Department of Electronic and Telecommunication Engineering
University of Moratuwa

Competitive Virtual Cycling Over 5G

Undergraduate graduation project feasibility report submitted in partial fulfillment
of the requirements for the
Degree of Bachelor of Science of Engineering
in
Department of Electronic and Telecommunication Engineering
University of Moratuwa

Supervisor: Prof. Dileeka Dias
Co-Supervisor: Dr. Kasun Hemachandra

Group members:
180639P - T.A.D.S. Thennakoon
180236D - H.A.D.G. Hettiarachchi
180288L - D.S.B.C.L. Jayaweera
180316A - U.W.R.A.L. Karunathilaka

16th December 2022

Abstract

Keywords: 5G Network, VR, Competitive Virtual cycling, SDR Implementation, Object Positioning, Unity Gaming Engine

Cycling has been a prominent field in searching for solutions for fitness issues. With the rapid development of technology, cycling has been moved into virtual platforms. In our project, we are targeting to develop a virtual cycling platform for two cyclists who are at different geographical locations to perform a competitive cycling experience. The purpose of the project is to encourage cyclists for virtual platforms with real-world experience to minimize risks in outdoor cycling. Furthermore, we are proposing the project to implement through a 5G network which is implemented using Software Defined Radio (SDR) to reduce the latency and high bandwidth issues. Each cyclist gets an oculus device to get the virtual experience while cycling in an indoor environment. Unity gaming engine would use to develop the gaming environment while the video playback will be done according to the cyclist's head orientation and speed. The paper describes about several algorithms that are useful in the implementation phase of the project and the pros and cons of target platforms and architectures.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

SDR	Software Defined Radio
URLLC	Ultra-Reliable Low Latency Communication
OAI	Open Air Interface
VR	Virtual Reality
HTTP	Hypertext Transfer Protocol
MPEG	Motion Picture Experts Group
MPEG-DASH	MPEG-Dynamic Adaptive Streaming over HTTP
HLS	HTTP Live Streaming
RTMP	Real Time Messaging Protocol
WebRTC	Web Real-Time Communications
VoIP	Voice Over Internet Protocol
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
MQTT	Message Queuing Telemetry Transport
CoAP	Constrained Application Protocol
BLE	Bluetooth Low Energy
AR	Augmented Reality
SDK	Software Development Kit
PCB	Printed Circuit Board

1. Introduction

This chapter will give you a brief description of the project. We hope to explain our project idea through the main problem statement we found and the main objective that we are going to propose. We are going to describe the major issues when we are cycling physically and how could give a better experience on virtual competitive cycling through our project scope. Furthermore, we would discuss the present virtual cycling platform providers and the difference between our idea with them in the novelty and uniqueness part. Finally, we'll look at some of the potential applications and user groups that could get advantages from our project.

1.1 Problem Statement

Health, fitness, and weight are becoming some major issues among people. As a solution to those issues, cycling has become very popular among almost all people without any age limit. However, outdoor cycling consists some problems related to safety and comfortable due to heavy traffic. Therefore, nowadays this has been moved into virtual platforms. At present this is done mostly for individuals using legacy networks like 4G. Not only that, we identified that there's a lack of platforms for virtual competitive cycling.

1.2 Main Objectives

We are looking for a solution that consists of time efficiency and high-energy workouts. The solution should be safer and more comfortable. As indoor cyclists, high-intensity interval training is a much more valuable thing. Therefore, our major objective is to give a competitive cycling experience to cyclists who are in different geographical locations with an immersive experience. Visualization of users' competition statistics and health details is another objective.

1.3 Project Scope

We hope to stream a 360-degree video in a 5G Core by undergoing fog architecture. The main thing is all the uplink and downlink communications are done through 5G. 5G is used to achieve low latency and high bandwidth requirements. Video is rendered according to cyclists' head orientation and speed. Based on the outputs of a gyroscope, the relative position between competitors is calculated. Those data will be used to show the competitor's avatar. MQTT is used to publish the sensor data. The user dashboard previews the data related to the competition such as how much distance traveled, recorded top speed, and competition statistics for the user-defined time periods. Another part of the dashboard is allocated for previewing the data related to health such as variation in heart rate, and calories burnt during a defined time period.

1.4 Novelty and Uniqueness of the project

Wahoo, Zwift, Rouvy and VZFIT are some current platform providers in virtual cycling. In Wahoo and Rouvy, they use a LED screen to show the video which is mounted in front of the cyclist. But Zwift and VZFIT provide VR(virtual reality) cycling experience. The platform provided by VZFIT does not only provide virtual cycling experience, but also indoor workout experience. All of these 4 platform providers introduced the competitive mode in their newest updates. But only Rouvy is using a Real-world video while all other 3 companies use artificial videos(Designed using a computer). One of our previous batches developed a project on virtual cycling. But they used a local server with WiFi technology. And also they did it for only one cyclist. **The novelty of our project** is we are going to combine all the above features in one platform. We hope to give a virtual competitive cycling experience with the immersive vision of a real-world video. The best thing is we are going to use 5G technology for all uplink and downlink communications.

1.5 Potential Applications

There are multiple user groups that could connect with the proposed platform. Mainly 360 video providers, game centers, fitness centers, and cyclists are the focused user groups. This would be a great opportunity for Sri Lanka because we can promote tourism as this would be a great opportunity to virtually travel all over the country. And also, this will be a new experience for our country because there are no such virtual competitive cycling platform providers in Sri Lanka.

2. Literature Review

This chapter contains a brief discussion of the main findings from the literature review. Mainly it's 5G network setup, video optimization techniques, network requirements, protocols that are used for communication, and 3d object positioning.

2.1 Review as per project

2.1.1 5G network

Why 5G?
As far as the network side is concerned, latency, bandwidth, and reliability of the network are the main challenges. We intend to address these challenges through the deployment of the 5G network since it provides the following key features.

Ultra-reliable low latency(URLLC)
URLLC is made possible through multiple advancements across the 5G standard and network architecture. URLLC supports use cases that require high network reliability and extremely low latency of approximately 1 millisecond for data transmission.

Network slicing
URLLC also relies on network slicing. It enables dynamic and efficient resource allocation and utilization among different services based on their requirements.

Available 5G standalone network options
Creating the 5G Core using OAI and connecting it with the SDR setup. [2] provides resources to deploy the 5G OAI Core.

2.1.2 Challenges in 360 video streaming

- High Bandwidth requirement and latency– Immersive experience provided by the VR application will be broken if a delay occurs or resolution drops. This can cause dizziness and motion sickness in the end user.
- Intensive computation power requirement – VR devices need high computational power since video processing should be completed in real-time.

The time from when the user moves their head, to the time when that change appears on the display is referred to as motion-to-photon latency (MTP). MTP of network VR applications should be under 300ms [1] , for VR applications to be more comfortable and immersive. If the latency is too high, users will perceive lag, or in the worst case get motion sickness. Biggest challenge in achieving this is the very short time available for stream the video frames from media server to the VR client device and render new frames after the processing.

2.1.3 Network requirements for 360 video streaming

The following table summarizes the minimum bandwidth and latency requirements for 360 video streaming.

Resolution	Equivalent TV resolution	Bandwidth	Latency (ms)
1K x 1K @visual field 2D_30fps_8bit_4K	240P	25 Mbps	40
2K x 2K @visual field 2D_30fps_8bit_8K	SD	100 Mbps	30
4K x 4K @visual field 2D_60fps_10bit_12K	HD	400 Mbps	20
8K x 8K @visual field 3D_120fps_12bit_24K	4K	2.35 Gbps	10

Table 2.1: Network requirements for VR applications

Perfect immersive experience can be obtained when high-resolution video content is used. But high bandwidth is required for high-resolution video content delivery.

2.1.4 Video optimization techniques [6]

There are a few video optimization techniques that are at the research level which can be used as a solution for high bandwidth requirements.

1. Dynamic Adaptive HTTP streaming [4] – This is a MPEG standard that provides the ability to stream video using adjustable bitrates. First, the video is split into short segments. Dash sever maintains multiple numbers of copies of each video segment with varying bitrates. Upon the HTTP request of the video player, it streams the video with dynamically varying bitrate and quality in response to the changes in bandwidth. Hence video player has the ability to switch between different quality levels during the video playback.
2. Tiling - In this method video is projected into 2D plane and split into numerous sections called tiles.
3. Viewport-based streaming [5] – In 360-degree video streaming, transmitting entire panoramic content to the user will be a waste of bandwidth. Because users only see the scenes in the viewport. This method has been incorporated with the above techniques. Hence transmission efficiency can be increased by identifying the current viewport and predicted viewport that corresponds to user head orientation. Then the tiles corresponding to the user's viewport are streamed in higher resolution and bitrate while the remaining part of the video frame is streamed in lower resolution.

2.1.5 Video Streaming Protocols

There are plenty of video communication protocols that can be used to stream video from a media server to VR device. HLS, RTMP, MPEG-DASH, WebRTC are some popular protocols. The following table provides a comparison between those protocols.

MPEG-DASH	HLS	RTMP	WebRTC
Uses HTTP servers	Uses HTTP servers	Relatively low latency	Widely used for web conferencing and VoIP
Provides Adaptive bitrate streaming	Provides Adaptive bitrate streaming	Widely supported by many devices	Provides Adaptive bitrate streaming
Open standard protocol	Relatively high latency. Low latency HLS is introduced as a solution	Compatible with H.264, MP4 and x264 video codecs	Compatible with H.264 VP8/9 video codecs.
Compatible with H.264, HEVC, VP9/10	Compatible with H.264 and HEVC video codecs		
Not compatible with apple devices			

Table 2.2: Comparison of different video streaming protocols

2.1.6 Sensor data Communication Protocols

The bicycle wheel speed and acceleration details should be sensitive to calculate the relative distance between cycles. Those data also must be shared between users to indicate the position of another competitor. MQTT, CoAP, and BLE are low-power communication protocols that use in constrained environments.

MQTT	CoAP	BLE
Based on publish subscribe architecture	Based on client server architecture	Cannot communicate over long distances
Connection oriented protocol. Hence end to end connection is maintained	Primarily, a one-to-one communication protocol for transferring information between client and server	Latency increases with distance
Many-to-many communication protocol for passing messages between multiple clients through a single broker	Uses UDP as transport protocol	Long standby time
Uses TCP as the transport protocol	Can communicate over long distance	
Can communicate over long distance		

Table 2.3: Comparison of different Sensor data communication protocols.

2.1.7 3D object positioning [3]

The task is related to Augmented Reality gaming as we get a recorded video feed and have to position a synthetic avatar. We can use a few gaming engines such as Unreal, Unity, and CryEngine to develop the game. We have chosen Unity Gaming Engine to achieve our task. We are selecting it because of the availability of lot of resources and AR development capabilities in latest Unity Engine. Real and virtual object identification, objects tracking, reaction on context changes and interoperability are the main functionalities of AR engines.
Usually, Augmented Reality engines are using Open Source Computer Vision Library (OpenCV). There are many Computer Vision capable AR SDKs for developing gaming environments such as Metaio, Vuforia, Wikitude, D' Fusion, ARToolKit, and ARmedia.
All the engines support 3D content. The concept of marker generation is helpful for 3D object positioning task. Vuforia and Wikitude have that marker generation feature but Metaio and ARmedia don't. Marker-based applications use a virtual avatar to position an object in given space. 3D content is placed within the user's field of view. Metaio, D'Fusion, and Vuforia can process just landscapes and 3D objects. Metaio, Vuforia, and Wikitude are available for free. We hope to get Vuforia SDK for our project.
We need AR glasses to show the video for the cycler. We need headsets that contain AR capabilities. Microsoft HoloLens, Google Glasses, Magic Leap One and Oculus Quest have AR glass capabilities. Oculus Quest supports Virtual Reality as well as Augmented Reality. We are using Oculus Quest.

2.1.8 Summary

According to the literature review, we identified possible approaches that can be applied in to our project. Furthermore, using the comparisons, we identified best technologies and protocols that are suitable for our application. MPEG-DASH and HLS are best video streaming protocols that can be used for video communication. MQTT protocol can be used as the data communication protocol between users. Vuforia SDK along with unity gaming engine can be used to develop the gaming environment for the VR devices.

3. Methodology

3.1 Proposed System Architecture

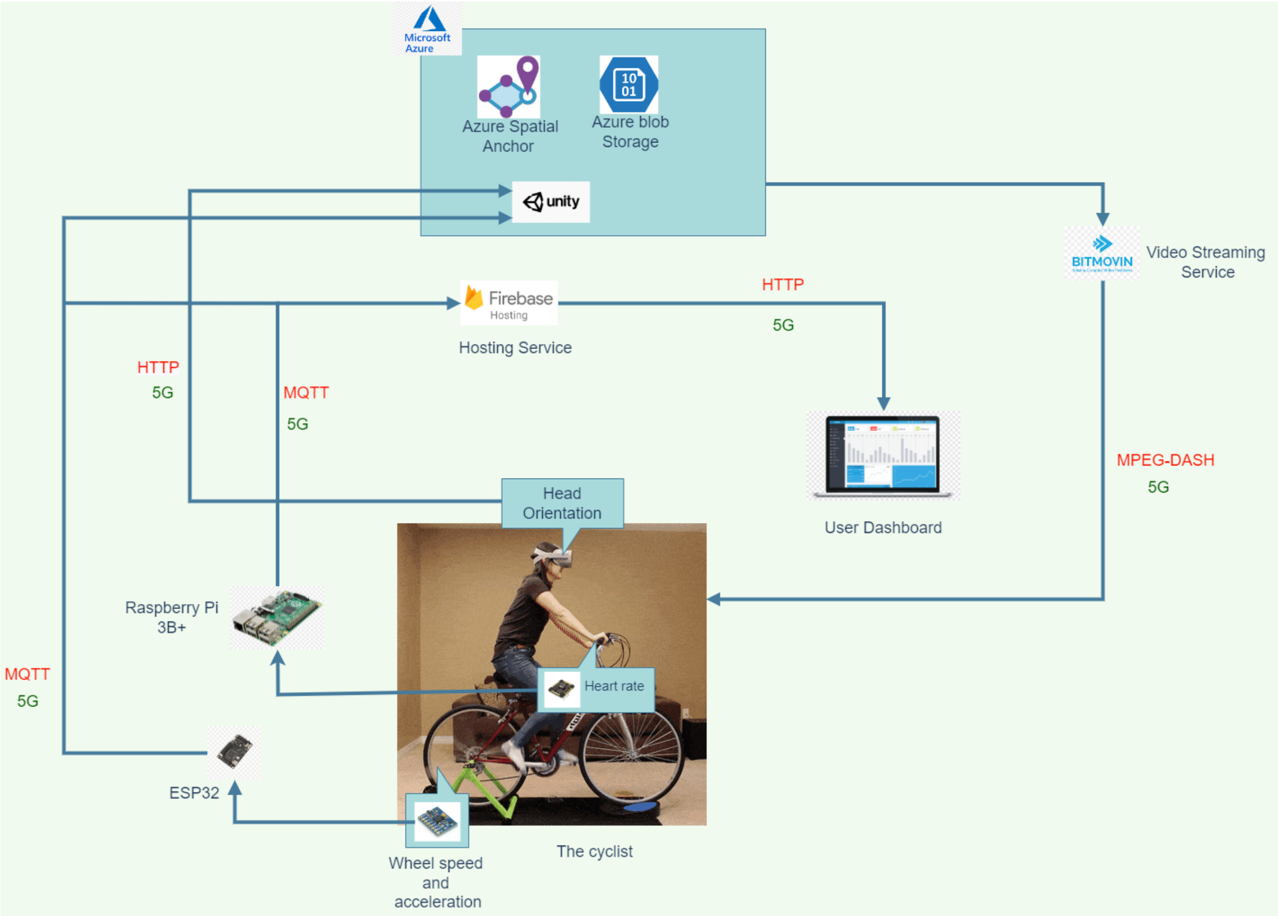

Figure 3.1: Proposed System Architecture

- MPU6050 sensor module, connected to ESP32 is used to measure wheel speed and acceleration. MAX30102 pulse oximeter and heart rate module are used to measure the user's heart rate.
- Speed data received at ESP32 will be sent to the mobile application, which is installed in a VR device, at another location through MQTT broker. This data will be used to calculate the relative distance between two users. Mobile application is developed using the unity gaming engine.
- Azure Blob storage is used to store videos. Azure spatial augmented reality SDK is used to object positioning and video processing. Then the rendered video is streamed to the VR device using the Bitmovin video streaming platform.
- User heart rate data received by Raspberry Pi and Speed data will be pushed to the Firebase database. Firebase web hosting services can be used to host the user dashboard which can provide details on user's real-time speed, distance traveled and amount of calories burnt during each session or user-defined time period.

3.2 Analysis of Alternatives

In the previously discussed method object, positioning, and video processing are done in the cloud platform. As an alternative method, this processing task can be moved towards the user which reduces the latency considerably. We have identified two system architectures that can be applied to this project.

1. Stream the video from local media server
2. Stream the video from a fog node that is implemented in core network

The following figures depict those two system architectures.

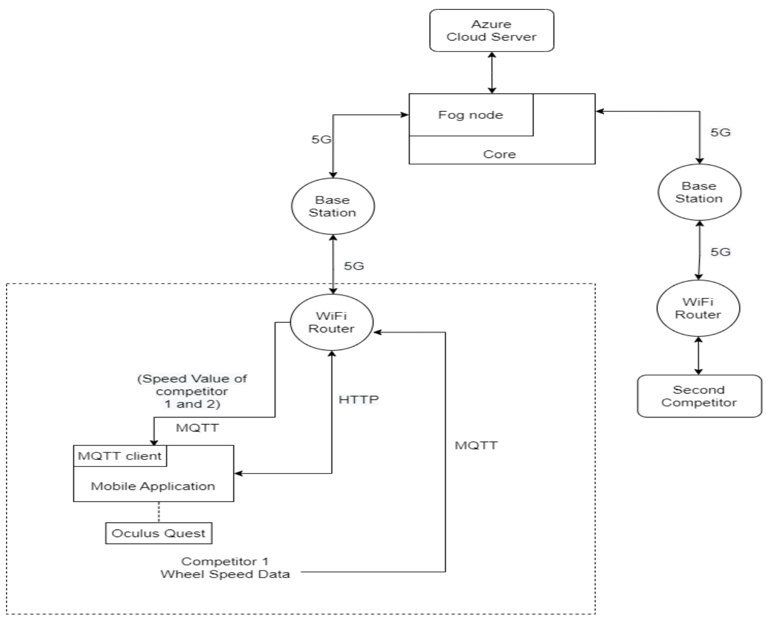

Figure 3.2: Video streaming from the Fog node implemented in core

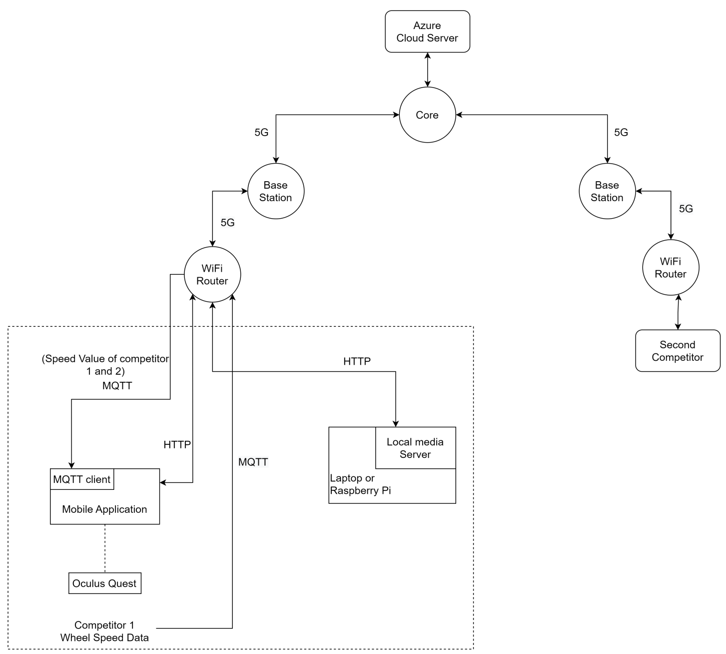

Figure 3.3: Video streaming from local media server

In both cases, videos are initially stored in Cloud storage. Upon the request of the user, videos are first downloaded into the fog node and local media server in each architecture. When the user selects a particular video through the application the request is passed to the local media server. If the video does not exist in the local media server then the video will be downloaded into the local media server. After the completion of downloading the video, the user can start cycling. The same mechanism can be implemented in the core network. The following table discusses advantages and disadvantages of each architecture.

System Architecture	Local media server	Fog node implemented in the core	Cloud server
Description	The user has to select and download a video from the cloud storage to the local media server according to their preference. Then the video will be streamed to the oculus. Processing and rendering happen in the oculus.	The user has to select and download a video from the cloud storage to the fog node according to their preference Then the video will be streamed to the oculus. Processing and rendering happen in the oculus.	Videos are stored in the cloud server. Both video processing and rendering happen there. Then the video will be streamed to the oculus.
Latency	Low	Medium	High
Sharing the media server among other users	Can be shared between users in the same LAN	Since videos are stored inside the core, videos can be shared between users that are connected to the same network core	Any user regardless of the connected network
The required processing power of the edge device	High	High	Low
Cost	Medium	Low	High

Table 3.1: Comparison between different system architectures

3.3 Risks and Risk Management Plan

3.3.1 Financial Risks

We identified three main social and financial risks in the project implementation. The first one is lack of awareness about virtual reality among people. In a country like Sri Lanka, most of the people are not aware about virtual platforms for cycling. We have to encourage them for the new technology with this platform. High cost for the product is another risk in the project. The clients have to buy a VR and speed measuring devices. Furthermore, limited customer base is another risk because of the lack of awareness and lack of resource availability(5G core and other physical equipment).

3.3.2 Technical Risks

Technically, there could be two major risks in project implementation. Mainly latency and the bandwidth issues would challenges in project implementation. We are supposing SDR implementation for the 5G core to minimize those issues. Motion sickness is another problem which would be affected by those latency and bandwidth issues.

3.4 The Budget

Item	No: of Units	Cost per Unit(Rs)	Total cost (Rs)	Availability
VR Head-set(Oculus)	2	Rs.172,500	345,000	One is available
Bicycle	2	40,000	80,000	Available
Sensors (2 MPU6050 modules and 2 MAX30110 modules)	4	1000	4000	Available
Raspberry pi	2	18,000	36,000	Available
ESP 32	2	1550	3100	Available

Service	Monthly charge	No: of Months	Total cost(Rs)	Availability
Azure Cloud services	18000	6	18,000	To be purchased

Total = Rs.486,100

Table 3.2: Approximate budget for hardware and software resources

3.5 Task Delegation

Task	Dilun	Dulsara	Aruna	Lakshan
Feasibility study	×	×	×	×
Literature review	×	×	×	×
5G environment setup		×	×	
Video rendering and streaming		×	×	
3D positioning and Gaming engine	×			×
Web Dashboard	×			×
PCB Designing study	×			×
Solidworks Design		×	×	
Prototyping and Demonstration	×	×	×	×
Working on a publication	×	×	×	×
Documentation	×	×	×	×

Table 3.3: Task delegation

3.6 Time line

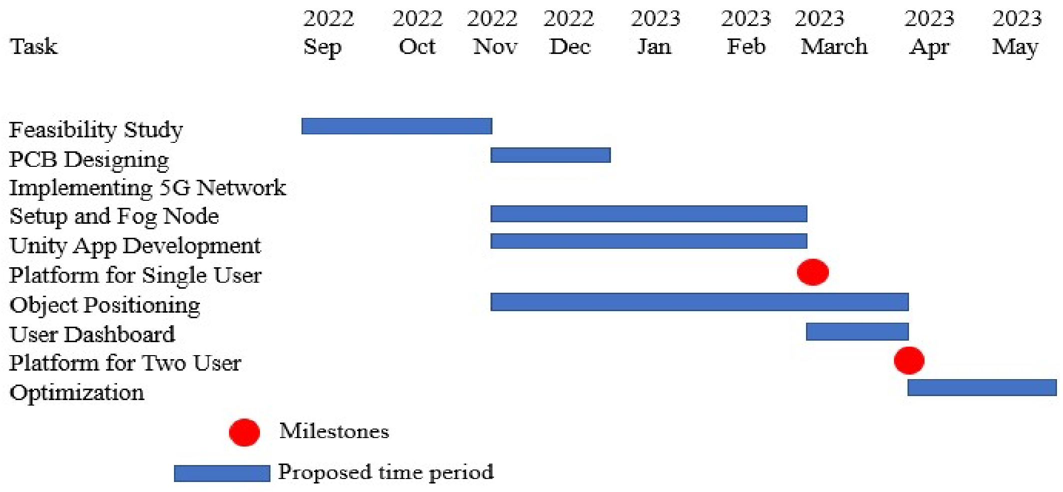

Figure 3.4: Project Time line

4. Discussion and Conclusions

This chapter includes a briefing on the findings of our literature review, the feasibility of the project, and the impact of this project both locally and globally. Finally, a conclusion is given with regard to what we are planning to do.

4.1 Main Findings of the Literature Review

According to the literature review, we identified possible approaches that can be applied in to our project. Furthermore, using the comparisons, we identified best technologies and protocols that are suitable for our application.

Our main finding was delay that can be occur during video streaming. Our first aim was to develop the project using cloud technology. All the video storing, streaming, and processing parts were supposed to do in a cloud. But after the feasibility presentations, we got the idea that if we do all of those in a cloud environment, there would be huge latency, and also it would increase the project scope. So we discussed and came up with new two architectures and then discussed their pros and cons of them. Finally, we decided to go with both fog architecture and local server architecture. Finally, a performance evaluation would be done for both architectures.

4.2 Feasibility

4.2.1 Technical Feasibility

We could successfully find many research ideas through literature reviews and the feedback from the feasibility presentation that are applicable to our development. Therefore, it is technically feasible to proceed with our project. We plan to implement the 5G network using the OAI Core, SDR device, and 5G modems. We hope to use some software packages for the development of our project. Unity gaming engine will be used for developing an android app that can take inputs of a video stream and sensor data. We plan to use the student version of Altium Designer for designing the PCB, and department workshop facilities for assembling the PCB. Additionally, we are very well supervised by Prof. Dileeka Dias and co-supervised by Dr. Kasun Hemachandra to successfully achieve our project completion. We have resource persons from the Dialog lab staff of the University of Moratuwa. As they are familiarized with some projects related to 5G we can get their assistance in our project.

4.2.2 Financial Feasibility

Despite the fact that a large budget was mentioned for our project, we have one Oculus device which was given by Prof. Dileeka Dias, and SDR device with two 5G modems which can be taken by the Dialog lab of the Department of Electronics and Telecommunications Engineering. Furthermore, we can find two bicycles with trainers, the necessary PCB equipments, and enclosure equipments without spending a huge amount of money. So, it is financially feasible to proceed with our project.

4.2.3 Social Feasibility

Since our project was pitched with the aim of introducing a user-friendly way of cycling, our main concern is our impact on society. The growing number of accidents and lack of comfortable in outdoor cycling is a burning social issue that is hoped to be addressed by this project. We hope to come up with an effective solution that is capable of giving a virtual competitive cycling experience.

4.3 Impact of the Project

4.3.1 Local Impact

In a country like Sri Lanka, outdoor cycling consists of some difficulties regarding safety and comfort. We guarantee the comfortable with a real-world experience through our idea. Cyclists can get a 360 view when cycling without any disturbance and risk. Furthermore, we are hoping to add a feature to measure health statistics in a web dashboard. This will be a good sign for not only cyclists but also people who are concerned about their fitness without any age limit to uplift their physical health through this implementation.

4.3.2 Global Impact

All the impacts discussed under Local Impacts can be applied globally as well. World-famous virtual cycling platform providers like VZFIT, ZWIFT, Rouvy, and Wahoo are also doing research regarding virtual competitive cycling for their upcoming products. We hope our project idea will definitely influence the global community to do more and more research around this scope. Additionally, we are planning to make a publication regarding our achievements through this project in a well-known journal. It will helpful for the improvement of virtual cycling via 5G.

4.4 Conclusions

Indoor cycling is getting improved day by day due to the risks of outdoor cycling. These indoor virtual platforms are much more comfortable compared with outdoor cycling. Current platform providers provide their service under three main implementations. They are virtual environments, competing with others and video-type if it is artificial or real. But the problem is none of them developed a platform to use the above first two things in one platform with a real-world video. Therefore we came up with this project idea to give a competitive cycling experience in a virtual environment that is much the same as the real world. This would be a good opportunity for Sri Lankans for a new experience as there are no such virtual cycling platform providers in Sri Lanka right now. As well, this can be used as a virtual platform for tourists who can't afford much time and money in a foreign country but are willing to get the whole experience in the touring country. This project could be further developed to use in fitness centers and 360 video platform providers. Therefore this project idea will be a massive development in virtual reality with cycling in a competitive manner in both local and global use cases.

References

[1] URL: https://www.huawei.com/minisite/pdf/ilab/cloud_vr_network_solution_white_paper_en.pdf.

[2] $Docs/DEPLOY_HOME.MDmasteroai/CN5G/OAI-CN5G-fedGITLAB$. URL: https://gitlab.eurecom.fr/oai/cn5g/oai-cn5g-fed/-/blob/master/docs/DEPLOY_HOME.md.

[3] Egils Ginters. 'Augmented reality use for Cycling Quality Improvement'. In: *Procedia Computer Science* 149 (2019), pp. 167–176. DOI: 10.1016/j.procs.2019.01.120.

[4] Ali Gohar and Sanghwan Lee. 'Multipath dynamic adaptive streaming over HTTP USING SCALABLE VIDEO CODING IN software defined networking'. In: *Applied Sciences* 10.21 (2020), p. 7691. DOI: 10.3390/app10217691.

[5] Feng Qian et al. 'Flare'. In: *Proceedings of the 24th Annual International Conference on Mobile Computing and Networking* (2018). DOI: 10.1145/3241539.3241565.

[6] En Sing Wong et al. '360-degree video bandwidth reduction: Technique and approaches Comprehensive Review'. In: *Applied Sciences* 12.15 (2022), p. 7581. DOI: 10.3390/app12157581.