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, Hardware Engineer

Jake Roskopf, Software 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

Computer networks and software interfacing skills will be needed for this project. Programming includes C# for app development within Unity.

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

The project requires us display the low latency, high throughput capabilities of the ARA network through an extended reality application that utilizes real time streaming protocol.

Applicable Courses from Iowa State University Curriculum

EE 321: Communication Systems I

This course covers a variety of modulation schemes, fundamental for understanding 5G and mobile networks.

EE 422: Communication Systems II

This course covers a variety of modulation schemes, fundamental for understanding 5G and mobile networks.

EE 285: Problem Solving Methods and Tools for Electrical Engineering

This course is an introduction to C programming course that can translate to better understanding the syntax of C# which is used for app development within Unity.

CPRE 288: Embedded Systems

This course is an furthered understanding and utilization of C that can translate to better understanding the syntax of C# which is used for app development within Unity.

COMS 327

This course is a C programming course that can translate to better understanding the syntax of C# which is used for app development within Unity.

New Skills/Knowledge Acquired Not Taught In Courses

For this project, the knowledge in the following areas were acquired to progress this semester:

ARA and communication systems:

- Computer networks
- Mobile networks (physical and digital architecture)
- 5G Technology

Where 5G technology can be applied:

- Current issues in agricultural and rural communities

Application development tools and streaming:

- Streaming Protocols (RTSP, HLS)
- XR/AR technology
- Unity (C#)

Data Collection:

- Wireshark (packet sniffer)

Table of Contents

List of Figures/Tables/Definitions

Figures

Tables

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.

Software Defined Kits (SDKs) - set of tools that allows developers to create applications for specific platforms or systems

Extended Reality (XR) - an umbrella term for augmented reality (AR) or virtual reality (VR), combining both a view of the physical world with digital interactable aspects

GStreamer – pipeline-based multimedia framework linking different media processing systems

Unity – a cross-platform game-engine

OBS Viewer – a free and open-source, cross-platform streaming app

Insta360 Pro – a unibody 360 VR camera with 6 lenses that shoots 8K video and photos in 3D and monoscopic formats, and supports up to 8K VR live streaming

Wireshark – Packet sniffing software used as a tool to analyze network measurements.

Real Time Streaming Protocol (RTSP) - Application-layer protocol used for controlling streaming media servers with play and pause commands.

HLS – HTTP live streaming media protocol for delivering visual and audio media

Round-Trip Time (RTT) - Duration it takes for a network request to go from a starting point to destination, then back.

Throughput – Rate of successful transmission over a communication channel.

Structural Similarity Index Measure (SSIM) - Method of defining the quality of a received image or video by measuring the similarity between two images.

1 Team

1.1 Team Members

Team Member Name	**Team Member Name**
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, specifically experience related to C#, will be required to develop our application within Unity.

Computer networks – Background in these fields will be important as we troubleshoot and collect data from the 360 camera to XR application over the ARA network. Data collection may also require use of C programming to determine SSIM scores.

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, which has helped in better understanding mobile networks. On the other hand, our software engineering students are familiar with different OSs like Linux and programming languages like C#. This has helped development of the application within Unity.

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.

The ARA team is currently able to stream a 360 camera into an XR headset via HLS, but noticeable latency is introduced, and the image displayed in the headset is "stagnant" as if it were just a monitor. It is not reactive to the movements of the user's head.

The main goal is to assist the ARA project in streaming on their XR headset via real-time streaming protocol (RTSP) from an Insta360 Pro camera. This will allow for the network to further be analyzed for data collection purposes.

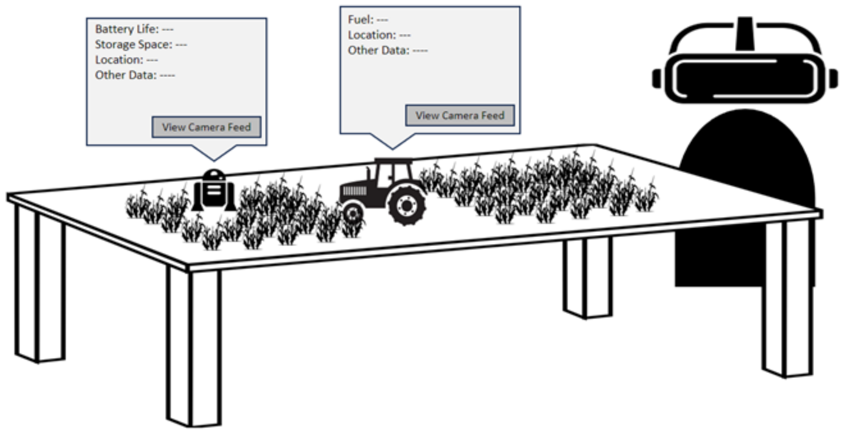


Fig. 1 Conceptual Sketch of XR Application

To further contribute to the ARA project, we are also tasked to conduct data collection and analysis of the current XR framework. This involves collecting measurements of metrics related to network performance and/or quality of service.

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.

Unity – By utilizing the game engine, we hope to use the VLC plugin to stream the RTSP link given to us. It also allows for future development as there are a wide range of tools available within the plugin.

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. Our focus will be utilizing XR but will implement video streaming to display high throughput, low latency capabilities. XR is a tool with many potential use cases, in our case being an application to display real-time video feed from a camera.

Currently there are tractors with such 360° cameras attached to them. They can be used to take in real time data and are currently serving as testbeds for the ARA network. Future uses can include yield estimation, animal and livestock monitoring, as well as other core functions desired by farmers.

Because of the broad nature of the application itself, it lends itself to serving as a core tool that can be used either to add onto or serve a role all on its own. A large aspect of this is data collection. On the ARA front, it is a tool that allows the ARA team to characterize stream metrics such as latency, FPS, and round-trip time. This allows for further testing and development of the network moving forward. It can also be used by farmers to retrieve data given the correct development takes place beforehand on their part.

3 Project Plan

3.1 Project Management/Tracking Procedures

For our project, we utilized 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 needed the flexibility to double back onto tasks as necessary. This was especially important for tasks such as testing, where the iterative nature of our project required some level of regression testing.

We tracked our progress through tasks through the use of Git/GitHub. The internal tools provided to us through Git allowed us to assign roles, track progress, and most importantly allowed 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 to make sure that any merged changes actually work is an invaluable tool. This also allowed 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 will also use Microsoft Teams to create scheduled tasks. This will allow us to document when our deadlines are and break down larger milestones into manageable tasks. Teams was also where we documented meeting notes. This was very important when we needed to refer to decisions made in the months prior and helped us form the direction we needed.

3.2 Task Decomposition

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

Decomposition:

- XR headset
  - Headsets we considered:
    - Meta Quest Pro, Magic leap 2, Hololens 2
  - Compare specifications of each headset
  - Selected the Meta Quest Pro as our headset
- Software
  - Determine tools needed to develop a useful XR app and to collect data
  - Considered many software tools:
    - Unity
    - Gstreamer, libVLC, OpenXR
    - Wire Shark
  - Learn more about how to properly utilize the software
  - Utilize a live camera feed stream into XR application
- Live Demo
  - Create and run camera livestream via libVLC and the XR headset
  - Document set up process
  - Implement stream analytic tools
- Front-End Development

    - Create and test XR UI
- Back-End Development
    - Build data analytics
    - Create way to store data if necessary
    - Set up live video capabilities
- Testing
    - Collect different streaming characteristics like FPS, SSIM scores, throughput, and roundtrip time

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

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

Once fall semester began, we began our XR development in earnest. We worked through many ideas of what this application was going to do but landed on a 360 live RTSP stream viewer. This was chosen so that we could collect data on streaming on the ARA network and create an application that has not been implemented before

In addition to this, we investigated SDK's that we wanted to utilize to create this live stream app– automating much of the work that may be beyond what we could achieve in only one semester.

Our main goal when the Fall semester began was to connect the XR headset to the ARA wireless network, as well as effectively utilize both SDK's as well as the live camera feed to quantify the networks capabilities. This meant lots of data collection, an intuitive UI to present data, and necessary features like a robust backend to support the endeavor.

As we progressed in the project and encountered both success and failure, we stepped back and re-evaluated what our new goals needed to be.

3.4 Project Timeline/Schedule

To best optimize our task schedule, we developed four main phases to our project that each has specified tasks and milestones that we strived to achieve along the way. By having this outline, we knew when we were beginning to reach a point to transition to the next phase. We wanted to maintain an organized project and gained success through this project schedule.

Phase 1: **Background Research and Project Familiarization**

To best understand our project, we wanted to learn more about how 5G networking has improved upon current technology and how our application utilized this to meet the needs of our customers. During this phase we had 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

We sought to make the initial connection between the XR headset and the ARA network a reality. This, along with testing the live video feed aspect, allowed us to developing our app. Tasks in this phase included:

- Begin deciding how to best collect data
- Test SDK implementation
- Run and create tests as to inform decisions on effectiveness + efficiency

Phase 3: Application development and internal testing

While we did not complete all our tasks in this section, we wanted to develop both a back end and front-end of the application to best suit our goals and intended purpose. This included the following tasks

- Back-end development
    - Further SDK work + testing of backend
- Front end development
    - UI development
- Testing often to ensure quality of product

Due to not having enough readily available RTSP plugins for Unity, we were unable to create a fully ready application. However, we were able to develop an app that includes the entire structure needed for this application to work once an RTSP plugin is developed.

Phase 4: Real-World User Review and Final Benchmarking

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

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

Again, we did not have a fully functional XR application; however, we were still able to conduct ample testing and better assess whether our application was practical in theory.

3.5 Risks And Risk Management/Mitigation

Our projects had risks that impacted us at different stages and developed a mitigation plan to navigate these times.

Risk 1– 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 were able, we talked to the Graduate students with the XR headset in-person. We discussed potential issues, how to set up the codebase within the headset, and other important aspects.

Risk 2 – 30% - Back-end algorithm development proved 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 3 – 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.

Mitigation: Communicate with our advisor on potential changes to the network

Risk 4 – 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.
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 had plenty of resources that supplemented our research and development in this project. First and foremost, we had 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 also were able to reach out to any of his graduate students who work on the ARA project, all of which have their own specialty. We 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 also met with Sharath who works on more of the software-defined aspects of the RAN.

Dr. Hongwei 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 had access to everything that the previous 5G project members had done, as well as the members themselves upon request. This allowed us to have a vast array of contacts that we utilized as necessary. In particular, Elisabeth K Adi and Evan Gossling were able to help us understand the camera streaming over the 5G network and XR applications, attended most of our meetings. They also provided us with many tasks to help them with their data collection.

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. Our project will reflect this desire to use their time more effectively.	Our application will allow farmers to check on their farm remotely and speed up repeatable tasks
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.	With our application being a "hub" of different farming devices, it will allow for increased monitoring of crops and data to help find more sustainable methods.
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

Our intended user would be a commercial farmer. A commercial farmer needs to be able to run their farm in an efficient and safe manner. This may entail but is not limited to increased yields and decrease in intensive labor. Advanced wireless opens a plethora of potential applications beneficial for the agricultural and rural communities.

Our client also has requirements that we must consider. Dr. Hongwei requires a solution that demonstrates high throughput while maintaining low latency. We spent most of the first semester honing down on an application that would be able to fall into this category.

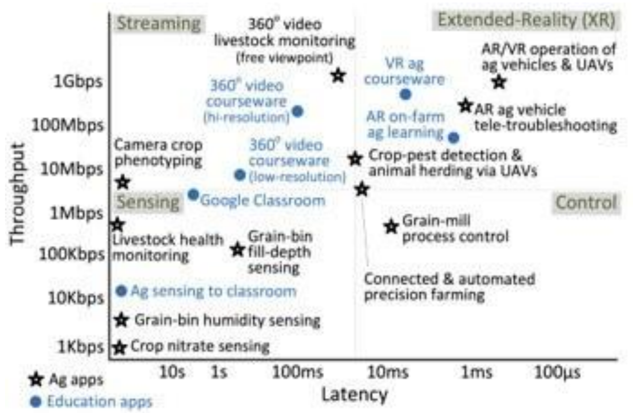


Fig. 2 Comparison Plot from "ARA: A Wireless Living Lab Vision for Smart and Connected Rural Communities" on Potential Agricultural and Rural 5G Applications

4.1.3 Prior Work/Solutions

Specific to the XR application, the ARA team was able to provide us with a working framework of XR streaming but it utilized HLS. Additionally, what was seen in the XR headset was like a flat screen rather than a wrapped interactive display. We were tasked to utilize RTSP and fix the visual issue. Throughout the semester we had learned that there was not an abundance of resources supporting the use of RTSP while streaming to an XR headset. However, we were able to find and develop a foundation for which a more interactive feel in the headset can be experienced.

As far as applications for 5G in rural and agricultural communities, we did conduct plenty of research in the first semester to narrow down our project.

Drones were one of many applications of advanced wireless in agricultural communities. There is research being done on how to use drones to create images of farmland. Furthermore, drones have been used to track soil moisture and using cameras or GPS on drones to automate targeted pesticide spraying. The example below from DJI's article on "The Use of Drones in Agriculture Today" uses infrared light to identify locations in the field that need moisture.

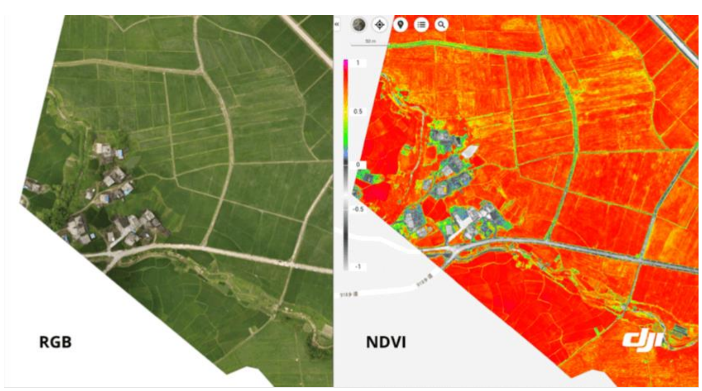


Fig. 3 Drone View Camera Variations from DJI's "The Use of Drones in Agriculture Today"

Additionally, 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. They utilize wireless technology such as 2G/LTE-M/NB-IoT.

Phenotype bots are a current research study done through ARA in collaboration with Iowa State looking at using robots to help with phenotyping crops. The team hopes to take advantage of the high throughput capabilities of the ARA network to sending that data through the wirelessly rather than replacing portable memory.

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. It utilizes the same Insta360 Pro camera that we had worked with in our project.

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.

4.1.4 Technical Complexity

Below are a few of the technical concepts or software we believed have been an important contributor to success:

- Basic computer networking
- Video streaming protocols (HLS, RTSP)
- Mobile network architecture
- C++ and Unity for application development

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-> XR Equipment, UI.

4.2.2 Ideation

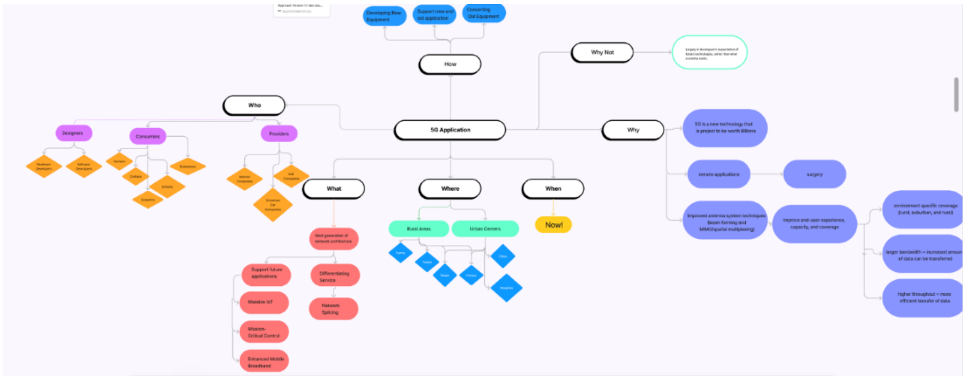


Fig. 4 5G Application Mind Map

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 an agricultural application, we went through many different design application ideas for different use-cases. We wanted to design 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.

There were many potential options when it came to platforms and tools for developing the XR application. After surveying our options, we decided to use Unity as the base platform for our application. We chose Unity due to the availability and variety of plugins and tools that are compatible. We used the Open XR toolkit along with Unity's own XR tools to create the framework for viewing and navigating 360 videos within the application. For the streaming part of the application, we looked initially at GStreamer, however decided against it because the support for RTSP protocol was lacking for Unity. We also investigated various scripts available on GitHub that provided support for RTSP streaming in Unity, however many of these were outdated or poorly documented. After trying to work with the other plugins we decided to switch to VLCUnity which provides an implementation for VLC media streamer within Unity.

One tradeoff that was made on the data collection side was the use of Python over MATLAB for SSIM score. For signal processing related courses at Iowa State, MATLAB has been the main software and language used to be able to compute concepts like filtering or correlation. MATLAB offers an SSIM function within the Image Processing Toolbox so this was the initial language used to compute an SSIM score with sample images from before and after transmission. However, after considering the thousands of images produced when our data was converted into frames (.png files), we decided to continue in Python with the "skimage" library since there was more documentation for string manipulation and file iteration.

4.3 Proposed Design

- 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
    - SDK packages
- Agricultural Education Aid

4.3.1 Design Visual and Description

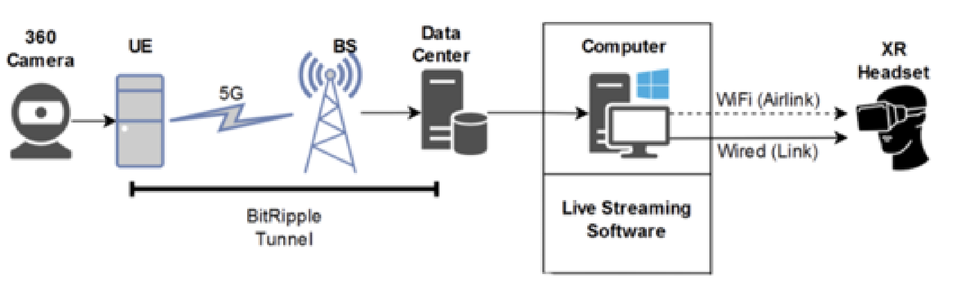


Fig. 5 Camera Live Streaming System Diagram

Fig. 6 Data Collection System Diagram

A user should be able to access the ARA wireless network, from there, the user will have the option to select a camera. 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 and metrics from the video feed. The data should be analyzed in real time, which would allow the user to see everything needed from the cameras.

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 will allow users to select an IP of a camera and stream the video to an XR device.
- Through 5G technology and the ARA wireless network, connections will be available to 360 video cameras
- 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 monitoring, autonomous vehicle control, and real time data collection

- The current application allows for the playing of native 360 videos, 2d videoeas as 360, and collection of performance metrics from live video streams, however the application is currently unable to connect to and display the live camera stream.

4.3.3 Areas of Concern and Development

A large concern of ours is backend development of the application, specifically being able to display the 360 streams being provided via the ARA network. Trying to work with the RTSP protocol proved to be a difficult task as 360 video streaming is still an emerging technology that does not have many resources to reference.

Another 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.

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 create an "All-in-one app" so that the user only needs to purchase one item that can be adapted to a larger range of tasks. We aim to have our XR design be 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.

Using Unity we were able to create an XR application that plays 2D and 3D video in a VR environment. The user is able to pan around the video as if they were at the location of the camera. We also developed methods of collecting throughput and response time of videos streamed over the ARA network. One struggle we encountered within our design was the implementation of live streaming video. We were unable to get a functional stream working within the application. After working with many frameworks and looking for various solutions we were unable to find a way for RTSP streaming to work within Unity. A lack of experience with Unity development and an unfamiliarity with the plugins we were working with posed a significant challenge to getting this feature implemented. Our application provides a baseline that can have additional features added, and be expanded upon by future teams working on the 5G project.

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.

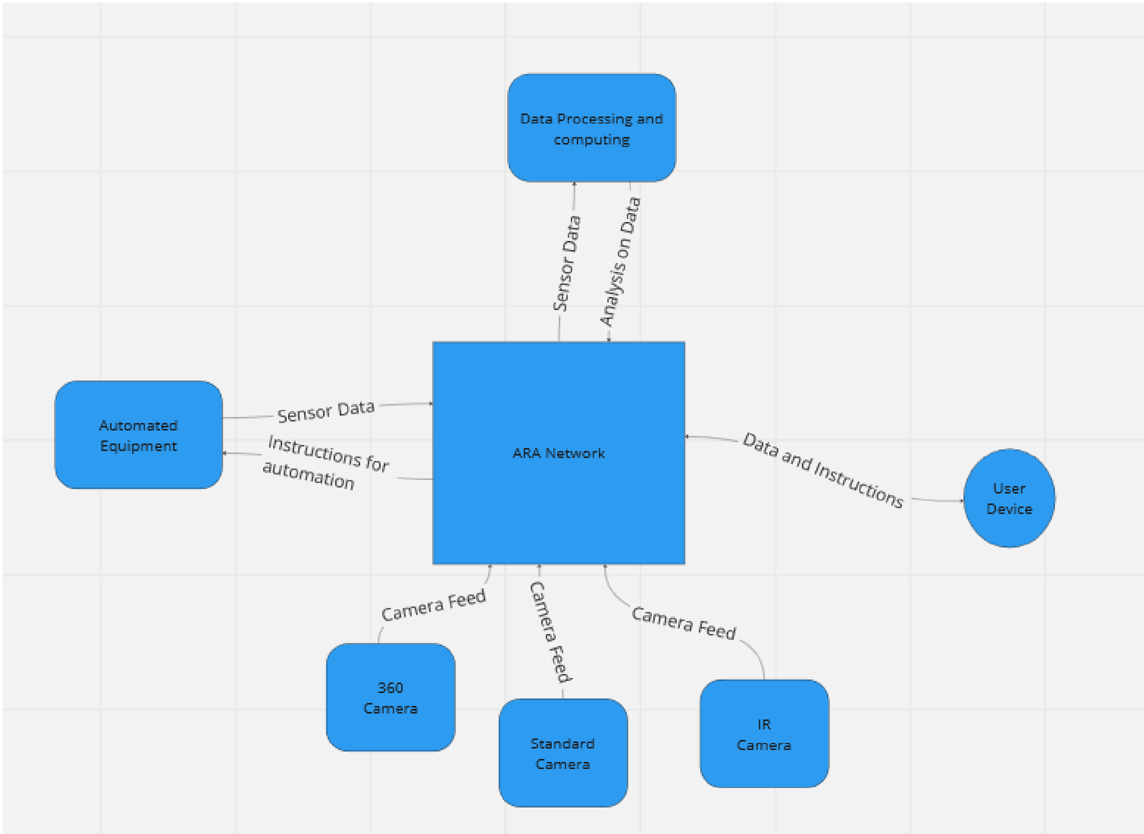


Fig. 7 Camera Live Streaming System Diagram 2

5 Testing

5.1 Unit Testing

We set out to test quality of experience (QoE) metrics such as frames per second (FPS) and structural similarity index measure (SSIM) score as well as quality of service (QoS) metrics like throughput and round-trip time.

We will be measuring the FPS of our application via the rendering statistics window offered within the Unity software. Unfortunately, we were not successful in finding a solution that allowed us to stream RTSP video onto the headset. Despite having a user interface and application that allowed to view a locally saved video, we determined collecting the FPS for this would not provide any useful information since it was not via RTSP.

Average SSIM was determined by calculating the SSIM of a pair of images before and after transmission over the ARA network while driving around Curtiss Farm, simulating a tractor. Recordings were saved while streaming the Insta360 Pro camera locally prior to transmission as well as at the receiving end. Any streaming viewer software is acceptable to use such as OBS Viewer or VLC. However, it is important that when the recordings are converted to frames (.png files at 30 FPS), the images must be the same size in dimensions. Border frames need to be added if necessary to be consistent with the 4K recording saved locally. Once two folders with matching frames have been created and named accordingly, Python scripts were used to compute the SSIM score of each frame. The results were used for an average, maximum SSIM score and minimum SSIM score. A library from OpenCV was used to grayscale the images then a function from the "skimage" API was used to calculate SSIM scores.

To gather throughput and round-trip time, OBS Studio was used to initiate communication with a mobile UE that was streaming the data from a camera out in the field. Wireshark, a packet sniffing software, was then utilized to be able to track the data live as the camera was streaming via OBS Studio. The software was able to filter the IP address of the UE to see any communication from that device on the Iowa State Wi-Fi. Wireshark offers analytical tools that were able to generate the graphs seen in the results section on throughput and round-trip time.

5.2 Interface Testing

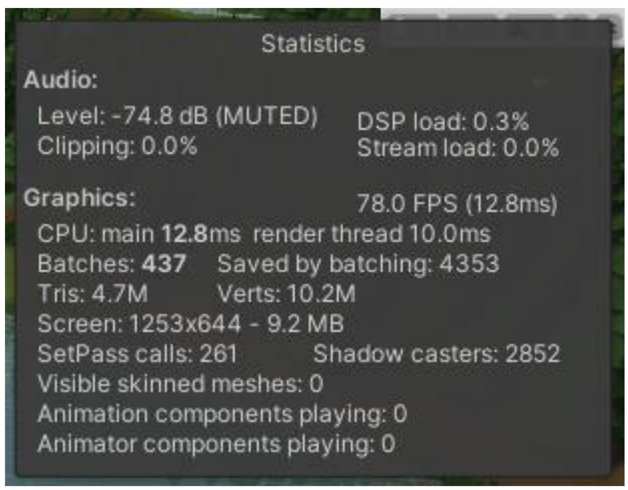


Fig. 8 Unity's Rendering Statistics Window

Unity's rendering statistics window will be our best way of getting qualitative data on our application. It is readily available within the software while an application is being tested. It provides information such as FPS which is the current number of frames Unity can draw per second. "CPU main" is the time taken to process one frame. This includes the time taken to process the frame update of the application and update the scene view in editor. On the other hand, "CPU render" is the amount of time taken to render one frame including the time taken to process the frame update for the game view but excludes the time taken in editor.

5.3 Integration Testing

The overall goal of testing the network and creating an application does not have any immediate critical integration paths. Both projects can be completed without any delay from the incompletion of the other project.

We currently have an application developed in Unity that is the foundation for user interface. The first step in testing the QoE would be uploading the application onto the XR headset and testing the ease in use. Impact from potential consumers would also be ideal.

Instead of gathering information of the currently developed application, the Unity team decided to focus their efforts on the integration of RTSP. This is the only critical integration that would impact any form of testing that needs to be done is the implementation of RTSP. Without this, our data collection team was only able to test the streaming framework excluding any measurements like latency that the XR application would produce.

5.4 System Testing

From what we had tested, all the metrics except for FPS collect data that encompasses the following infrastructure:

Camera → UE → Base Station → Data Center → Client's Computer

Since we were not able to stream successfully via RTSP, the data that was monitored stopped at the client's computer which would be streaming the video. If the XR headset is wired (baseband) connected to the client's computer, there may be little to no impact to QoS and QoE. However, if the XR headset itself was processing the video without the use of the client's computer, this could affect the performance.

5.5 Regression Testing

Since we are working with the ARA team, we want to respect their resources and other current projects. To make sure we didn't cause any damage to lab equipment or infrastructure, we were guided on proper accessing or operating processes.

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.

5.6 Acceptance Testing

We tested the QoS metrics of the application via Wireshark. Having a graduate team to work alongside, we were able to verify the data collected with the methods that they used to collect data and determine the accuracy of it. It would be advantageous to use more than one data collection method for the same metric to be able to compare.

The non-functional requirements include the user interface and the front end of our system. After our first iteration of the application that played a locally saved file, we sought feedback from our faculty advisor/client. Provided we had completed streaming via RTSP, we would have liked to focus more of our effort into testing and surveying potential users to improve our UI.

5.7 Results

The SSIM score was on par with research studies done like "Cell Fusion: Multipath Vehicle-to-Cloud Video Streaming with Network Coding in the Wild". This study compared the SSIM score of many other studys in the use of advanced wireless for vehicle automation. Low SSIM scores may be affected by other metrics like stall ratio, causing frames to not match up temporarily.

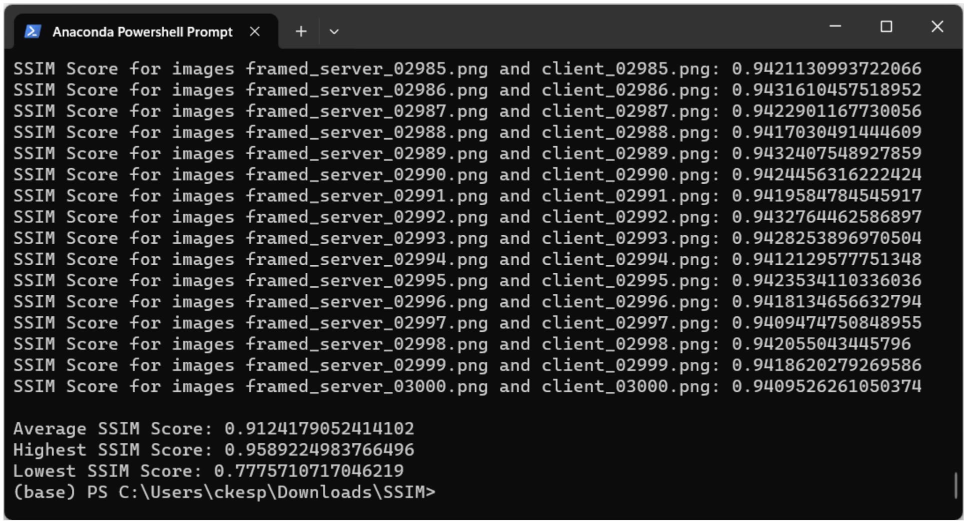


Fig. 9 SSIM score results

As for throughput and round-trip time, our measurements fell short of what was expected in figure 2. We do, however, see spikes of higher throughput. Additionally, we had confirmed that RRT introduced by the ARA network is around 0.34 ms. Data centers to clients may introduce additional increase in time depending on the uses own network speeds (i.e on-campus vs. utilizing a VPN at off-campus). Additionally, we're connected to the ARA network through a connection with the Iowa State network, optimally the application would be run on the same network the video is streamed from. The overall average round-trip time sits at around 50-80ms which is in agreement with the values we had been provided by the ARA team.

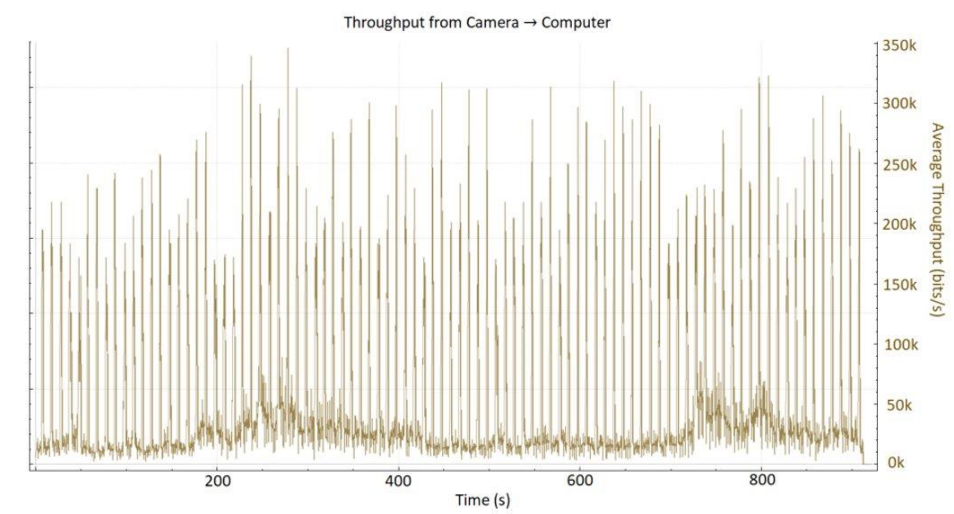


Fig. 10 Wireshark's TCP Graph on Average Throughput of Streaming Framework

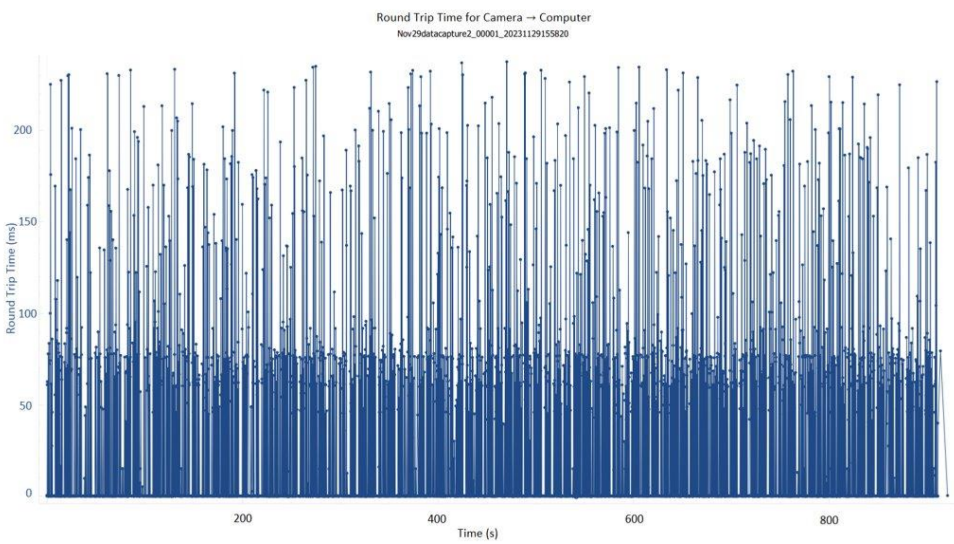


Fig. 11 Wireshark's TCP Graph on Round-Trip Time of Streaming Framework

6 Implementation

The current project in Unity is a combination of scripts, 3D materials, and other components such as a canvas and an event system to provide the viewer with the best user experience. In terms of scripts, we mostly focus on integrating the camera with proper 360° movement. This allows the user to use the headset to the full range of its capabilities. Similarly, we are utilizing the XR Plugin to handle head movement and interaction with each element. Once overlayed properly onto the existing 3D elements and canvas, each allows us to create an immersive experience with the project. There are buttons and a search bar which also serve the function of controlling the video, which at this point is local and not remote.

To implement the RTSP element, we use the VLC Unity plugin. Published by the VideoLAN organization, it is a robust tool that can show many types of stream types and other sources of input.

We have tested other plugins as well to try and find the best solution to stream the RTSP link provided by Dr. Hongwei and associates. This includes FfmpegWithOpenVCForUnity, LibVLCSharp, and the RTSP_Unity_Plugin. Each either lacked proper documentation, are severely out of date, or posed other issues that could not be properly addressed. As such, we worked with the VLC unity plugin as it provided the most up to date codebase, and the best built-in tools with example scenes for testing purposes. This, among other efforts to make an attractive UI design, served as the core focus for Unity development.

6.1 User Guide

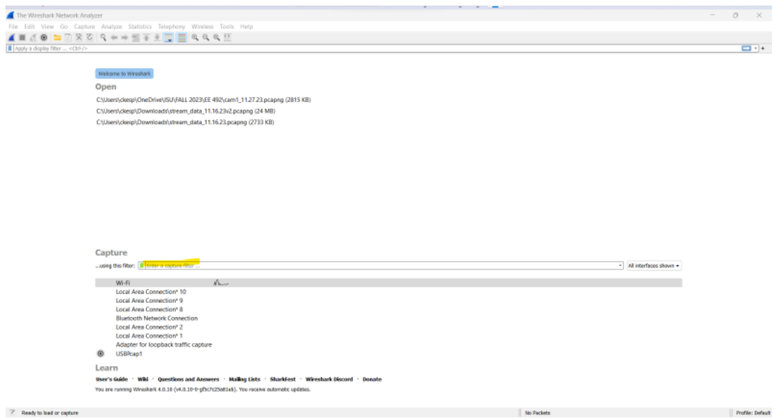
Unity:

1. Clone the repository into a folder for easy access, ensure that Unity is installed
2. Open project by opening into the appropriate location
3. Start the project with the Play Button in the middle of the Unity application screen
    a. Video may take a second to initialize
4. Manipulate the screen using your mouse or equivalent input directly on the video
5. Buttons
    a. Play Button: first button on the far left, click to play local video
    b. Pause Button: Click to pause the video
    c. Stop Button: Stops the video and must re-click the play button to restart the video
6. Search bar
    a. Copy local link to video into the search bar directly above the buttons, and click enter

Wireshark:

1. Install Wireshark from https://www.wireshark.org/

2. Open the software and enter “host [ip address of UE/camera/ARA network]” to filter out any communication between your device and the UE.



3. There are multiple features within Wireshark that allow the user to see different measurements on the network.
    a. Telephony >> RTP >> RTP Streams
        i. Provides information on percentage of packets lost, max jitter, and mean jitter
    b. Statistics >> Capture File Properties
        i. Provides information on packets per seconds (pps), average packet size (bandwidth), and average bytes per second (bps)
    c. Statistics >> TCP Stream Graphs
        i. Provides information on average throughput and round trip time (RTT)
    d. Statistics >> I/O Graphs
        i. Provides information on packets per second visually over time

OBS Studio:

1. Install OBS studio at https://obsproject.com/download
2. Select the “+” icon under sources to add a Media Source
3. Uncheck “Local File”
4. Check “Restart playback when source becomes active”
5. Input the RTSP or HLS stream link provided
6. Press “OK”
    a. It may take a few moments for the stream to be pulled into the viewer

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 and should be protected. Conflicts of interest should also be clearly communicated as the conflicts arise.
HEALTH, SAFETY, WELL-BEING	To hold paramount the safety, health, and welfare of the public. Treat all fairly.	The work done by engineers should keep the safety of the public and society as a top priority.
PROPERTY OWNERSHIP	To accept criticism, correct errors, and give credit to whom it is due.	Not taking credit for work done by others and accepting 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 endanger the environment and ensure that products are long lasting to minimize 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 did this well with the amount of general research we performed on 5G applications and XR technology.

Financial Responsibility: This is not so applicable to our project. Because of the expanse of the ARA project most pieces of technology are already available to us. However, we did provide research and recommendations on the type of headset to purchase and the desktop to run Unity applications.

Communication Honesty: The general information of our project is not sensitive, but we will take precautions before disseminating internal material and code. We don't anticipate possible areas of personal conflict, but if they arise, we will disclose that information.

Health, Safety, Well-being: We will ensure our application does not unintentionally jeopardize the safety of the public.

Property Ownership: We've made use of other people's work both within the ARA project and through opensource material and other pieces of software. We give the people responsible for this existing work credit for what they have done and do not claim it as our own.

Sustainability: If our work was incorporated into a larger agricultural or rural project it could have more consideration for sustainability. As it is, none of our practices pose a threat to the environment or have low product lifetime.

Social Responsibility: If our work was transitioned from a private research and development team to a marketable product, then there would be a responsibility to educate this market on how our technology works.

7.3 Most Applicable Professional Responsibility Area

Property Ownership is the most applicable area for our project. As mentioned above, our project is dependent on the previous work done by many other and it is important that this is acknowledged properly. In addition, most of the other areas would be areas of greater importance if our work was to be incorporated into another project, not for our project in it of itself.

8 Closing Material (Caleb)

8.1 Discussion

Our project had two main goals that we aimed to complete over the fall semester. These goals included an application that properly conveyed the benefits of 5G networks and data collection on the network regarding our application. The data collection should summarize the quality of service (QoS) and the quality of experience (QoE) for the application, while giving insight into network performance.

Using research and development done during the spring semester and summer, we were able to move forward on a VR application created using Unity, then determine and implement metrics and measurement techniques that were able to quantify the QoS and QoE for users of our VR application, and the network. The VR application had to make use of real-time streaming protocol (RTSP) stream, as this streaming protocol allows for transportation of live video and audio content.

RTSP is not widely used as it stands because the quality of streamed data is entirely dependent on the capability of the network the data is being transmitted over. The development of an application that can reliably present an RTSP stream, while maintaining good quality would give insight into the capabilities of the 5G 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 and Unity as a framework to facilitate communication between the video stream, VR headset and ARA network. With this groundwork in place, and the Meta Quest Pro chosen as our VR headset, we moved into phase two and focused on developing an application that took advantage of RTSP streaming and 360 video.

Over the summer, we spent time familiarizing ourselves with Unity application development and explored some of the potential obstacles we might come across. Staying in contact with the ARA team, we were able to set up the necessary equipment to avoid these obstacles, which let us immediately start the development of the application during the fall semester.

Through meetings with our advisor/client, it was decided that we should look to do some data collection for both the application and the network. From previously conducted research, and more research into the topic, we decided to investigate metrics that define the QoS and QoE. These metrics turned out to be SSIM index, throughput, and round-trip time (RTT). These metrics helped us characterize the performance of the 360 camera over the network, which translated to performance of our application for users. Collectively, we also decided to look for ways to collect data within Unity, either through built in components or open-source add-ons. We found some useful solutions for tracking data through a user and a project running off a server. Unfortunately, for the testing portion of our application where a local computer is running the application, they did not come into much use. We kept them in mind for the future.

The VR application development took a very significant amount of time, as our group members had little to no experience with Unity. However, the application development proceeded smoothly with many elements taken into consideration for UI design, performance, and accessibility. The application was also tested within Unity with a test 360 video loaded onto the device running the application. Moving onto the RTSP stream implementation, as mentioned earlier, RTSP streams are currently not widely used. We found some tools that could be added onto Unity that claimed to support RTSP streaming, but we found they did not. We began developing our own solution for RTSP streaming support within Unity. Unfortunately, there has not been any luck running our application with the RTSP stream. We are confident on the path towards a solution to this problem with the work we have done and are currently working on.

Overall, we are proud of the progress we have made so far and look forward to the future of this project. We believe that our research into 5G technology and the development of a VR headset application that can stream real time video and audio over 5G could have significant implications for the future of technology in rural communities, and our project is only the surface of what is possible with 5G systems. We all give our thanks to the ARA wireless team for providing this wonderful learning experience with these leading-edge systems and technology.

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 XR streaming application with RTSP support for 360 video along with collection of performance metrics from the video stream

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_______