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

Team 12

Advisor/Client:

Dr Hongwei Zhang

Undergraduate Team:

Caleb Kitzelman, Hardware Engineer

Cristofer Espinoza, Software Engineer

Jake Roskopf, Hardware Engineer

Andrew French, Hardware Engineer

Vibhu Dhavala, Software Engineer

Sam Rettig, Software Engineer

sddec23-12@iastate.edu

https://sddec23-12.sd.ece.iastate.edu/

Executive Summary

Development Standards & Practices Used

Modulation schemes, computer networks, and software interfacing skills will be needed for this project. Programming includes C and command line for Linux OS.

Here are the IEEE standards we have considered.

IEEE 802.11-2020

IEEE Standard for Information Technology --Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks--Specific Requirements – Part 11: Wirless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

ISO/IEC/IEEE 12207-2017

ISO/IEC/IEEE International Standard – Systems and Software Engineering – Software Life Cycle Processes

IEEE/ISO/IEC P15026-3

IEEE/ISO/IEC Draft International Standard – System and Software Engineering – Systems and Software Assurance – Part 3: System Integrity Levels

Summary of Requirements

- High data rate application to show the capabilities of 5G and the ARA network
- Low latency application to show the capabilities of 5G and the ARA network
- Connect a camera to the ARA network for live video streaming
- Research and deployment of extended reality (XR)
- Use of GStreamer to interface between the camera and the XR headset

Applicable Courses from Iowa State University Curriculum

- EE 321: Communication Systems I
  - Knowledge in modulation schemes
- EE 422: Communication Systems II
  - Knowledge in modulation schemes
- EE 285: Problem Solving Methods and Tools for Electrical Engineering
  - Introduction to C programming
- CPRE 288: Embedded Systems
  - C programming
- COMS 327
  - C programming

New Skills/Knowledge acquired that was not taught in courses

- Knowledge in computer networks
- Knowledge in mobile networks (physical and digital architecture)
- Knowledge in 5G Technology
- Knowledge about current issues in agriculture and rural communities
- Knowledge in software interfacing

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List of figures/tables/symbols/definitions

Radio Access Network (RAN), system that performs wireless communication connecting users to the Internet.

Base Station (BS), specific point within RAN or mobile networks architecture where it transmits and receives wireless data.

User Equipment (UE), in field transceiver that communicates with the BS. Examples include your mobile phone.

1 Team

1.1 Team Members

Team Member Name	Major
Caleb Kitzelman	Electrical Engineering
Cristofer Espinoza	Electrical Engineering
Jake Roskopf	Electrical Engineering
Andrew French	Electrical Engineering
Vibhu Dhavala	Software Engineering
Sam Rettig	Software Engineering

1.2 Required Skill Sets for Your Project

Software – Background in software will be very important for this project as we communicate with different hardware. Whether it is UE to BS connection (command line for Linux Ubuntu set-up and C for optimization) or creating the multimedia framework from the video stream to XR applications, software experience is required.

Hardware – Background in hardware will be important when selecting the appropriate equipment and optimizing modulation schemes within our UE and BS. A general understanding of signal processing is also important.

Computer Networks – Background in networking would be ideal in understanding architectures related to mobile networks.

1.3 Skill Sets covered by the Team

Our team is comprised of four electrical engineering students and two software engineering students. All our electrical students are familiar with C to some degree. Of the four electrical engineering students, three are communication systems focused and are familiar with the basics of different modulation schemes and carrier systems. On the other hand, our software engineering students are familiar with different OSs like Linux and programming languages.

1.4 Project Management Style Adopted by the team

The team will operate on collective management. All actions are discussed and decided as a team. If there are any instances where opinion is split since we do have an even number of team members, we will have Caleb decide how to move forward. This responsibility was agreed upon by all team members. As the project progresses, we will delegate roles as we see fit or necessary. Team members will be held responsible for what is assigned to them.

1.5 Initial Project Management Roles

These are non-technical roles that we have agreed upon as a team to be carried out throughout the entirety of this project.

Role	Description	Team Member Name
Manager	Keep us on schedule and following the road map, make decisions that can't be made democratically.	Caleb Kitzelman
Communicator	Communicates with resources (graduate students, professors, etc.) and sets up meetings.	Cristofer Espinoza
Documenter	Documents design changes, results and other data.	Jake Roskopf
Assignment Coordinator	Ensuring ECPRE 491 class assignments are turned in.	Sam Rettig

2 Introduction

2.1 Problem Statement

5G allows us to not only transfer large data efficiently, but at faster speeds. We are looking to make commercial farming more efficient through the capabilities enabled in 5G specifically with video streaming and XR.

2.2 Requirements & Constraints

High Data Rate - Our first requirement was to find an application to use the ARA network, showing the true capabilities of 5G. We needed an application that would demand a high throughput.

Low Latency – Another requirement once we have determined our application is optimizing for low latency. An advantage of 5G technology is the ability to have time-sensitive applications. We want to ensure that our live streaming application shows as close to real time as possible.

Video Stream – Upon researching the applications enabled in video streaming alone, we have decided to utilize it as our high throughput application. This will require us to be able to connect a camera to the ARA network and create an interface to be able to stream live data.

Extended Reality (XR) - Dr Hongwei has also highly pushed for an XR application. This will require research into equipment and deployment.

GStreamer – We will also be required to do research on a framework that enables us to interact between the video stream and XR headset. We have been suggested to investigate GStreamer as a solution.

2.3 Engineering Standards

IEEE Standard for Information technology-- Local and metropolitan area networks-- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 8: IEEE 802.11 Wireless Network Management

Our project is closely tied to wireless networks and must follow current network protocols. IEEE 802.11 outlines these protocols and standards, and it is essential our project follows them so it can connect with other devices.

ISO/IEC/IEEE International Standard - Systems and software engineering -- Software life cycle processes

We will be creating an application that creates a combination of hardware, firmware, and software and as such we will need to consider the physical lifespans of our components. Thus, in order to meet the needs of our potential customers and stakeholders we'd need to inform them of the lifespan constraints and maintenance needs of our application.

IEEE Standard Adoption of ISO/IEC 15026-3 -- Systems and Software Engineering -- Systems and Software Assurance -- Part 3: System Integrity Levels

Our application will have to be sufficiently implemented without any major issues. This will mean dependable sub-systems, high overall functionality, and reliable output or performance. This will also be dependent on the 5G network, as it is an external dependency that we cannot directly control. Thus, we will need to make sure that our system is able to maintain a stable connection as long as the hosting process is available.

2.4 Intended Users and Uses

Commercial farmers are the primary beneficiaries of our project. There is a plethora of ways video streaming can be applied to agriculture. The basis behind most use-cases is the ability to read video streaming data via ML image recognition to make decisions. This is also known as "computer vision".

Crop growth monitoring is a very intuitive approach to utilizing video streaming. This can be via phenotyping in-field or from a drone to get a bird's-eye-view. NDVI mapping is a current common monitoring method where it measures relative biomass or vegetation. After finding an area that could use extra attention, remediation can be applied to greater precision. This effectively results in less costs and greater efficiency.

Another use-case for video streaming in agriculture is yield estimation. Using similar methods to crop growth monitoring, there is potential to be able to actively estimate yield.

Animal monitoring whether it be livestock, poultry or fish, live video streaming with different sensors such as temperature can help farmers be more aware of their animals' health. To be able to be proactive and prevent fatal health issues can decrease losses in profit.

Automating produce sorting and farming robots are also a possibility enabled by live video streaming like harvesting produce that is ripe and leaving those that are not. This can also apply to produce that has gone bad and ensuring that it does not get mixed it. This ensures quality of products to customers.

Security monitoring for remote farms would also be helpful against trespassers or animals that can harm livestock and or crops.

3 Project Plan

3.1 Project Management/Tracking Procedures

For our project, we will utilize the agile-waterfall project management style. We chose this style for two reasons, the first being that we have very clearly defined steps which need to be completed before others. Despite this fact, we will need the flexibility to double back onto tasks as necessary. This will be especially important for tasks such as testing, where the iterative nature of our project requires some level of regression testing.

We will track our progress through tasks through the use of Git/GitHub to start out with. The internal tools provided to us through Git allow us to assign roles, track progress, and most importantly allow for the software development to have high accountability. The ability to create a branch of the software, implement tests and manipulate code, as well as make sure that any merged changes actually work is an invaluable tool. This will also allow for hardware development to be tied to the same place; creating a complete picture of where we are, and what we have left to complete.

We may expand out to using Trello as needed in the future, as it may better suit certain tasks better. This may be pertinent especially in the case of hardware tasks.

3.2 Task Decomposition

Our tasks heavily revolve around the use of XR and connection to the ARA wireless network via a headset. Thus, our project requires many disparate tasks that do not immediately connect to each other.

Decomposition:

- XR headset
    - Current headsets we are considering:
        - Meta Quest, Magic leap 2, Hololens 2
    - Compare specifications of each headset
    - Present findings to Dr. Hongwei on 4/24
- Software (GStreamer)
    - Learn more about how to properly utilize the software

- Live Demo
    - Create and run camera livestream via GStreamer and the XR headset
    - Document set up process
- Front-End Development
    - Create and test XR UI
- Back-End Development
    - Build data analytics
    - Create way to store data if necessary

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Our primary goal for the spring semester is primarily focused on setting up the project for the fall semester. Thus, our goal is to present our findings to Dr. Hongwei so he can make an informed decision on what will be the best XR investment. Similarly, with the massive help from graduate students, we strive to have a working live demo to present by the end of the spring semester.

Once fall semester begins, we will begin our XR development in earnest. As of right now, we have several ideas that we can develop towards:

- Precision farming
- Ag based learning via headsets
- Other ideas

Thus, we will need to connect the XR headset to the ARA wireless network and GStreamer if this condition is not met before the fall semester. This will also mean developing algorithms to properly obtain and analyze data; especially in the case of precision farming. This, among creating an intuitive UI, will be our main goal for the fall semester.

As we progress in the project and encounter both success and failure, we will be able to step back and re-evaluate what our new goals need to be.

3.4 Project Timeline/Schedule

To best optimize our task schedule, we have developed four main phases to our project that each has specified tasks and milestones that we are striving to achieve along the way. By having this outline, we then know when we are beginning to reach a point to transition to the next phase. We want to maintain an organized project and hopefully gain success through this project schedule.

Phase 1: Background Research and Project Familiarization

To best understand our project, we want to learn more about how 5G networking has improved upon current technology and how our application will utilize this to meet the needs of our customers. During this phase we have the following tasks:

- Meet with Dr. Hongwei and ARA wireless team
- Find readings and information on 5G networking

- Researching agricultural communities to better understand their needs for certain applications
- Begin looking at Use-Case scenarios to start developing an application focus

Phase 2: Initial demonstration and connection

Before the end of the spring semester, our goal is to create a live demonstration using the XR headset and the ARA wireless network. To do this, our tasks are as follows:

- Report on XR headsets
- Meet with graduate student to learn more about how to connect to the ARA network
- Once we get the headset, create initial connection using GStreamer

Phase 3: Application development and internal testing

We will develop both the back end and front-end of the application to best suit our goals and intended purpose

- Back-end development
    - Algorithm creation + tuning + testing
- Front end development
    - UI development
- Testing often to ensure quality of product

Phase 4: Real-World User Review and Final Benchmarking

After our project reaches its final stages, we want to conduct a final assessment of its usability. We will run our final tests and conduct user interviews to evaluate if it is reaching the needs of our customers. During this time, we will:

- Conduct final testing
- Develop a report of our successes of our project
- Assess real-world uses of our applications
- Present our project

3.5 Risks And Risk Management/Mitigation

Our projects have risks that may impact us at different stages, as such mitigation (if necessary) is necessary to set up.

Risk 1 – 10% - We will be unable to procure an XR headset within a reasonable time window before spring semester ends.

Risk 2 – 35% - Creating the initial connection and demonstration may prove harder than foreseen, delaying our ability to present to the faculty at the very end.

- Mitigation: As soon as we are able, talk to the Graduate students with the XR headset in person. Discuss potential issues, how to set up the codebase within the headset, and other important aspects.

Risk 3 – 30% - Back-end algorithm development proves to be difficult, leading to slower than expected delivery of testable software

- Mitigation: Research and do our best to set up the software environment before fall semester to mitigate initial issues. Create Git branches to isolate versions of code.

Risk 4 – 5% - Updates are made to the ARA network that would break our application or maintenance procedures that prevent us from performing tests on the network.

Risk 5 – 15% - latency between the XR headset and camera feed proves to be a large issue and needs to be reduced

- Mitigation: Test as frequency as possible, creating a solid bases for expected results that we can reasonably achieve

3.6 Personnel Effort Requirements

Include a detailed estimate in the form of a table accompanied by a textual reference and explanation. This estimate shall be done on a task-by-task basis and should be the projected effort in total number of person-hours required to perform the task.

Task	Person-hours Required to Complete	Reference/Explanation
Meet with Dr. Hongwei and ARA project team	Dependent on bi-weekly meetings, as well as when required otherwise	Hour biweekly meetings to touch base, check progress and direction of our project.
Readings and research information on 5G networking for background knowledge	20 hrs / person	Using a book as well as other resources provided, learn more about 5G and how it works.
Research XR headsets	5 hrs/ person	Research and create compiled document on what XR headset would be most advantageous for our utilization.
Front end Development	40 hrs/ person	Develop our applications front end (algorithm)

Back End development	40 hrs / person	Develop appropriate back end for our application, dependent on the project goal.
GSteamer utilization	TBD	Network test with the ARA wireless network.
Testing goals / requirements	40 hrs / person	Create testing procedures for software to maintain quality. Phase 2/3: 3 Months.
Resource list	Less than 1 hr	Keeping track of our resources as the project progresses is important so that we know who we can go to for specific information or specific aspects of wireless communication. (UE, BS, RAN, Software vs hardware)
Re-evaluate successes/failures	2 hours in group discussion	Find out what we did well, as well as what we can improve upon.
New goals	1 hour	Adjust to unexpected challenges that we need to meet and add additional features to our design.
Improve current applications	TBD on what we need to revise	Improve our current implementation of the project.
Final testing	TBD	Create and run final tests to confirm our projects status, and what to do next semester.
Create and develop Report	5 hrs / person	Develop final report with all our findings, success as well as things we can improve upon.
Real World applications	15 hrs / person	Conduct tests in real-world test cases and user experience.

Present project	1 hr / person	Gather all the results to present to our advisors and customers. Summarize the project successes and failures

3.7 Other Resource Requirements

We have plenty of resources that can supplement our research and development in this project. First and foremost, we will have access to Dr. Hongwei's expertise in the 5G field. Dr Hongwei is a professor in the Department of Electrical and Computer Engineering as well as the Department of Computer Science. He has been able to provide a list of helpful resources to supplement our understanding of 5G as well. We can also reach out to any of his graduate students who work on the ARA project, all of which have their own specialty. We have met with Joshua Boateng, who is a graduate student currently amid his own project which utilizes the ARA Network and 5G to create a self-driving tractor. He specializes in more hardware aspects. We have also met with Sharath who works on more of the software-defined aspects of the RAN.

Dr. Hongwei has also introduced us to two other professors that we could also reach out to. Dr. Marie-Jose Montpetit is a research affiliate with MIT who has interests in wireless internet and network coding applications. Dr. Myra B. Cohen is a professor and chair of software engineering in the Department of Computer Science at ISU.

Finally, we have access to everything that the previous 5G project members have done, as well as the members themselves upon request. This allows us to have a vast array of contacts that we may be able to utilize as necessary. In particular, one Elisabeth K Adi has been able to help us very much, now attending most of our meetings.

4 Design

4.1 Design Context

4.1.1 Broader Context

Area	**Description**	**Examples**
Public health, safety, and welfare	Since our product relates to XR, we want to make sure our application takes into consideration the user's physical safety when using the device.	Minimizing eye strain, minimal movements to avoid collisions, privacy of data, etc.
Global, cultural, and social	Farmers are hardworking, thus always looking for better ways to do their job.	Automation in feeding will allow farmers to prioritize the health of their animals in other areas like

	Our project will reflect this desire to use their time more effectively.	living conditions, and also reduce work on their end.
Environmental	Our project can make farming more sustainable and less demanding for the farmer. This will lead to higher yields, quality of product, and more efficient time allocation.	Higher quality crops can be produced because of automation, especially if that means picking them as soon as they are of the highest quality.
Economic	Our project will allow farmers to be more precise with their farming techniques. This will help them save money in future endeavors and maximize profits	Automation: analyze how much food is left in each area, and automatically use a robot or another device to deliver the precise amount that is needed. Livestock: Analyze how much each animal eats, leading to a higher understanding of dietary items. If they eat higher quality food, the animal could be sold for more.

4.1.2 User Needs

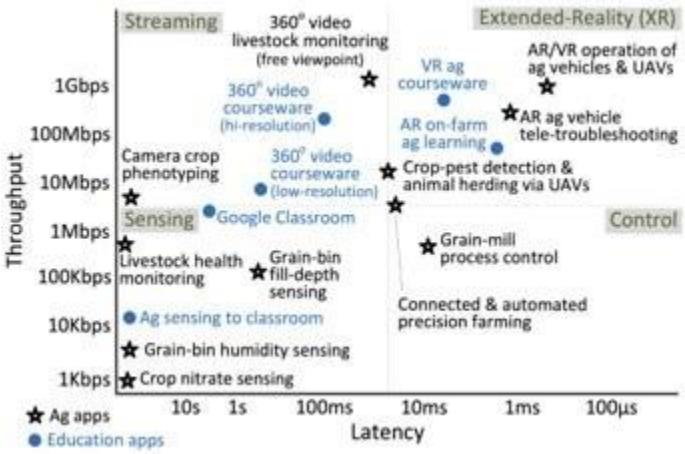
Users:

- Commerical Farmer

A commercial farmer needs to be able to run his farm in an efficient manner and because of this he wants to utilize new technology as it becomes available.

- Dr Hongwei's requirements

Dr. Hongwei needs our solution to use a data rate and latency in our design that would require a 5g network to accomplish, so that our project can be of value to his 5g research.



4.1.3 Prior Work/Solutions

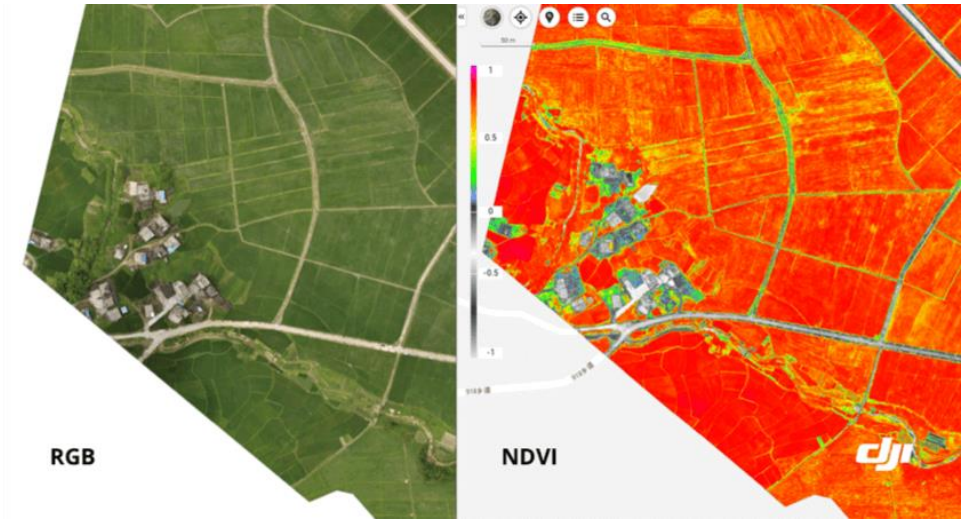
- There exist current ways to connect video feed and other data wirelessly such that it can be viewed and processed remotely.
- Previous solutions are not designed or optimized for the new 5g ARA network and similar networks that will become increasingly available to farmers and rural communities.

Our system will be designed to use the ARA network and potentially future 5g networks.

- Drone Usage

There is research being done on how to use drones to image farmland to create images of farmland to track soil moisture and other research on using the cameras to automate targeted pesticide spraying. Below is an example of using infrared light to identify locations in the field that are in need of moisture.

https://enterprise-insights.dji.com/blog/drones-in-agriculture,



- IoT soil sensing

Some companies are currently using wireless infrastructure for soil sensing. Soil can be tested for pH levels, mineral content, soil moisture, and salinity among a plethora of other factors to plant health. Testing is performed to improve nutrition in soil, protect the environment from contamination by runoff and leaching of excess fertilizers, and aid in the diagnosis of plant culture problems. This allows for optimized and efficient crop production. Farmers save money from reduced yield loss and apply only the amount of fertilizer needed.

One company that is currently doing this is Farm21, based in Amsterdam. They provide in-field soil probes to capture agricultural data. Their technology utilizes previous wireless technology (2G/LTE-M/NB-IoT).

- phenotype bot

Current research is being done through ARA in collaboration with Iowa State looking at using robots to help with phenotyping crops and eventually will involve sending that data through the wireless network.

https://arawireless.org/research/agriculture-use-case/,

- Insta360 Pro John Deere video feed

John Deere is working on automating seeders, sprayers, and combines with the use of sensors and cameras which requires high-speed and high-data-rate connections between the sensors and the tractors.

https://arawireless.org/research/agriculture-use-case/,

- Microsoft smart farming

Microsoft is conducting research on how to minimize the costs of collecting and transmitting data for smaller farm settings. For example, using balloons instead of drones and using TV whitespace to transmit data instead of the frequency bands that make up Wi-Fi.

https://www.microsoft.com/en-us/research/uploads/prod/2022/09/Democratizing_Data-Driven_Agriculture_Using_Affordable_Hardware.pdf,

https://www.microsoft.com/en-us/research/uploads/prod/2020/04/SIGCOMM_Editorial.pdf,

-XR Usage

XR technology has advanced to be a useful tool in a business setting. Being able to have visual aid through XR equipment and still be able to interact with your physical environment greatly benefits workers.

[XR Set Research.docx (sharepoint.com)]

4.1.4 Technical Complexity

To be successful in our design we need to understand a variety of complex topics such as the ones listed below

- understanding of communication system modulation techniques
- understanding of developing technology such as massive MIMO, beamforming, network splicing
- understanding of computer/mobile network architecture
- embedded system C programming for 5G RAN solution

Additionally, we will be transmitting our data of the ARA wireless network which is something other projects, such as the phenotyping bot, have not yet implemented into their design.

4.2 Design Exploration

4.2.1 Design Decisions

Past Decisions:

- Current ARA projects' progress -> video feed

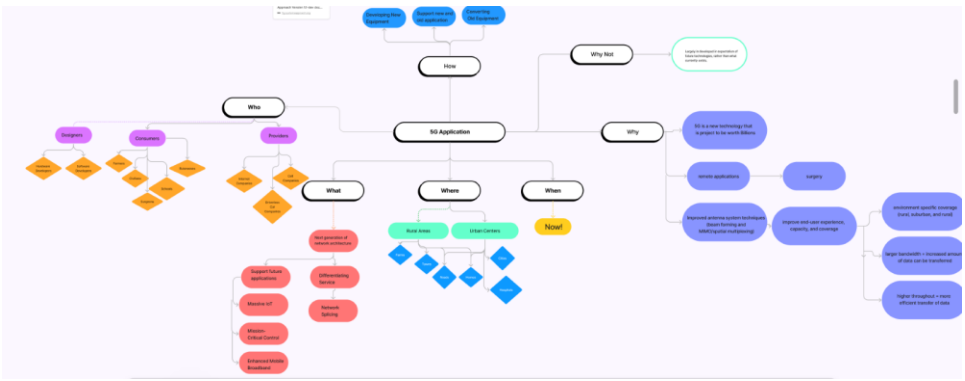
- Dr Hongwei's requirements -> XR, video feed, automation OVER IoT Sensing

-Interacting with the network ->srsRAN_Project open-source code (C)

-User experience-> Monitor displays, VR equipment, displayed information, etc.

4.2.2 Ideation

For one design decision, describe how you ideated or identified potential options (e.g., lotus blossom technique). List at least five options that you considered.



The project proposal given to us was very open-ended. Our advisor prompted us to develop an application to run on the newly created ARA 5G network that either focused on agriculture or educational purposes. Once we decided on following through with the agricultural application, we went through many different design application ideas for different use-cases. We wanted to find an application we thought would meaningfully impact the agricultural community and utilize the full power of the new 5G technology.

To figure out our options, we first looked at the current issues within agriculture and potential applications we could create to solve these problems. Some of these issues were as follows:

- Soil contamination
    - Use soil sensors and IoT devices to monitor soil quality
- Livestock monitoring
    - Use biometric sensors and video feed to give real-time updates to farmers
- Crop Growth
    - Pheno-bots and drones give collect data for real-time and high throughput phenotyping and precision farming
- Agricultural Automation
    - Use drone to autonomously spread pesticides on crops
- XR Farming
    - Use VR equipment to remotely control farming equipment or to improve the user farming experience

4.2.3 Decision-Making and Trade-Off

After brainstorming our potential applications, we assessed the feasibility of each project and if the project would benefit by using the new 5G network. Because our client's main concern is applications that utilize the high data transmission and low-latency aspects of the 5G network, we decided to choose an application that utilizes video data. This data can be crucial for making real-time decisions while farming and the private network allows for data speeds that are not common in other rural areas. This limited our choices to both livestock monitoring and using VR/XR to improve upon current farming methods. Since our advisor is eager to begin both these applications, he has directed us to start looking into both and begin the groundwork for future improvements.

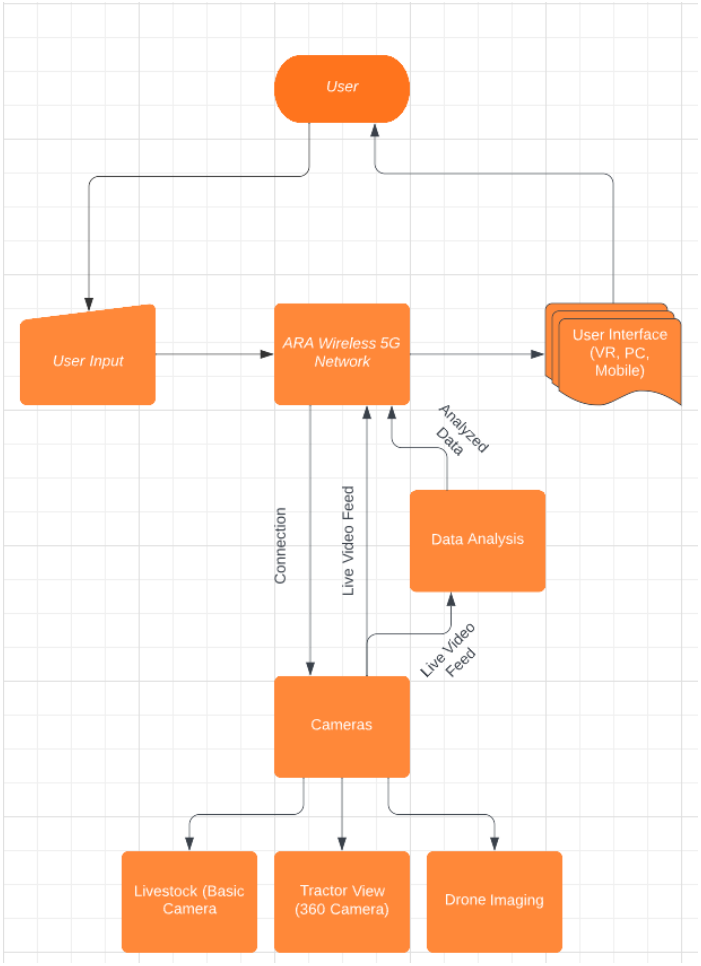
4.3 Proposed Design

Discuss what you have done so far – what have you tried/implemented/tested?

- IoT soil sensing
    - Look at what composes the soil (minerals, etc) and deliver data to farmer
- 5G srsRAN solution (open-source code for UE-BS connection)
- Live video feed applications and data analysis
    - Possibly investigate OpenVR (open-source VR code) and ways to implement them into agricultural applications
- Automation in farms
    - Automate feeding

- 5G Security analysis
    - Look for exploits, issues that can be either patched or used later
- XR equipment
    - HoloLens 2, Magic Leap 2, Meta Quest Pro
    - SDK packages
- Agricultural Education Aid

4.3.1 Design Visual and Description



A user should be able to access the ARA wireless network, from there, the user will have access to a few different cameras. With the combination of 5G and the connection to the cameras, the user will have a live video feed and be able to see what the camera(s) see in real time. The user should be able to view analyzed data that comes from the video feed. The data should be analyzed in real time, which would allow the user to see everything needed from the cameras.

Once a video connection is made through the ARA network, this data should be used to create useful UIs such as XR applications. These applications can range from educational uses to precision farming.

4.3.2 Functionality

The functionality of our design is quite simple on a top-level, generic look:

- Users will have access to the ARA network. User interface can range from mobile devices to desktop computers, to even virtual reality devices
- Through 5G technology and the ARA wireless network, connections will be available to many different cameras (IR cameras, 360 cameras, basic security cameras, etc.)
- From this connection, data from cameras will be seen in real time by the user. The cameras can be used for many different applications such as livestock farming, autonomous vehicle control, and real time data collection

How well does the current design satisfy functional and non-functional requirements?

- The current design is experimental and a top-level look into many possible applications. We are looking at live video feed applications, so now, we are working on developing the connections and 5G code related to live video feed. From there, we plan on looking into ways of collecting and analyzing data from that connection, and creating a process where there is very little to no latency between the user and the application.

4.3.3 Areas of Concern and Development

An immediate concern of ours is testing our code and solutions for the live video feed. We need to look at many performance characteristics, such as throughput, delay, delay jitter, reliability, quality of experience, etc. We need to be able to properly determine these performance characteristics to create the best solution possible for our design.

Developing a connection with the network is also a small concern of ours. We are all quite new to networking, however, we have many people in this project that can help with this.

We plan on sitting into some of the tests currently being worked on and developed with the ARA network. We've contacted many different researchers in this field and are setting up times to come and observe experiments and performance characterization.

We also are concerned about creating an XR application that effectively debuts the ARA network's capabilities. Since the ARA network supports higher data rates, we will be able to get real time footage and analysis from cameras that are connected to the network. We want to be able to utilize this in a helpful way to improve upon current farming methods.

4.4 Technology Considerations

Discuss possible solutions and design alternatives

Strengths	Weaknesses

- better coverage due to beamforming techniques - higher system spectral efficiency - broadband cable internet-like experience (10Gbps peak data rate, less than 1ms latency) - higher throughput	- obsolescence of previous generation devices that are not 5G capable - new infrastructure required, not necessarily a cheap transition

Since the transition to smart farming could potentially be expensive, we aim to design "All-in-one devices" so that the user only needs to purchase one item to do a larger range of tasks. We plan to make our XR design adaptable to many use-cases.

4.5 Design Analysis

Our group has discussed at length what projects we want to focus on, and of all the projects none of them have stuck as long as the projects in development on the ARA wireless website.

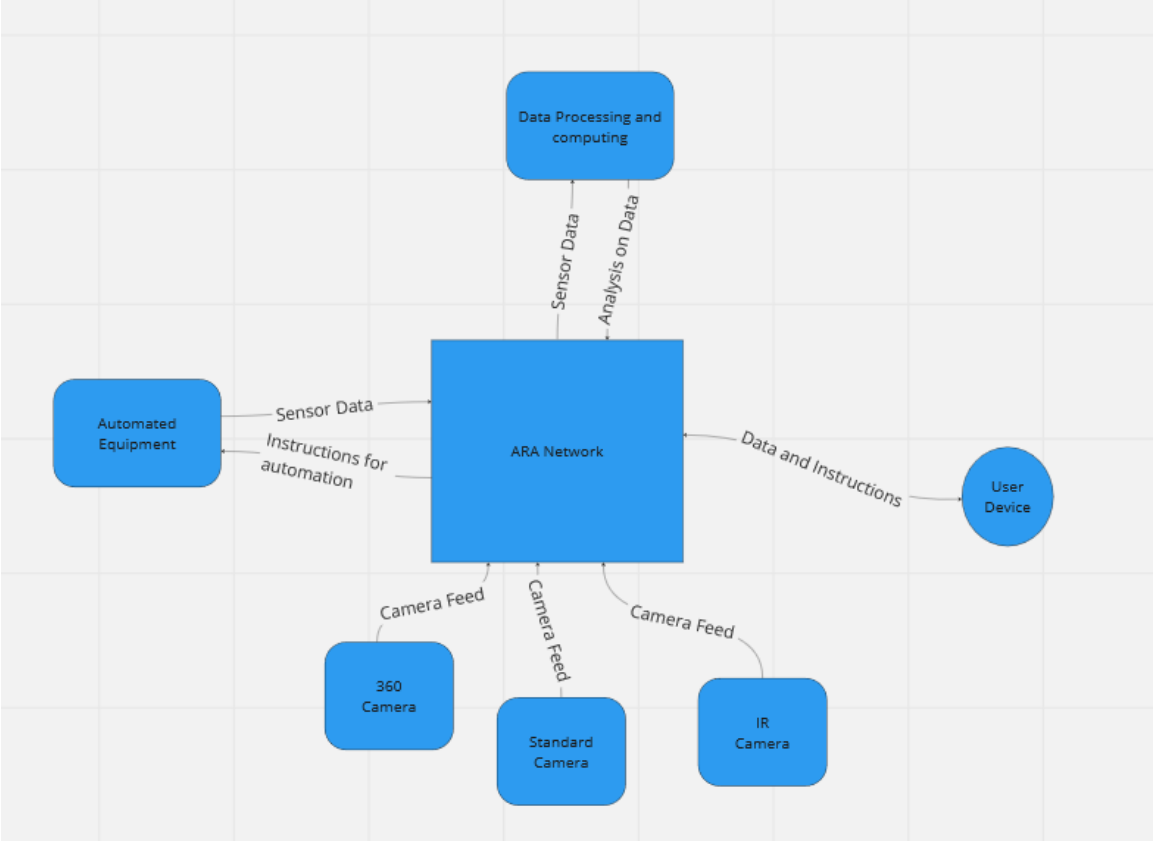
Projects like IoT soil testing are useful, but ultimately would fail to effectively use the full range of 5G capabilities. Thus, the current idea with the most traction is the Live video feed application and data analysis. This project has several advantages that do not exist in other areas:

1. The hardware (for the most part) exists and is easy to install and use.
2. The live analysis can be delivered instantaneously, allowing for up-to-date data at all times.
3. 5G by its nature is not tied to wires, thus allows for interconnectivity over vast areas.
    a. This allows for different key factors to be analyzed all at once, and as the data begins to come in consistently, allows for trends to be created.
4. Implementations of similar projects are in active development, or otherwise have resources for us to utilize.

For these reasons and many more, live video analysis is only one of the two strongest designs for us to look at. This further extends to Automation, which makes life easier as a baseline for farmers.

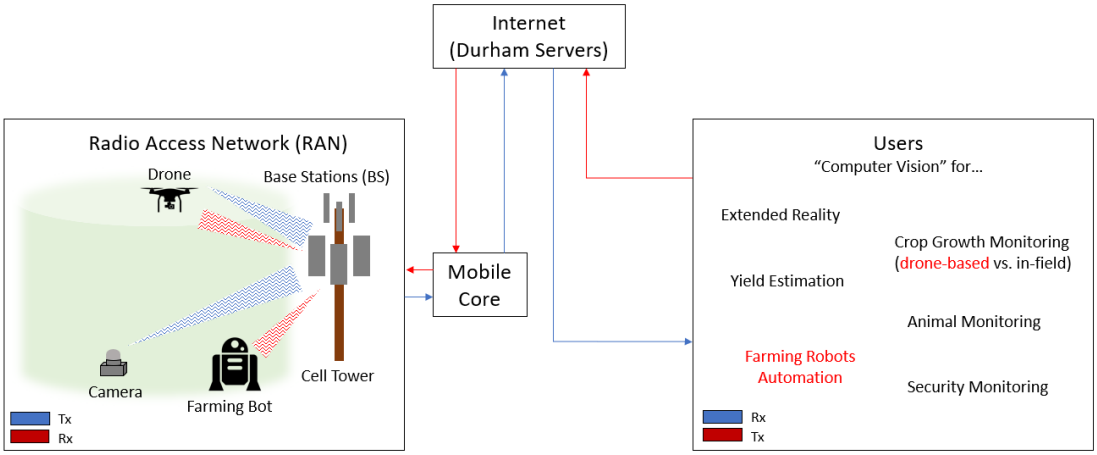
4.6 Design Plan

Because of the open-ended nature of our project our design plan had to be adaptable to the various projects we wanted to investigate. A lot of the modules already exist separately for the most part so our design had to incorporate these existing modules together. All of our modules are dependent on the ARA Network which is how we establish the 5G connection between devices.


Data Processing and computing
Sensor Data
Analysis on Data
Automated Equipment
Sensor Data
Instructions for automation
ARA Network
Data and Instructions
User Device
Camera Feed
Camera Feed
Camera Feed
360 Camera
Standard Camera
IR Camera

5 Testing

5.1 Unit Testing



Since we are using the ARA network, the infrastructure like the base station on the cell towers will likely already be configured to a certain modulation scheme to optimize performance of specific applications. If not, this is one area of the project we will need to test. Along with the transmission of the video feed from user equipment (UE) in the field, these units will be tested for the characteristics defined in our requirements by Dr Hongwei (latency, throughput, and delay jitter to name a few). We are currently in discussion with graduate students on how this will specifically be tested but we would imagine for the latency, testing will be like the echo and response used to ping.

For the video processing, we will need to verify that the application, which still needs defined, works correctly.

When using the XR will need to confirm that data is successfully being transmitted to the headset and can be displayed and for our application based on the video feed, we will need to verify that it is processing the video feed correctly.

5.2 Interface Testing

Although we have not yet developed specifics for the front-end of our 5G application, we will at the very least have an app for users to be able to see the video feed virtually anywhere. This video feed will be used for "computer vision". Computer vision is the process of analyzing digital images/video for quantified information or decision making. We're in the process of defining whether our specific application will have a livestock or crop focus.

Interface testing will consist of analyzing the data we provide the user. This will be dependent on the application we decide to create, as different applications will require differences in testing. For example, if we decide to provide a live count of livestock in a certain area, we will need to test the accuracy of that data, but if our application is to be used in automating a tractor or remote controlling a vehicle then we'll need to ensure a low latency connection and correct calculations.

5.3 Integration Testing

Our project has an information flow of Camera → UE → Network → Computer → Processing → XR Headset → User. With each of the steps from the camera to the end user we will need to verify that they are working correctly. Testing some logic flows will be hard to do individually, and will thus be done in logical chunks.

The UE will likely be able to display the camera feed, so we can verify that connection.

From the computer we will then verify that we can send a ping from the UE over the network to the other end. Then we will test whether a video file can be sent from one end to the other.

We will test the processing by first testing the ability to conduct the processing on images. Then we will verify that it can process a string of images, videos.

For the XR headset we will test that we can display an image on the headset. Then we will test that we can display a video on the headset.

5.4 System Testing

The end goal of our group is to have each component of design work cohesively together to form one overall design. In the end, that will mean connecting each component of our design together to verify that they function together. However, before that final test there will be a variety of tests in between. We will want to verify that each component in the design is working as desired individually, then we will look through the chain of the design to analyze what connections between components could be tested to verify they work together. If our design is of the form Camera → UE → Network → Computer → Processing → XR Headset → User, then we will want to conduct testing between the different subsections. A logical breakdown be testing Camera → UE → Network → Computer with one test, then test Computer → Processing → XR Headset → User with another.

5.5 Regression Testing

Since we are working with an ISU lab and ARA, we want to respect their resources and other current projects. To make sure we don't cause any damage to either group's lab equipment or infrastructure, we will make sure to have the proper training and approval needed to operate it.

For our own project, we want to have checks and documentation in place, so we are keeping track of changes within the project's hardware and software along with safe testing. To make sure the software doesn't lose functionality with new additions, we will use GitHub's tracked changes to monitor the edits that are made to the code. The software team will also add comments and documentation to the code so that new users can follow the code and know how it works.

To maintain our project's hardware, we will make sure that each member of the hardware team is made aware of the limitations of each component and create a list of possible issues or risks that each component could encounter. This will allow us to create a protocol when working with the hardware so that its safety and maintenance is always prioritized. Since we will be working with equipment that may be kept outdoors, we will also need to research their durability to the weather in case we need to construct additional protection for them and potentially only keep them

outdoors for testing. Overall, we just need to be mindful and careful with our equipment to minimize accidental damage.

5.6 Acceptance Testing

Functionality requirements are quite easy to demonstrate being meant. The video connection and the data analysis can be shown quite easily. For example, showing the video feed and live data on a screen would more or less suffice by showing the functionality requirements. To really go into detail, we will be characterizing the performance of the systems to show the throughput, delay, delay jitter, and overall performance of the system. This will be how we show a high-level view of the functionality requirements.

The non-functional requirements will be more difficult to show. This will be the user interface and the front end of our system. How easy is it to navigate? How easy is it to understand? Would commercial farmers be capable of using this system to its fullest? These are some of the questions we will look to address once the functionality of our project is fulfilled. To test this, we will have many different people use our project and give feedback on the experience and how it could be improved.

5.7 Security Testing (if applicable)

N/A

5.8 Results

We have not started testing.

6 Implementation

At the moment, we want to form a connection with a headset and the network by the end of this semester. This will show a presentable application, although very simple. A viable headset is currently being investigated and we hope to have one picked out and ordered shortly. This can then be turned into many different applications, such as a VR educational experience, or precision farming.

A video feed is being worked on at the moment by an undergrad student working in the lab. We hope to learn more about how this is being done, so we can investigate ways of analyzing the live video feed for different applications.

7 Professionalism

This discussion is with respect to the paper titled "Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment", *International Journal of Engineering Education* Vol. 28, No. 2, pp. 416–424, 2012

7.1 Areas of Responsibility

IEEE Code of ethics:

2. to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems;

Area of Responsibility	IEEE Code of Ethics	How does it address?
WORK COMPETENCE	To maintain and improve technical competence.	Work competence and the IEEE code of ethics is about creating solutions and technology that 1. Work as expected and solve the problem. And 2. Solve the problem in a way that takes advantage of technological breakthroughs and keeps pushing technology forward
FINANCIAL RESPONSIBILITY	Honest estimates, reject bribery, give proper credit to the contribution of others	Financial responsibility keeps work done by professionals unbiased and geared in the right direction.
COMMUNICATION HONESTY	Protect others' privacy, and disclose conflicts to affected parties.	Some work done in the professional field is quite sensitive. There should be clear, concise communication regarding some issues and work that arises as it arises
HEALTH, SAFETY, WELL-BEING	To hold paramount the safety, health, and welfare of the public. Treat all fairly	Work done by engineers especially should keep in mind the health and safetey of the public and society first.
PROPERTY OWNERSHIP	To accept criticism, correct errors, and give credit to whom it is due.	Not take credit for work done by others. Accept criticism as a form of bettering oneself as an engineer.
SUSTAINABILITY	To strive to comply with sustainable development practices. Reveal factors that might endanger the environment without delay.	Ensure products and solutions made don't danger the environment. Make sure products last long to reduce waste.
SOCIAL RESPONSIBILITY	Improve the understanding of society about emerging technologies	Make sure everyone knows about what is being worked on and developed. Ensure society (especially if affected by technology) understands how the technology works and what possible risks come with it.

7.2 Project Specific Professional Responsibility Areas

Work Competence: This definitely applies to our project's professional context. We are working with an emerging technology, and to ensure our work is of the upmost standard, everyone working on the project must be up to date on how the technology works, and how to apply it to our possible applications. Our team is performing very well when it comes to this area. All of us are diligently working on learning about generalized 5G technology, and the specialized technology we are working with now.

Financial Responsibility: This is not so applicable to our project. We do have some equipment that will have to be purchased, but it will be done through the funding of the project. We plan on getting equipment that meets the project's current and future needs as well.

Communication Honesty: The 5G networks being used in rural areas affect the population of these rural areas, however, it shouldn't be affecting others privacy. People in these areas will be aware of the capabilities of the network and what some of the applications can do.

Health, Safety, Well-being: This is unrelated to our project. None of the applications we are looking at will be detrimental to the health and safety of the public.

Property Ownership: We might be using quite a few open-source resources, and work done by others in the project, so it will be important that we keep in mind others work and give credit when due. We haven't quite come across this area yet, as we are still early on in our applications.

Sustainability: Our applications are based in agricultural settings. We must make sure that none of our applications pose any threat to the soil, plants, animals, etc. that reside on farms our applications will be deployed to. The applications we are currently looking at/working on will not pose any threat, so this isn't applicable

Social Responsibility: We are bringing new technology to a rural area that will not have seen this before. This area will be very important. The people using this technology might also be wary of how it works, so we will have to be very on top of keeping our potential users aware of how our technologies work. Our group is keeping this in mind as we develop our applications. We are doing quite well.

7.3 Most Applicable Professional Responsibility Area

Social Responsibility is the most applicable area for our project. As mentioned above, introducing a new technology to an area can be quite intimidating to people that reside in that area. It will be very important that we keep everyone up to date with the progress of the technology and how it works.

8 Closing Material

8.1 Discussion

Our project had two main phases that we aimed to complete over the spring semester. In phase one, we conducted extensive research into 5G technology and its current applications. This helped us refine our application ideas and select a VR headset for development.

During phase two, we focused on connecting the VR headset to the ARA network and enabling video streaming. While we have been able to develop a localized streaming application, we have not yet tested video streaming on the ARA network due to its limitations.

Moving forward, there are still risks and challenges that we will need to overcome, such as acquiring a VR headset or experiencing difficulties in streaming video over the ARA network. However, despite these challenges, we are on track to completing phase two by the end of the spring semester. Our goal is to have a demo of a VR headset that can stream video over the ARA network.

8.2 Conclusion

Over the spring semester, we made significant progress towards completing the first two phases of our project, which aims to make commercial farming in rural areas more efficient through the capabilities enabled in 5G. Phase one involved researching 5G technology and finding an application to use the ARA network, showing the low latency and high throughput capabilities of 5G.

We identified live video streaming as a high-throughput time-sensitive application. Dr. Hongwei suggested we explore an XR application, and we conducted research on the necessary equipment and deployment. We investigated VR headsets, such as Quest 2, HoloLens, and Magic Leap 2, and explored GStreamer as a framework to facilitate communication between the video stream, VR headset and ARA network. With this groundwork in place, we moved into phase two and focused on connecting the VR headset to the ARA network and establishing a video stream.

While we have been developing a localized streaming application, we have not yet had the opportunity to test video streaming on the ARA network due to its limitations. Nevertheless, with help from graduate students, we are on track to completing phase two by the end of the spring semester, with the goal of having a working demo of a VR headset capable of streaming video over the ARA network.

Looking back, we acknowledge that there were constraints that hindered our progress. one issue we faced this semester was project ideation. After we familiarized ourselves with 5g we spent a lot of time bouncing back and forth between ideas such as soil sensing, drone surveying, automated farming, and XR farming. We didn't have a clear goal for many weeks which hindered our progress to our final goal now. One thing that we could've done differently was to spend less time figuring out specific applications. Since all of our ideas involved a camera feed, we could've developed a mock streaming application that could later be tweaked to fit a specific idea. Another issue we've faced with completing phase two is the limitations of the ARA network, video streaming has not possible over the network, however the graduate students working on the ARA project are working towards having that functionality by the end of the semester. Although there are risks involved in completing the demo, such as not being able to acquire a VR headset in time or experiencing difficulties in streaming video from the headset over the ARA network, we remain optimistic about its potential.

Overall, we are proud of the progress we have made so far and look forward to further developing our project in the future. We believe that our research into 5G technology and the development of a VR headset that can stream video over 5G could have significant implications for the future of technology in rural communities.

8.3 References

L. L. Peterson and O. Sunay, *5G mobile networks: A systems approach*. Erscheinungsort nicht ermittelbar: Morgan et Claypool Publishers, 2020.

5G New Radio in bullets. S.l.: self published, 2019.

8.4 Appendices

8.4.1 Team Contract

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

Team Members:

Vibhu Dhavala

Cristofer Espinoza

Andrew French

Caleb Kitzelman

Samuel Rettig

Jake Roskopf

Required Skill Sets for your Project: (if feasible - tie them to the requirements)

- Software background
  - C Programming Language
- Electronic/Hardware configuration
  - RF Circuitry
  - General Signal Processing
  - Sensor connectivity
- Networking

Skill Sets Covered by the Team: (for each skill, state which team member/s cover it)

- Software
  - Vibhu, Samuel
- Communcation Systems
  - Cristopher, Jake, Andrew
- VLSI Circuitry

- Caleb

Project Management Style Adopted by the Team: (can be a combination)

- Collective management. Action is discussed and decided as a team. Roles will be split up depending on individual talents and skills.
- Individuals will be held responsible for what is assigned to them.

Initial Project Management Roles: (enumerate which team member plays what role)

- Manager
- Documenter
- Document Manager
- Communicator

Team Name __sddec23-12_ARA Project 5G Application___

Team Members:

1) _Vibhu Dhavala_____ 2) _Samuel Rettig_____

3) _Cristofer Espinoza_____4) _Jake Roskopf_____

5) _Andrew French_____ 6) _Caleb Kitzelman_____

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:
   - Monday 1:30 PM – 2 PM @ Durham 91 (Bi-weekly, face-to-face)
   - Wednesday 5 PM – 6 PM @ Coover 491 Lab (Weekly, face-to-face)
   - Sunday (as needed, virtually via Discord)

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

3. Decision-making policy (e.g., consensus, majority vote):
    - Consensus between group members

4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):
    - One designated scribe at the start of every meeting
    - Scribe will record meeting notes, key points, objectives for the next meeting
    - Documented on OneNote (Sp23 – F23 Meetings)

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:
    - Team members are expected to attend all general meetings
    - Any absences are accepted so long as communicated prior to the meeting
    - Late or missing members are responsible for inquiring about any missed information

2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
    - Team members will be responsible to complete tasks that have been mutually agreed upon at the time of the deadline
    - Communication is expected if a member is unable to complete their task prior to the deadline

3. Expected level of communication with other team members:
    - Team members must communicate attendance and availability when needed

4. Expected level of commitment to team decisions and tasks:
    - Decisions and tasks will be determined collaboratively
    - No responsibility will be provided to a member unless mutually agreed upon

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):
   - Vibhu Dhavala-Software
   - Cristofer Espinoza-Communicator, Software
   - Andrew French-Hardware
   - Caleb Kitzelman-Manager, Hardware
   - Samuel Rettig-Document Manager, Software
   - Jake Roskopf- Documenter, Hardware

2. Strategies for supporting and guiding the work of all team members:
   - Team will practice positive constructive criticism
   - Team will be respectful of others' ideas

3. Strategies for recognizing the contributions of all team members:
   - Verbal affirmation, contributions and efforts prior to the meeting will be discussed during the meeting

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.
   - Jake- Communication Systems / Analog Design
   - Samuel - Software
   - Vibhu - Software
   - Caleb – Analog VLSI Circuitry / RF Circuitry (Light background until next semester)
   - Cristopher – Communication Systems
   - Andrew – Communcation Systems

2. Strategies for encouraging and support contributions and ideas from all team members:
   - Discord
   - Weekly meetings

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?)

    - Direct confrontation discussed between group members
    - Consensus between group members that if a problem is being observed it can be brought up

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
    - To create a good foundation for realization of our project
        - Determine our application of 5G in either the educational aspect or agricultural and rural field
        - Plan and prototype our application.

2. Strategies for planning and assigning individual and team work:
    - Throughout the meetings we will discuss progress and direction
    - Responsibilities will be determined by goals for the next project meeting

3. Strategies for keeping on task:
    - Encouraged to check-in with any interesting research, findings, or progress via SMS or Discord
    - Tasks and responsibilities will be delegated/determined prior to the end of every meeting

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?
    - Infractions will be addressed during the team meetings
    - Resolution will be mutually created to avoid future infractions
        - Ex:
            - Adjustment to meeting time
            - Relieved of some responsibilities
2. What will your team do if the infractions continue?
    - Contact and address the issue to Professor Rachel Shannon

****

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) _____Vibhu Dhavala_____ DATE _____2/19/2023_____

2) _____Cristofer Espinoza_____ DATE _____2/19/2023_____

3) _____ Andrew French_____ DATE _____2/19/2023_____

4) _____ Caleb Kitzelman_____ DATE _____2/19/2023_____

5) _____ Samuel Rettig_____ DATE _____2/19/2023_____

6) _____ Jake Roskopf_____ DATE _____2/19/2023_____