi-Fi) - ensures devices can communicate and interoperate within a local area network

Summary of Requirements

Our project should:

- include material from open-source platforms, namely OpenAirInterface,
- incorporate lab-based learning modules (in efforts to teach learners how to simulate and build their own 5G network with ARA resources),
- include assessments of knowledge for each module, and
- make use of ARA's remote field testing capabilities in the labs.

Applicable Courses from Iowa State University Curriculum

- CPR E 308: Operating Systems
- CPR E 458: Real-Time Systems
- CPR E 489: Computer Networking and Data Communications
- EE 224: Signals and Systems
- CYB E 331: Applications of Cryptographic Concepts
- CPR E 430: Network Protocols and Security
- CPR E 431: Basics of Information Security

New Skills/Knowledge acquired that was not taught in courses

- SDRs
- Open-Air Interface (OAI)
- 5G basics and beyond

Table of Contents

List of figures/tables/abbreivations/definitions

- **ISU**: Iowa State University
- **5G**: 5th Generation Mobile Network
- **NR:** New Radio; referring to the radio technology of 5G networks
- **SDRs:** Software Defined Radios
- **MIMO**: Multiple–Input Multiple-Output
- **mmWave**: millimeter-Wave; refers to the 24-100 GHz range, notably a range that can carry an incredible amount of data
- **LEO**: Low Earth Orbit (LEO) satellites used to efficiently transmit signals
- **UE**: User Equipment's that can establish a connection to the network
- **RAN**: Radio Access Network links the user equipment to the core network
- **Core Network**: Or mobile core, is a critical component of a 5G network, it is responsible for connecting the radio access network such as the internet

- **Ultra-High Definition (UHD)**: refers to the excellent quality used for working with USRP hardware and visualizing waveforms
- **USRPs:** Universal Software Radio Peripherals; used to connect to a computer through a high-speed link, which software uses to control the USRP hardware and transmit/receive data
- **OpenAirInterface (OAI)**: an open-source software-based implementation of the LTE system

1 Team, Problem Statement, Requirements, and Engineering Standards

1.0 Team Members

- Zachary Zemlicka – CYB E
- Joshua St John – CPR E
- Varun Advani – CPR E
- Jared Melcher – S E
- Lukas Zerajic – CPR E
- Christopher Sell – CYB E

1.1 Required Skill Sets for Your Project

- Cloud Equipment and computing
- Basics of networking and terminologies
- AraHaul and AraRAN
- 5G mobile networks
- Basics of Real-Time Systems and Schedulable, Predictability.
- Understand and how to operate “Open Air Interface”

1.2 Skill Sets covered by the Team

- Basics of networking and terminologies (Zach, Chris, Varun)
- Real-Time Systems and Schedulable, Predictability (Joshua, Varun)

1.3 Project Management Style Adopted by the team

- Collaborative style
- Everyone holds everyone accountable

1.4 Initial Project Management Roles

- Chris (leader/manager)
- Lukas (secretary, records meeting notes and uploads them to Cybox)
- Josh/Jared (editors of senior design website)
- Varun (edit preamble as needed)
- Zach (edit/add to Teams channels as needed)

2 Project Plan

2.1 Problem Statement

With the ARA project only recently being started up in July 2021, there are limited resources available for undergraduate and graduate students to prepare for joining the ARA project. These students are required to have a baseline knowledge for the use of ARA technology. Knowledge especially within SDRs and OAI will allow for meaningful contributions to further expand the solutions created by the use of ARA resources in rural communities.

2.2 Requirements & Constraints

- Learning materials should include material from the following open-source platform:
  - OAI
- Learning materials should incorporate hands-on lab-based learning modules
  - Simulate the building blocks of a 5G network
- Learning materials should be tested to effectively assess learning effectiveness
  - Testing effectiveness of platform among:
    1) The other members of our group (alpha testing)
    2) Students not involved with the project and unknowledgeable about 5G in context of ARA (beta testing)

Explanation of "hands-on lab-based learning modules":

To fulfill the requirement of incorporating hands-on learning, we have been authorized to use ARA resources to conduct relevant field tests. Below is a list of technologies that are used on the ARA project with 5G networks. We have conducted further research into these key topics and brainstormed ideas to incorporate the use of these technologies into our hands-on learning experiments. While each experiment may not specifically be about the below technologies, the concepts and tasks to be completed will incorporate some use of these technologies. Note that this list may be changed as the labs continue to be developed and modified.

- Small cells
  - Helps alleviate some of the signal stress of 5G towers (RAN) by splitting up the load – extend 5G range, energy saving
- MmWaves
  - High bandwidth connection, low latency, fragile (constraint)
- Mid-Band
  - In the absence of mm Waves, helps keep the connection up, but increased latency (constraint)
- Low earth orbit satellites
  - Helps increase the range of 5G connections
- Massive Multiple Input Multiple Output (MIMO) Antenna's (Common technology associated with 5G)
  - Improves network capacity/performance, allowing for multiple users to communicate simultaneously at the same frequency band

Researched accessibility constraints for the above field tests:

- mmWave – efficiency could be improved, but they work
- Cost – low profitability in rural areas

- Weather/plants/trees/environment – transmission of certain 5G frequencies are affected

2.3 Engineering Standards

3GPP (3rd Generation Partnership Project) - The name of the standard for 5G as a whole and the name of the body who creates the standard

Restructured Text (Sphinx) - The coding language for making documentation tied to our GitHub

IEEE 802.X (Wi-Fi) - ensures devices can communicate and interoperate within a local area network

2.4 Intended Users and Uses

Who benefits?

- Undergraduate senior design Iowa State students on this project

Who cares that it exists?

- Researchers already using ARA resources
- People trying to gain access to ARA resources for experiments

How will they use it?

- Prepare undergraduate/graduate students to be successful in this senior design project
- Define and teach the baseline knowledge needed to use ARA resources

2.5 Task Decomposition

Members will be split into the following groups and will focus their research and learning in efforts in these areas, however due to the dependent nature between SDRs and OAI, large group meetings will still be very common:

GROUP 1: SDRs

1. Chris
2. Josh
3. Varun

GROUP 2: OAI

1. Jared
2. Lukas
3. Zach

The deliverable statement for this project is as follows:

> **Create 5G learning materials (e.g., wiki pages and hands-on labs) to prepare undergraduate students for experimenting with advanced wireless systems using testbeds such as ARA which supports 5G platforms such as OAI and USRP SDRs.**

In context of this deliverable statement, our deliverable will be broken down into the learning modules listed below, with each module having 1) wiki page-style content that teaches the concept and 2) step-by-step laboratory experiments utilizing ARA resources that directly implement the previous wiki page content.

0) **Module 0: 5G Basics**
   - The content in this module entirely references the content from the Old 5G Site that explain the basics of 5G networks, meant to orient and ease the learner into the content.
1) **Module 1: Fundamental Concepts of SDRs**
   - Experiment 1: Transmitting, Receiving, and Visualizing Waveforms using UHD and GNU Radio
   - Experiment 15: Simulating a Simple Radar System
2) **Module 2: Modulation and Communication Techniques**
   - Experiment 2**:** Modulation and Demodulation Techniques
   - Experiment 5: Implementing a Simple OFDM Transmitter and Receiver
   - Experiment 6: Frequency Hopping
   - Experiment 18: Advanced Modulation Techniques Exploration
3) **Module 3: Signal Processing and Analysis**
   - Experiment 3: Signal Filtering and Noise Reduction
   - Experiment 4: Spectrum Analysis
   - Experiment 8: Channel Simulation and Analysis
   - Experiment 13: Basic Signal Generation and Analysis
   - Experiment 14: Exploring Signal Reflection and Multipath
4) **Module 4: Data Encoding and Packet Communication**
   - Experiment 7: Data Encoding and Decoding
   - Experiment 10: Implementing a Simple Packet Radio System
5) **Module 5: Practical Applications and Systems**
   - Experiment 11: Basic RF Signal Propagation and Path Loss Measurement
   - Experiment 12: Implementing a Basic Wireless Communication Link
   - Experiment 16: Implementing a Basic Positioning System
   - Experiment 17: RF Spectrum Scanning and Interference Analysis
6) **Module 6: OAI and 5G Technologies**
   - Experiment A: 5G Network Deployment and some form of Optimization
   - Experiment 19: OAI 5G core network basic deployment using docker-Compose
7) **Module 7: Cognitive Radio and Dynamic Spectrum Access**
   - Experiment 9: Cognitive Radio Basics
   - Experiment B: Dynamic Spectrum Access and Management in SDRs

2.6 Project Management/Tracking Procedures

Our group will use the Agile project management style. The main reason for this is because we need the adaptation aspect that is present with Agile. We will do one sprint for a short time, then gather together to see what changes we need to make for the following sprint.

We have a lot of topics to research, organize, then implement across all of the 7 modules, and since it should be done as a group, we will need to check-in frequently with everyone to ensure everything stays together as progress is made.

For tracking procedures, we will use the Microsoft Teams group that our advisor provided to us, specifically the NextG Exploration “F23-Sp24 Tasks”, which is similar to the GitHub Issues board.

2.7 Project Proposed Milestones, Metrics, and Evaluation Criteria

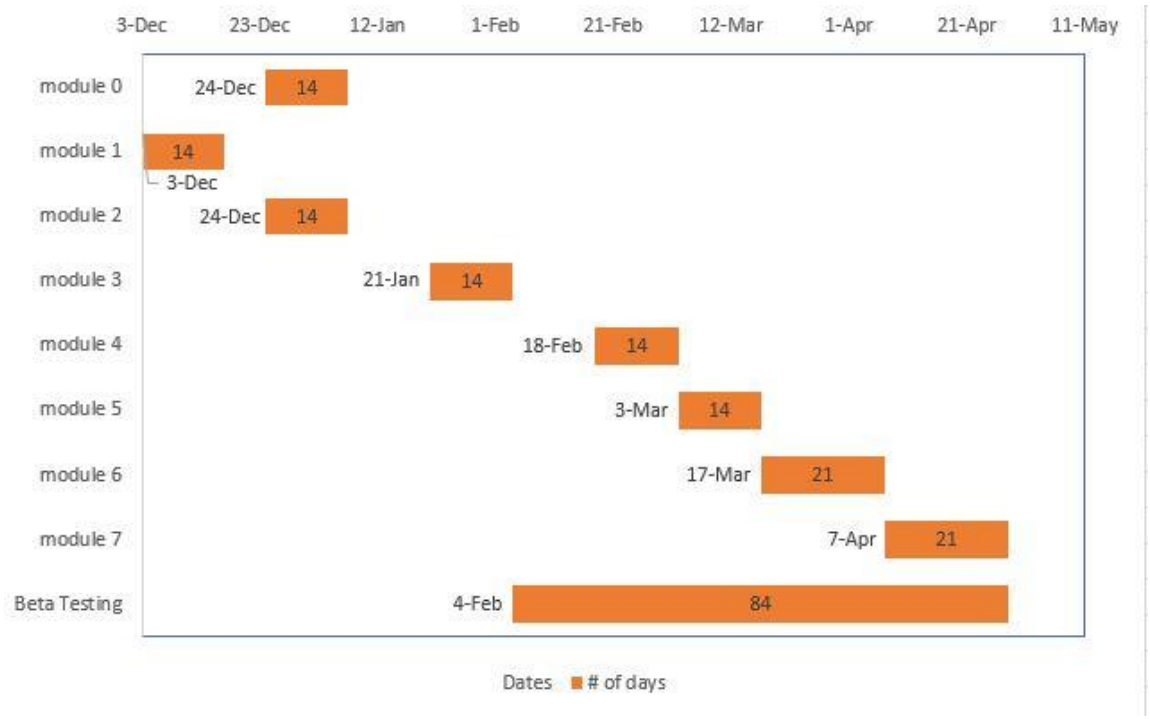
Our project planning is module-based. In this sense, modules act as milestones. Planning, implementation, and alpha testing all occur at the same time for each module due to the nature of our project. Beta testing will begin once about half of the project (module 3) has been completed.

2.8 Project Timeline/Schedule

A breakdown of the module-focused schedule to complete all learning modules is below:

	Week #	**Start Date**	**Task List**
FALL	Week 12	11/5/2023	- *Project direction was reevaluated, re-plan project*
	Week 13	11/12/2023	
	Week 14 (**BREAK**)	11/19/2023	
	Week 15	11/26/2023	
	Week 16	12/3/2023	- **BEGIN** module 1 - 7 Dec: Board Presentation @ 3pm
	Week 17 (**FINALS**)	12/10/2023	**FINALS**
WINTER BREAK	Week 1	12/17/2023	- **FINISH** module 1
	Week 2	12/24/2023	- **BEGIN** module 0 - **BEGIN** module 2
	Week 3	12/31/2023	
	Week 4	1/7/2024	- **FINISH** module 0 - **FINISH** module 2
SPRING	Week 1	1/14/2024	
	Week 2	1/21/2024	- **BEGIN** module 3
	Week 3	1/28/2024	

	Week 4	2/4/2024	- **FINISH** module 3 - **BEGIN** beta testing
	Week 5	2/11/2024	
	Week 6	2/18/2024	- **BEGIN** module 4
	Week 7	2/25/2024	
	Week 8	3/3/2024	- **FINISH** module 4 - **BEGIN** module 5
	Week 9 (**BREAK**)	3/10/2024	
	Week 10	3/17/2024	- **FINISH** module 5 - **BEGIN** module 6
	Week 11	3/24/2024	
	Week 12	3/31/2024	
	Week 13	4/7/2024	- **FINISH** module 6 - **BEGIN** module 7
	Week 14	4/14/2024	
	Week 15	4/21/2024	
	Week 16	4/28/2024	- **FINISH** module 7
	Week 17 (**FINALS**)	5/5/2024	FINALS



2.9 Risks And Risk Management/Mitigation

- **For all module planning tasks, there are risks of:**
  - Privilege oversights with ARA software - 10%
  - People falling behind and being unable to keep up with the rest of the group – 40%
- **For all module implementation tasks, there are risks of:**
  - Lack of reStructuredText/Sphinx experience – 10%
  - Writing unclear explanations to all audiences – 45%
- **For both alpha and beta testing tasks, there are risks of:**
  - People failing to check each other's work thoroughly – 50% - *With GitHub, we will have at least two members check another person's work before committing to the main branch. With other work, we will have groupmates ask for someone to check their work at certain points and make sure confirmation is received from the individual(s) checking it (we may keep a log to track who checks who's work to keep accountability as well)*
  - Scheduling problems when conducing the usability test – 25%
- **For the group work aspect, there are risks of:**
  - GitHub conflicts – 20%
  - Members of the group absent at meetings – 10%
  - Members of the group forgetting to communicate – 10%
- **All of these risks lead to an incomplete and substandard product, specifically:**
  - A product that does not thoroughly walk through how to use SDR and OAI – 55% - *We will constantly be asking our client to check our work with each component we finish to make sure it is to their satisfaction (since they have the most knowledge on all the material needed to be included)*

    - Not enough labs with quality content to test user knowledge – 55% - *We have a list with many brainstormed ideas for labs and if we do not have enough, we can break up the bigger labs into smaller modules. We can hold a meeting to specifically brainstorm more ideas for labs if needed.*
    - Users are left confused about the relevant material needed to understand ARA and its applications – 65% - *This will be addressed as the user traverses the modules. There will be knowledge checks with each lab and module to ensure the user understands what is happening in the lab and how it correlates to 5G network functionality.*
- **Therefore, mitigation of all these requirements strongly depends on the following:**
    - Staying together as a group throughout the process by checking in frequently with each other, especially at each weekly meeting
    - Scheduling even more meetings outside of assigned meeting times if tasks need to be completed or any lab members fall behind the group
    - Asking questions to our advisor as soon as possible
    - Keep finetuning the ideas we are planning to implement (think about ways we can improve on the method used to deliver the material)

2.10 Personnel Effort Requirements

Task Performed	Explanation	Hours Required
Attend assigned weekly meetings	Every week the group has scheduled meetings at Sunday 2pm via Teams that help with issues that may arise and to ensure the project is getting completed according to the Agile framework	~3 hours a week
TA and Client Meetings	We have meetings bi-weekly with our client on Fridays at 5pm. And we meet with our TA every week but alternates between Wednesday at 5:30 and Friday at 5:30. We are required to attend these meetings so we can stay on track as a team.	0.5 - 2 hours per week
Complete small group tasks	Every week the assigned small groups are scheduled certain tasks that are required to be completed by everyone. Once an individual completes this task, they should log the completion in the Meetings tab within Microsoft Teams so our client can see what we have done	~6 hours per week

2.11 Other Resource Requirements

5G document website to learn and to expand the contents on the website. We will use powder (sample packets with 5G RAN's), GitLab, ARA Software and Hardware, and more. Here is a list of information and some of the books that we are allowed to share with others that are currently relevant to our current project direction:

- 5G Site Documentation: https://5gsitedocumentation.readthedocs.io/en/latest/
- 5G Mobile Networks: A System Approach: https://5g.systemsapproach.org/
- Computer Networks: https://book.systemsapproach.org/
- USC cellular Scheduling Information: https://www.ece.iastate.edu/~hongwei/group/publications/UCS.pdf
- LPD real-time scheduling: https://arxiv.org/abs/2101.01768
- Sphinx: https://sphinx-tutorial.readthedocs.io/
- BubbleRAN: https://bubbleran.com/
- ARA sandbox: https://arawireless.readthedocs.io/en/latest/ara_technical_manual/sandbox_service.html
- OAI: https://www.openairinterface.org/

3 Design

3.1 Design Content

Our project design revolves around developing a comprehensive learning tool for undergraduate students, utilize key resources of the ARA wireless living lab project, setup at ISU and neighboring areas. This tool is centered around the exploration and application of SDRs, specifically using USRPs and an open-source platform OAI. The design content encompasses:

1. **Integration of ARA Resources:** Harnessing ARA's capabilities, including SDRs, and the OAI platform, to create an immersive learning environment. The integration will allow future undergraduate students to delve into the practical aspects of wireless communication using state-of-the-art technology, and use this tool and ARA's resources to design a Senior Design project of their choice.
2. **Simulated Learning Environment:** Leveraging ARA's sandboxed environment, that represents various elements of wireless networks such as Base Stations (BS) and User Equipment (UE), to deliver hands-on labs and experiments teaching students about the capabilities of SDRs in a risk-free environment.
3. **Transition to Real-World Applications:** Designing a pathway for students to transition from what was taught in the sandboxed environment, to real-world experiments that involve utilizing the capabilities of an OAI platform to facilitate field experiments, establishing actual BS and UE links.
4. **Congregation of Labs Uniting as a Single Lab:** As the learner continues to explore the learning platform, they will learn the contents within the wiki pages, perform quizzes to verify materials read, and perform labs. These labs will congregate together as a single lab towards the end of the learning platform, creating their own 5G network using ARA's tools, hardware, and software provided.

3.2 Design Complexity

The design of our project integrates multiple components and subsystems, each grounded in distinct scientific, mathematical, or engineering principles, demonstrating its technical complexity. Firstly, the SDRs aspect incorporates digital signal processing, modulation techniques, and error correction methods, all of which require a solid understanding of mathematical concepts like Fourier transforms and signal theory. The USRPs, serving as the hardware interface, involve principles of radio frequency engineering, signal integrity, and hardware-software integration, requiring knowledge in electrical engineering and computer science. Furthermore, the OAI

platform brings in elements of network architecture and real-time software development, based on principles of computer networking and software engineering.

Our project scope includes multiple challenging requirements that match or exceed current solutions or industry standards, adding to its complexity. Using SDRs and OAI, the learner will create labs after learning information based on 5G on the learning platform. These labs will build on each other to a singular lab, where the learner will be able to create their own 5G network as the finale of the learning platform and the labs.

3.3 Modern Engineering Tools

We are using many tools for this project, such as:

1) **GitLab**
    a) for team editing so that everyone has the ability to edit
2) **GitHub**
    a) the 5G Site stores its source code here; the Git**Lab** will be synced with this Git**Hub** so that changes to the GitLab persist onto the GitHub
3) **ReadTheDocs**
    a) the 5G Site presents its compiled source code from ReadTheDocs
4) **Sphinx & HTML**
    a) the 5G Site is written in Sphinx and compiled into HTML
5) **GNU Radio**
    a) To provide a framework for simulating radio systems (crucial for SDRs)
6) **Linux Tools (e.g., Bash, SSH, Netplan)**
    a) Using fundamental Linux environment tools for scripting, remote access, network configuration – all of which are essential for managing the ARA resources and SDR/USRP functionalities
7) **Network Simulation Tools (e.g., NS3, GNS3)**
    a) These are employed for creating detailed network simulations, which are vital for testing and validating network protocols and configurations in a controlled, risk-free environment.
8) **Performance Monitoring Tools (e.g., Wireshark, perf, GDB)**
    a) These tools are essential for analyzing network traffic, monitoring performance, and debugging, helping to optimize our applications and troubleshoot issues.

3.4 Design Context

The main community for this document will also be the audience, which are the future students taking 491 senior design class. By the end of the project, we hope to apply what we've learned to get comfortable conducting field tests with ARA resources and possibly help solve existing problems with 5G, especially in rural and urban areas.
With this big-picture view in mind, here are some examples of how 5G can affect certain fields/areas:

Area	Examples
Public health, safety, and welfare	With 5G accessibility available in rural areas, safety can be improved by increasing automation of unmanned technological equipment. This will decrease accidents with the faster latency provided by 5G (Real-Time Systems).

Global, cultural, and social	The entire world will be affected by an improvement in 5G simply because rural areas help feed a large percentage of the world. With 5G access in rural areas, they will be able to, for example, check the quality of crops and livestock remotely and efficiently.
Environmental	To increase accessibility, this will require more technology to be implemented, which can increase energy and therefore cost. Although solar power could be used, this adds another problem of energy efficiency and how much is required to power such technology in rural areas.
Economic	5G can be costly. This is part of the reason why 5G accessibility is still a problem in some parts of the world, especially in those with a lower population. The learning platform that we are creating is considered free for learners, which will be able to access ARA equipment and tools to perform experiments for free, provided that they are allowed access.

3.5 Prior Work/Solutions

5G open-source platforms provided by the client:

- srsRAN
- OAI
- O-RAN Software Community

Below is a list of more provided ARA software, which allows us access to the ARA Sandbox and Field Hardware. Additional open-source platforms in relation to 5G include:

- Open Compute Project
- Aether
- Open5GCore
- Introduction to open source private LTE and 5G networks
- The site linked here is the closest representation of our product and previous work that provides the biggest influence on the product being developed by our team.
- Advantages here are that the previously existing site provides a general outline of the necessary learning components of understanding and applying 5G. It shows us what information is already included which allows us to build on the information and generate detailed labs using ARA sandbox.
- Shortcomings here are that the site already includes significantly in-depth information and learning tasks that require us to think of higher-level concepts and we have to think of ways to differentiate our product from this already existing product.
- Pros:
    - Higher level learning modules
    - Labs
    - More in-depth information

- Cons:
    - Lots of overlapping information
    - Learning material with be updated by similar

3.6 Design Decisions

1) Incorporating the use of interactive, hands-on labs
    a. Taking advantage of ARA Tools such as Sandbox in a manner to help convey information concerning 5G networks. These labs with help users gather an understanding on SDRs, OAIs, USRPs, etc. By teaching users this information, it will force them to gather a grasp on how 5G networks operate.
    b. We will have multiple labs within a module. One will be implemented using ARA Sandbox, which can be used to understand concepts virtually using ARA's equipment and tools. The other lab involves real life applications, which will use SDRs and OAI and ARA's field resources and can be accessed remotely. These labs will build on each other as the user progresses to develop a network towards the end of the learning platform.
2) Connecting our private GitLab with a public GitHub and ReadTheDocs
    a. We were given a private GitLab from our client that was designed to contain the program for our website. The website is hosted using ReadTheDocs which contains the labs that are created and information. Due to ReadTheDocs needing a public Git in order to host the website we decided we would clone the private GitLab to a public GitHub in order to connect to the host.
3) Using simple English and easy-to-understand language
    a. A big part of our project is appealing to an audience that has basic knowledge of 5G and is seeking to learn. Because of this, we will be avoiding the overuse of complex technical jargon. Although some technical words will be needed, we will do our best to describe and define them to ensure our materials make sense to all learners.

3.7 Proposed Design

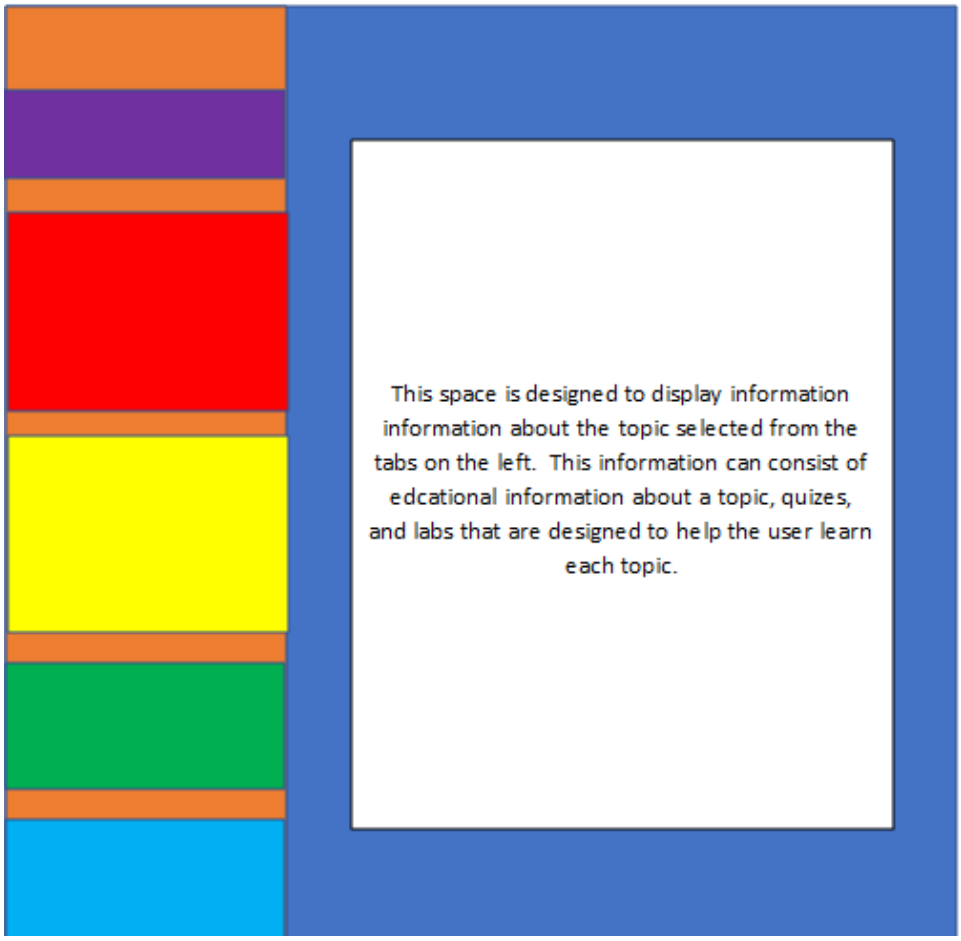
The following have been implemented/tested...

1. Linked the GitLab and GitHub with ReadTheDocs to be able to edit the learning platform.
2. Completed a list of modules & ordered them into a progression leading toward a final lab.
3. Completed a researched list of experiments to use for each module and distributed them amongst all the modules

3.7.1 Design 0 (Initial Design)

Design Visual and Description

"New" 5G Site – Webpage Layout



Key:

Orange: represents the five main topics that are represented on the website

Purple: represents the "Getting Started" page on the website. This will contain brief information that the learner should know before diving deeper into the material.

Red: represents the learning modules that are available on the website. Each one of these sub topics will have several tabs as well to help with assist with the learning and a quiz at the end to ensure the user understood the material.

Yellow: represents multiple experiments that are accessible for the learner to help further insight on material. These will be hands-on and will assist the learner through the labs to help gain experience applying the information from the modules.

Green: represents the "ARA Technical Overview" page. This goes into detail about how ARA operates and helps gain a further understanding. This tab will go into detail about ARA infrastructure, backhaul networks, and wireless access networks.

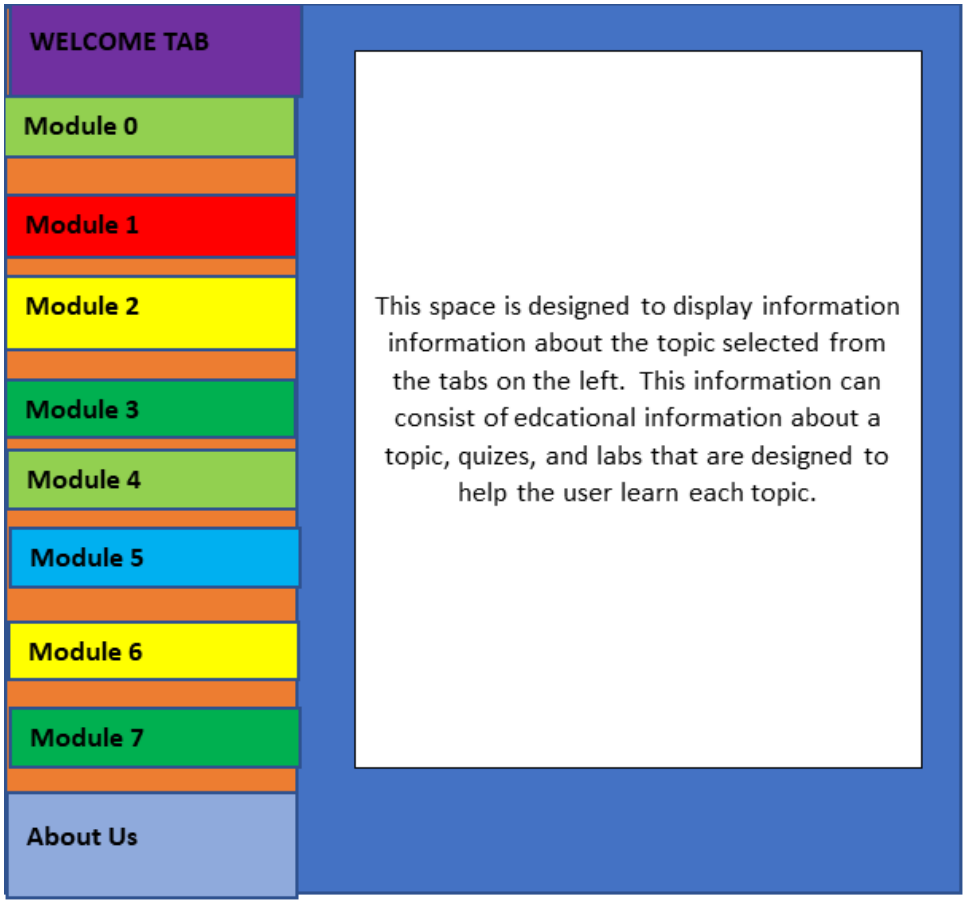
Blue: represents the "About Us" tab which is a brief description of each team member. This is used so the user can gain a quick understanding of who created the website and the background experience of each member.

The diagram above demonstrates how the GitLab is linked to ReadTheDocs. We have all our code stored in a private GitLab that allows us to make modifications locally. From there, we then clone the GitLab to a public GitHub in order to establish a connection to the host for the website ReadTheDocs. ReadTheDocs is able to read our files from the public GitHub to generate the visible website.

Functionality

The current design is designed to provide a user with access to an open-source learning enviroment that has the ability to educate them about 5G networks. This will be done by creating a module that will strictly contain information that involves 5G networks. There will be another module that will contain a list of experiments that user can complete to further their learning on the topic. These experiments will use ARA software to create real world examples within 5G topics. The functional requirement will be established by using ARA software such as Sandbox to create labs for the user. The non-functional requirements will be created by ensuring the performance of ARA's software is working correctly for the labs. Another non-functional requirement will be to ensure that the user is able to comprehend and maintain the educational services provided to them. All labs will be implemented within sandbox but also have real world applications as well. Sandbox is designed to implement designs within a virtual enviroment therefore removing the need to complete them in real life. Overall, the design does a good job of satisfying functional and non-functional requirements.

3.7.2 Design 1 (Design Iteration)



The new Design will be laid as seen above and the tabs will be represented as follows...

Welcome tab: Brief introduction to the project

Module 0: 5G Basics

Module 1: Fundamental Concepts of SDRs

Module 2: Modulation and Communication Techniques

Module 3: Signal Processing and Analysis

Module 4: Data Encoding and Packet Communication

Module 5: Practical Applications and Systems

Module 6: OAI and 5G Technologies

Module 7: Cognitive Radio and Dynamic Spectrum Access

About Us: Brief introduction to the team members

This is a major change from our first design because we have switched to a module-based system. Each module will contain 3 types of information: 1) wiki pages, 2) quizzes, and 3) labs. The lab topics will be related to the topic and are listed in Section 2.5.

We switched to this method because we determined this was the best way for learners to be educated while retaining information that was provided. This method also allows our team to satisfy the functional and non-functional requirements.

This new design created labs that require the use of ARA Sandbox. Each module has 2 labs, 1 that utilizes the ARA Sandbox and one that makes use of ARA's field equipment. The labs themselves will guide the learner through all the steps needed to utilize these resources. This design also does a better job of fulfilling non-functional requirements because it presents information in a more digestible way.

3.8 Technology Considerations

GitHub vs GitLab

A private GitLab was given to be able to host our learning platform on ReadTheDocs. Pretty quickly it was found out we had no way to make the repository public to properly host what was needed. A secondary GitHub was used to be able to host the ReadTheDocs as GitHub allowed us to do what we needed.

reStructured Text (Sphinx) vs MkDocs

Although Sphinx was the suggested markup method for us to use to write the "new" 5G Site, MkDocs was also considered because of its relative ease of use compared to Sphinx. However, after realizing ARA utilizes Sphinx for most of its documentation, we decided to stick with Sphinx for continuity and familiarity purposes.

3.9 Design Analysis

Design 1 is a more effective design. Once the design has been implemented, a series of Alpha and Beta testing will occur (see Section 4.4 for more details), and following that we will improve the design and make changes accordingly:

Some possible ideas for the future based on the state of our design are:

- More coverage of 5G concepts in all modules
- More interactive exercises to further solidify learning
- Possibly supplemental websites or resources that can help even more for those that need more information to assist with the information posted on our learning platform.

4 Testing

4.1 Unit Testing

Testing Units:

- **SDR Software Modules:** Testing of signal processing and modulation algorithms/scripts.
- **USRP Hardware Interface:** Testing for communication between software and USRP hardware.
- **OAI Configurations:** Validation of custom OAI configurations in controlled environments.

- **Lab Experiment Scripts:** Testing the lab experiment scripts being walked through for accuracy and reliability.
- **GitHub/ReadTheDocs:** Testing the documentation updates pushed to our public GitHub repository trigger rebuilds on ReadTheDocs.

Tools:
GNU Radio, UHD tools, OAI Software Suite, Network Analysis Tools (e.g. Wireshark), PyTest/Manual Testing of scripts, GitHub webhooks, and ReadTheDocs build framework.

4.2 Interface Testing

Software-to-Hardware Interface:

- **Composition**
  - This interface comprises the interaction between the SDR software modules (such as GNU Radio or custom Python scripts) and the USRP hardware.
- **Testing**
  - Verify that commands sent from the software are correctly executed by the USRP hardware, and that the data received by the hardware is accurately captured and processed by the software.
- **Tools**
  - UHD Utilities for direct interaction with USRP, automated scripts for functional testing.

Software-to-Software Interface:

- **Composition**
  - Encompasses the communication and data flow between different software components, such as between GNU Radio and custom scripts or between different modules within OAI.
- **Testing**
  - Ensure data transmission and command execution between software modules, verifying data integrity and correct functionality.
- **Tools**
  - Custom test scripts, Python for automation, GNU Radio for internal module testing.

User Interface to Backend System Interface:

- **Composition**
  - Involves the interaction between the graphical user interface (GUI) or command-line interface and the backend software and hardware systems.
- **Testing**
  - Check that user inputs via the GUI or command-line are accurately translated into actions by the software, and that system status is correctly reflected in the user interface.
- **Tools**
  - Manual Testing or potentially the use of GUI testing tools like Selenium.

4.3 Integration Testing

The critical integration paths for our design were broken down into four parts which are described in detail below

DR Software and USRP Hardware Integration:

- **Justification:**
  - The core functionality of the educational tool depends on effective communication between the SDR software and USRP hardware, and this integration is crucial for accurately conducting experiments and demonstrations in SDR technology.
- **Testing Method:**
  - Tests will involve executing specific signal processing tasks using the SDR software and verifying the correct signal transmission and reception by the USRP hardware.
- **Tools**
  - GNU Radio for software simulation, UHD Utilities for interacting with USRP hardware, and manual testing or potentially custom scripts for automating testing.

OAI Integration with USRP:

- **Justification**
  - For advanced labs involving 5G simulations, the integration between OAI and USRP devices is vital.
  - This allows for realistic demonstrations of 5G network functionalities in the field, within an educational setting.
- **Testing Method**
  - Setting up 5G network scenarios using OAI and USRP, and testing various network functions such as data transmission, handovers, and signal processing.
- **Tools**
  - OAI software suite for network setup, network analysis tools like Wireshark for monitoring and troubleshooting.

Integration of Lab Experiment Scripts with SDR/OAI Systems:

- **Justification**
  - The scripts guide students through the lab experiments and need to interact flawlessly with the SDR and OAI systems to ensure an effective learning experience.
- **Testing Method**
  - Conducting lab sessions using these scripts, observing their interaction with the SDR and OAI systems, and collecting feedback on their effectiveness and ease of use.
- **Tools**
  - Python or Bash scripts for controlling SDR and OAI operations, feedback collection tools for assessing user experience.

Documentation Hosting on ReadTheDocs Integrated with GitHub:

- **Justification**
  - The integration between GitHub and ReadTheDocs is crucial for maintaining up-to-date, accessible, and version-controlled documentation.
  - It's vital for ensuring that students and educators have the latest information and guides for the SDR and OAI based labs and experiments, designed by leveraging ARA's resources.

- **Testing Method**
    - Verification of the sphinx html build for the document on a localhost/python server, and regular verified updates of documentation pushed to the GitHub repository.
    - Verification of integration between GitHub and ReadTheDocs via the GitHub webhook, to host the documentation on ReadTheDocs.
    -

4.4 System Testing

As written in Section 2.5, our strategy for system level testing is to separate our group of 6 into 2 groups as follows:

GROUP 1: SDRs

1. Chris
2. Josh
3. Varun

GROUP 2: OAI

1. Jared
2. Lukas
3. Zach

Once separated into these groups a complete system test would be performed with Alpha and Beta testing to ensure the learning material is fully being grasped by the learner. Given the groups above, these tests would proceed as follows:

Alpha:

- Group 1 checks Group 2, Group 2 checks Group 1
- Make improvements

Beta:

- Conduct usability study with 2 uneducated, non-teammates
- Make improvements

4.5 Regression Testing

During the implementation of changes, Alpha testing will be a constant process until everything is implemented.
After the implementation of changes and the next "best" version of the teaching materials has been achieved, impromptu Beta testing will occur to verify the functionality of the labs being as understandable as possible.

4.6 Acceptance Testing

Similar to the Regression Testing approach, we will use the people tested in the Beta testing phase and our client/faulty advisor to verify if the labs and wiki pages work as intended. Once it passes Beta testing, our deliverable will be considered "Accepted".

4.7 RESULTS

Overall, for our project, we are limited on what kind of testing methods we can use because we are creating a website with learning materials. We can test how the website is created and how it works and the materials inside the website to make sure the contents that we preview make sense and works using Alpha and Beta Testing. Thus, the results of these type of tests are the people that perform alpha and beta tests making sense of the lab and that they are functioning correctly. The website tests are working as intended as well.

- First: we would do **Alpha** testing which would involve users within the project to perform the labs and look through the website to ensure they are making sense of the material. And performing the labs to make sure that they are receiving the correct outcomes and values. As well as proof-reading the website for grammar issues as well.
- Second: we would perform **Beta** testing which would entail users that are not in our senior design group and have no knowledge of 5G. These users would be people that have no knowledge of our deliverable and go through the website to ensure that it makes sense to a new user and that they have the abilities to produce the results that are expected with the lab, and verifying that the instructions are valid and to spot any anomalies.

5 Implementation

For next semester our team will be creating teaching modules that will consist of educational information (written in the stype of wiki pages), quizzes, and labs. These modules will be based around 5G networking with an emphasis on SDRs and OAI.

These modules are designed for the learner to learn enough so they can contribute to the ARA project. Therefore, when creating these modules, we will need to ensure they cover any material that may be seen within the ARA project or 5G networks.

Once all the modules are created, our group will then perform alpha and beta testing as mentioned above and below. These tests will be performed by performing two tests to ensure our learning materials work:

1) Alpha: consists of members on the team testing the product to ensure to works correctly. Once this stage is completed, we will make modifications, then move on to Beta testing.
2) Beta: consists of students from the university using our learning materials to ensure learners can understand the content and complete the labs.

Overall, next semester will consist of creating and implementing all the parts of the modules and ensuring they work with thorough testing.

6 Professionalism

6.1 Areas of Responsibility

Area of Responsibility	Definition	NSPE Canon	ACM Code of Ethics	Difference from NSPE
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence.	Perform services only in areas of their competence; Avoid deceptive acts.	Conduct work with integrity, quality, and the vision of continuous improvement	ACM has a heavy focus on quality of work with an emphasis on continuous improvement while NSPE is focused on conducting work only in your field of study
Financial Responsibility	Deliver products and services of realizable value and at reasonable costs.	Act for each employer or client as faithful agents or trustees.	Use skills to benefit society, clients, and employers while maintaining in obligation to the law.	ACM has a focus on benefiting society while NSPE focuses on just the client and employer.
Communication Honesty	Report works truthfully, without deception, and understandable to stakeholders.	Issue public statements only in an objective and truthful manner; Avoid deceptive acts.	Honesty is a fundamental component of trust so all statements should be transparent and truthful.	ACM focuses on being fully transparent on everything that is released while NSPE is only about statements.
Health, Safety, and Well-Being	Minimize risks to safety, health, and well-being of stakeholders.	Hold paramount the safety, health, and welfare of the public.	Conduct work in a manner that looks out for the health, safety, and well- being of both an individual and society.	ACM focuses on individual safety as well as the public while NSPE is only about the public

Property Ownership	Respect property, ideas, and information of clients and others.	Act for each employer or client as faithful agents or trustees.	Honor property rights such as copyrights and patents.	ACM focuses on honoring property rights while NSPE focuses on acting for the client or trustees.
Sustainability	Protect environment and natural resources locally and globally.	N/A	Promote environmental sustainability both locally and globally. Be mindful of impacts and minimize negative consequences.	ACM promotes Enviromental sustainability and there is nothing listed for NSPE.
Social Responsibility	Produce products and services that benefit society and communities.	Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.	Act responsibly and ethically with the consideration of the wider impact of their work and always have the publics best interest in mind.	ACM focuses on the impact that an individual's work has on the public. While NSPE focuses on the individual themself.

6.2 Project Specific Professional Responsibility Areas

Area of Responsibility	**Does it apply to the project?**	**How well is the team performing?**

Work Competence	Yes, our project requires us to perform high quality of work that will be used as teaching material so it needs to be accurate.	Medium
Financial Responsibility	No there is nothing currently that is required from our client financially.	N/A
Communication Honesty	Yes, making sure that we are able to accurate work in a quick manner is very essential to our project.	High
Health, Safety, and Well-Being	No, there is not a chance of anyone being at risk due to our project design being mostly completed virtually.	Medium
Property Ownership	Yes, we are using ARA software so it is essential that we follow their guidelines and rules.	High
Sustainability	No, our project does not have anything to do with the environment.	N/A
Social Responsibility	Yes, we are creating an open-source platform for students to get educated therefore we are benefiting society.	High

6.3 Most Applicable Professional Responsibility Area

Social Responsibility is a major factor within our project because we are creating material that is designed to educate learners. Our project uses a module-based approach that will contain educational information, a quiz, and a lab. We choose this approach after doing research because it offers a variety of ways to check what you have learned. From the traditional textbook and

multiple-choice quiz to hands-on learning, implementing all these ways to teach has a high success rate for educating learners.

Our project will specifically ephasize the use of hands-on labs. Modules will be designed to ensure that the learner walks away will an understanding of 5G networks, especially within SDRs and OAI. Our team demonstrates a massive need for social responsibility due to our goal of producing a product that benefits society.

7 Closing Material

7.1 Discussion

Our Senior Design Project focuses on developing an educational tool using SDRs and OAI, aiming to provide a comprehensive learning platform for undergraduate students. The project encompasses a series of carefully designed labs, facilitating hands-on experience in the field of wireless communication technologies.

Our primary goal is to provide a learning tool with wiki pages, quizzes, and labs to demystify the concepts of SDRs and 5G technologies for undergraduate students, and equip them with all that they need to plan, design, and execute a project related to 5G and make use of ARA resources. The series modules, from basic signal generation to advanced network technologies, allows students to progressively build their understanding and skills. The labs will be designed to provide practical insights and offer tangible demonstrations to critical wireless communication concepts

7.2 Conclusion

As we reflect on the progress of our Senior Design Project it's evident that while we are in the initial stages, strides have been made towards establishing a solid foundation for the educational tool centered on SDRs and OAI.

Our primary goal is to develop a comprehensive and interactive learning platform for undergraduate students. This platform is designed to enhance their understanding of SDRs and OAI through a series of structured modules, each comprising wiki pages, quizzes, and hands-on lab experiments.

So far, our efforts have been focused on:

Educating/Orienting Ourselves: We have put in an effort to learn the basics of 5G, specifically focused towards learning cellular networks and SDRs, so that we are well equipped to design a learning tool that educates future undergraduate students. We've also spent some time learning about ARAs resources, which will be the primary resource/testbed for our learning tool.

Module Development: We have successfully outlined a series of educational modules that progressively cover the fundamental and advanced aspects of SDRs and OAI.

Website Layout Design: A preliminary layout for the project's website has been conceptualized. This layout strategically organizes educational content into wiki pages, quizzes, and labs for each module, ensuring an intuitive and educational user experience.

The best plan of action moving forward involves:

Content Development and Integration: Fleshing out each module with detailed content, interactive quizzes, and lab instructions.

Website Implementation: Transforming the website layout into a functional and navigable online platform.

Lab Development and Testing: Creating and rigorously testing each lab experiment to ensure it aligns with the educational objectives of the corresponding module.

Although we are behind schedule, defining and integrating an engineering design component that satisfies the requirement posed a significant challenge, leading us to eventually decide that wiki pages, hands-on labs, and quizzes should be our final deliverable.

7.3 References

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7.4 Appendices

Below are the appendices containing additional information relating to the purposes of our group policies.

7.4.1 Team Contract

Team Members:

1) Zachary Zemlicka	2) Joshua St. John
3) Varun Advani	4) Jared Melcher
5) Lukas Zerajic	6) Christopher Sell

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:
    - **Sunday 2pm via Discord, or we communicate when meeting in person. If we meet in person a room will be reserved in this case.**

- **Purpose: help with issues that may arise and to ensure the project is getting planned/completed as best as possible according to the Agile framework**

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., email, phone, app, face-to-face):
   - **We will do nearly all of our communication via our Discord server. This includes (but is not limited to) reminders, updates, and other important links or information for project success. For communication with our advisor Dr. Zhang, we will be using Microsoft Teams and the chat that Dr. Zhang created for us.**
3. Decision-making policy (e.g., consensus, majority vote):
   - **To make a decision, everyone will first share their ideas so that everyone's voice is heard. Then, a discussion over each of the ideas will occur. If after the discussion a decision cannot be made, the matter will be brought to Dr. Zhang to get his advice and sway the decision.**
4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):

   - **Lukas will record and upload meeting notes to Cybox. If he is unavailable, someone else will take his place.**

Participation Expectations

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

All team members are expected to be in attendance, either virtually or in-person. If a weekly group meeting was decided to be in-person, but person X had a conflict during that time, they are expected to communicate their conflict as soon as they are able. If it is an emergency and they cannot inform the group, they are expected to inform the group after the emergency.

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

Everyone is expected to fulfill the tasks they are assigned to the best of their ability. Tasks will be added to GitLab Issues so we have a constant record of what has been completed.

3. Expected level of communication with other team members:

Communication will be essential throughout the entire project. Therefore, full transparency is expected from everyone. Responses will be expected in a timely manner according to the person's circumstances.

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

Everyone is expected to contribute weekly with transparent communication. Contribution and communication are the main expectations.

Leadership

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

Chris is the leader/manager and Lukas is the secretary. As long as things are communicated throughout the group and everyone asks questions if they are not aware of what is going on, things will be fine.

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

Overall, we are a team. If someone is struggling, they should speak up and others will try to assist. If issues are brought up before they become even larger problems, we will have no issues being successful.

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

We will review GitLab Issues to review and reflect on peoples' completed tasks at each meeting.

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.
    a. **Joshua St. John** is a computer engineering major, he has experience in software and hardware. Some of the languages he is familiar with: C Programming, Java, Verilog, HTML, CSS, VHDL. Hardware experiences: Oscilloscopes, Function Generators, Multimeters, probing, breadboards, FPGA boards, and understands early concepts of electrical system analysis. Joshua loves versatility and would prefer a variety of jobs involving both software and hardware if possible.
    b. **Christopher Sell** is a cyber security engineering major. He has programming experience in Java, Verilog, C, VHDL, and Python. He has worked with FPGA boards, embedded systems, and a variety of cyber security tools such as John the Ripper, Hashcat, nmap, and Wireshark. He also has an intermediate level of experience using Linux operating systems and command line, including Ubuntu, RedHat, and Kali Linux.
    c. **Zachary Zemlicka** is a cyber security engineering major, he has an experience with C programming, Java, Verilog, and VDHL. Has had some hardware experience with Multimeters, breadboards, Oscilloscopes, and probing. Also has experience with lower-level security such as network and transport layer protocols. Has worked with multiple network traffic analysis applications like Wireshark and has brief knowledge in forensic analysis.
    d. **Lukas Zerajic** is a computer engineering major and has experience with Java, C programming, Verilog, VHDL, and small amount of Python.

Some hardware he's specifically worked with are also Oscilloscopes, Function Generators, Multimeters, FPGA boards, and electrical system/circuit analysis as well as components of electric circuit design. He has done some work with data communications and networking and has specifically used Wireshark in packet capture and analysis.

e. **Jared Melcher** is a Software Engineering major who has experience with Java, C, C++, Verilog, and a little bit of Python. He has also worked in the past at a small rural ISP using Ubiquiti AirMAX CPE and sector antenna equipment. With the job, school, and home life he has gotten bit of experience with the Linux command line mostly in Ubuntu and Fedora. He has also had to use Wireshark briefly to troubleshoot issues on the network at work.

f. **Varun Advani** is a Computer Engineering major and has experience with both Hardware and Software. Some of the programming languages that he is experienced with are: C, C++, Python, LabView, Java, JavaScript, MATLAB, VHDL, Verilog, and Bash. He has hardware experience working towards designing enclosures for Web Relay's and Lighting Controller's, working with NI hardware for Data Acquisition and Signal Conditioning, and working with multimeters, breadboards, oscilloscopes, and probing for circuit design. He has some basic experience with cryptography tools and with using Linux Operating Systems on AWS EC2 instances.

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

As a team, we need to be good listeners and well as good communicators. Chris will send biweekly checkups in Discord and everyone will react with how things are going, then action will be taken after all reactions have been obtained.

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?)

If there is a collaboration or inclusion issue, it can be brought up at any time, however the weekly team meeting is the ideal time, since during that time we will discuss conflict resolution. If this does not work, then the issue will be brought up to our TA during a TA meeting. If the issue still persists, then it will be escalated to Dr. Tyagi.

<u>Goal-Setting, Planning, and Execution</u>

1. Team goals for this semester:
    a. **Learn from the information provided**
    b. **Understand deliverables and expectations for Spring semester**
2. Strategies for planning and assigning individual and team work:
    a. **Before assigning work, a list of tasks will be written down and then delegation will occur as needed. This is because not everything needs to be delegated.**

3. Strategies for keeping on task:
    a. **Anyone at any time can bring up concerns about staying on track.**

Consequences for Not Adhering to Team Contract

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

Our disciplinary process is split into 3 layers. The first layer is talking about it as a team at the team meeting and resolving it that way. If this does not work, it will move to the second layer, which is informing the TA at a TA meeting of the infraction. If this still does not work, it will be escalated to the third layer, which will involve Dr. Tyagi. If you are signed below, you will be held to the contract and the previously explained course of action will follow.

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

If they continue, the case will be escalated to Dr. Tyagi as previously explained. If they still continue, it becomes a matter of course participation which is out of our hands.

****

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) Christopher Sell **DATE 9/8/2023**

2) Jared Melcher **DATE 9/8/2023**

3) Joshua Thomas St. John **DATE 9/8/2023**

4) Lukas Zerajic **DATE 9/8/2023**

5) Zachary Zemlicka **DATE 9/8/2023**

6) Varun Advani **DATE 9/10/2023**