5G Networked Drone

Sponsored by UM-SJTU Joint Institute

Design Review 1

YANJUN CHEN, Student, UM-SJTU JI, *markchen_yyjs@sjtu.edu.cn*

XIANGYU SHI, Student, UM-SJTU JI, *gargantua@sjtu.edu.cn*

YE WEI, Student, UM-SJTU JI, *wei_ye@sjtu.edu.cn*

YICHI ZHANG, Student, UM-SJTU JI, *zhangyichi2017@sjtu.edu.cn*

YIFENG KUAI, Student, UM-SJTU JI, *kuaiyifeng0502@sjtu.edu.cn*

JIANRONG XIAO, Mentor, UM-SJTU JI

CHONG HAN, Instructor, UM-SJTU JI

Figure 1: DJI M600 drone [4]

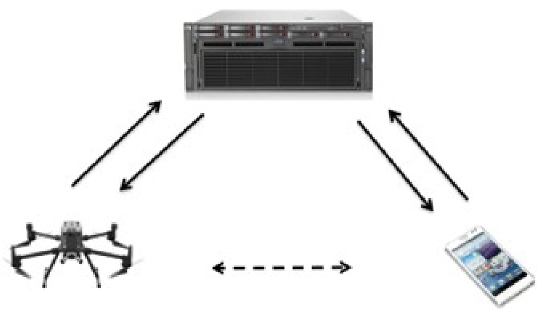


Figure 2: Our Primal Design of the Network System [4]

Contents

1 Abstract

With the popularization of individual drones, drone hobbyists have easier access to drone products from companies like DJI. The development of 5G mobile network provides possibility to supervise drone's performance distantly. In this report, we propose our design of a 5G Networked Drone and other contents regarding the Design Review 1. Our project is expected to use 5G network to realize a direct connection between a mobile App and the drone, without the help of a remote controller. Compared with benchmarks such as DJI MAVIC 2, our 5G networked drone is expected be elegantly controlled in a longer distance and have efficient information transmission. Also, we perform a Quality Function Deployment (QFD) process to evaluate the engineering requirements. Our group members are divided into an App development group and an on-board development group. A Gantt Chart is provided to illustrate the plans and milestones. According to the scope of our project, we will make a mobile App, a server for relay transmission, and a Linux program in the on-board environment to realize the 5G communication passway.

Keywords: 5G network, drones, mobile App development, Linux system, server

2 Introduction

In recent years, drones have been more and more popular, both in commercial use and individual use. It can function as patrolling, mapping, irrigating, and etc. However, the current drone communication system faces a multitude of problems. Current drones transmit the control signal and the video from on-board cameras by the point-to-point Radio Frequency (RF) communication. A remote controller is always required to transmit control signals, even if a mobile App is applied. The main drawback is that for most drones, the distance between the drones and the controllers is limited within 5 kilometers. As a result, many specific tasks which need a more distant control are impossible to complete. Another issue is that it will be very difficult for supervision, where all drones are connected to wireless LAN. Severe safety issues may be caused using drones without effective supervision.

However, if drones are able to be connected to the mobile network, such as 4G-LTE or the new generation 5G network, the above limitations can be eliminated. The advantage is that since the drone is connected to the mobile network, it can be controlled from anywhere, using a mobile App. Moreover, the transmission bit-rate will be improved to a great extent, due to the high performance of 5G technology. By connecting all the drones into the mobile network, it will also be easier for the government to supervise, in case something terrible will occur.

We, therefore, aim to build a 5G-connected drone network. In our design, users can control the drones through an APP on the cellphone. Through the network, the app will upload the control signals onto a server. Since the drone is also connected into network, the control signals will be downloaded by the drone from the server. In the meantime, the information collected by the drone can be sent back to the user through the server as well. The system ensures the advantages of remote control and high speed of transmission. With the realization of 5G-connected drone, many scenarios will be made possible, such as package delivery and remote travelling.

3 Background Information

3.1 Drones under 4G Network

There are some existing researches about drones controlled by 4G-LTE or 5G network. When 4G network is used to control the drone, there are some distinct drawbacks, such as unstable delay and relatively low data transmission speed [1]. Below are some statistics in the research paper.

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Delay(ms)	96	48	15	382	24	24	60	47	93	30	77	102	NA	48	30

Figure 3: Time Delay under 4G Network in [1]

The second row is the time delay of the command transferred from the controller to the drone in microsecond. There are two relatively high delay, which are 382 ms and 102 ms. There is also a packet loss. This could be critical because packet loss may lead to the loss of control of the drone, which possibly causes damage to either the drone or people.

TD-LTE video transfer group	Number of frames sent	Transmission bit rate (KB/S)	Time cost by transfer (s)	Packet loss rate (%)
1	1000	265.71	85	0~1
2	1000	256.56	87	0~1
3	1000	232.62	84	0~1
4	1000	256.73	90	0~1
5	1000	231.44	87	0~1
6	1000	227.13	88	0~1
7	1000	263.21	85	0~1
8	1000	228.30	86	0~1
9	1000	231.88	88	0~1
10	1000	243.47	84	0~1

Figure 4: Data Transfer of 640*480p Video Speed under 4G Network in [1]

4G network can satisfy the transfer requirement of 640*480p video quite well, however, when high-resolution video is needed, 4G network is unable to satisfy the requirement.

3.2 Drones under 5G Network

There also exist some researches about drones under 5G network. For example, researchers use Raspberry Pi as the embedded platform and Pixhawk as the flight control to implement their design [2].This implementation allows video to be transmitted to multiple users. Problem are pointed out that the transmission range of 5G signal is not as far as 4G signal, which makes the researchers adopt a hybrid networking plan.

3.3 Benchmarks

From what is discussed above, some essential benchmarks can be concluded. First of all, delay and speed of data transfer under 5G network are the most important features needed to be focused. Second, the time ratio that the drone uses to transfer data through 5G network is also worth considering, because it affects what resolution of the video should be adopted. Also, compared to the long distance from the drone to the remote controller linked by RF signal, the distance, or the height from the drone to the 5G base station should also be considered.

Below are some benchmarks from research papers.

Experiment	Link	Mean throughput	5G mean throughput	Time in 5G
Liftoff	Downlink	345 Mbit/s	387 Mbit/s	67%
	Uplink	44 Mbit/s	39 Mbit/s	96%
Horizontal flight at 30 m	Downlink	388 Mbit/s	618 Mbit/s	57%
	Uplink	46 Mbit/s	46 Mbit/s	100%
Horizontal flight at 100 m	Downlink	354 Mbit/s	644 Mbit/s	53%
	Uplink	47 Mbit/s	42 Mbit/s	66%

Figure 5: Performance of 5G-Base-Station-Connected Drone in [3]

This research includes height of drone, speed of data transfer, and time ratio of data transfer using 5G network [3].

Specifications	Max Transmission Distance	Live View Quality	Max Transmission Bitrate	Latency	Way to control
Values	6 km	720p@30fps/ 1080p@30fps	40 Mbps	120-130 ms	Remote controller

Figure 6: Performance of DJI Mavic Air 2 [5]

This is on the official site of DJI. This type of drone is controlled with RF signal, and it shows benchmarking statistics such as distance, video resolution, data transfer speed and delay.

4 Engineering Specifications

4.1 Target Customers

We define our target customers as three main different groups:

1. Drone hobbyists
2. Professional Drone Photographers
3. Delivery businesses

4.2 Customer Requirements

A network with customer terminals, a server for processing instructions and data, and drone terminals is expected. In terms of functionalities, it should meet the following customer requirements:

4.2.1 Qualitative Requirements

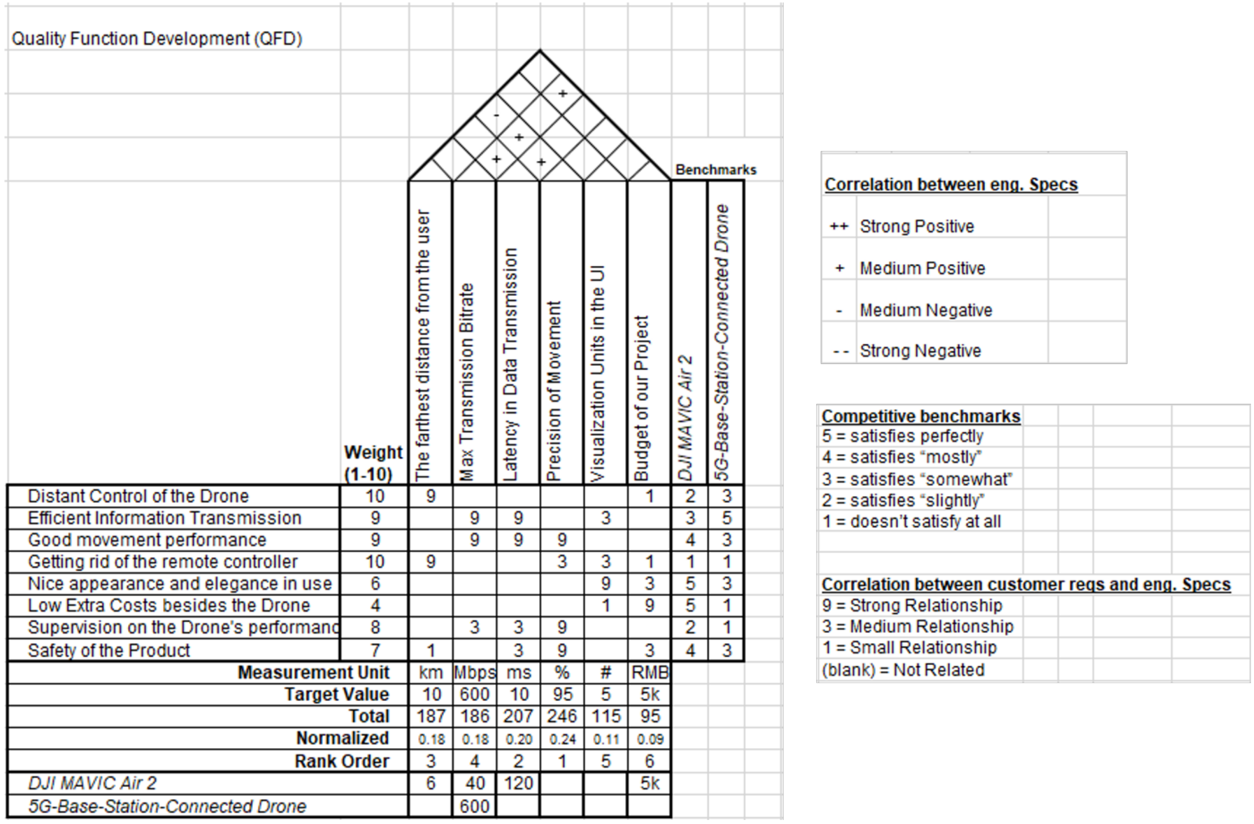
1. Distant Control of the Drone
2. Efficient Information Transmission
3. Getting Rid of the Remote Controller
4. Good Movement Performance
5. Nice Appearance and Elegance in Use
6. Low Extra Costs Besides the Drone
7. Supervision on the Drone's Performance
8. Safety of the Product

4.2.2 Specific Quantified Requirements

The above qualitative customer requirements can be translated into more specific engineering targets by the following process:

1. The distant control can be shown simply by the farthest distance from the customer terminal that the drone can travel in our experiments.
2. The efficiency of data transmission itself is not a single statistical measurement, it actually includes several aspects: upload bit rate, download bit rate and latency.
3. Companies like DJI have already provide fantastic control of drones by the remote controller. To confirm our potential customers to accept our design, our product should achieve competitive performance as those using a remote controller. This requires the drone to have very precise movement, and fast data transmission as mentioned.
4. For the drone to have good movement performance, we must ensure high transmission rate and low latency. Also, we can measure the movement performance in percentage of precision through experiments.
5. Our design should achieve its elegance by having a nice-looking user interface, which largely depends on the number of visualization displaying units.
6. As the drone itself already cost a lot of money, our customers may not want to spend more extra money besides the drone. Then we have to lower the cost in RMB of our design.
7. Once the drone is connected to our network, we can have supervision on the drone's location, speed, battery level etc. through the user interface. It highly depends on the data transmission rate.
8. The safety of the product is closely related to the data transmission and how good our user interface is in conducting real-time information of the drone.

4.3 Quality Function Deployment (QFD)



Quality Function Development (QFD)

	Weight (1-10)	The farthest distance from the user	Max Transmission Bitrate	Latency in Data Transmission	Precision of Movement	Visualization Units in the UI	Budget of our Project	Benchmarks: DJI MAVIC Air 2	Benchmarks: 5G-Base-Station-Connected Drone
Distant Control of the Drone	10	9					1	2	3
Efficient Information Transmission	9		9	9		3		3	5
Good movement performance	9		9	9	9			4	3
Getting rid of the remote controller	10	9			3	3	1	1	1
Nice appearance and elegance in use	6					9	3	5	3
Low Extra Costs besides the Drone	4					1	9	5	1
Supervision on the Drone's performanc	8		3	3	9			2	1
Safety of the Product	7	1		3	9		3	4	3
Measurement Unit		km	Mbps	ms	%	#	RMB		
Target Value		10	600	10	95	5	5k		
Total		187	186	207	246	115	95		
Normalized		0.18	0.18	0.20	0.24	0.11	0.09		
Rank Order		3	4	2	1	5	6		
DJI MAVIC Air 2		6	40	120			5k		
5G-Base-Station-Connected Drone			600						

Correlation between eng. Specs	
++	Strong Positive
+	Medium Positive
-	Medium Negative
- -	Strong Negative

Competitive benchmarks
5 = satisfies perfectly
4 = satisfies "mostly"
3 = satisfies "somewhat"
2 = satisfies "slightly"
1 = doesn't satisfy at all

Correlation between customer reqs and eng. Specs
9 = Strong Relationship
3 = Medium Relationship
1 = Small Relationship
(blank) = Not Related

Figure 7: QFD Table of Our Project

Based on our analysis on customer requirements and specific quantified requirements, along with our benchmarks, we create the QFD chart above. We consider "Distant Control of the Drone" and "Getting Rid of the Remote Controller" as the two most important customer requirements our design should meet. Also, we consider "Efficient Information Transmission" and "Good Movement Performance" as significant as well. A weight from 1 to 10 is assigned to each customer requirement, with 10 representing the highest demand and 1 representing the lowest.

On the top of the table are the quantitative engineering specifications obtained from the analysis of customer requirements. The correlations between customer requirements and engineering specification are score by 1, 3 or 9, with 9 representing strongly correlated, 1 representing weakly correlated, and 3 in between. A blank means the corresponding requirement has 0 correlation with the engineering specification. The correlations between the engineering specifications themselves are demonstrated by "++","+","-","–", from most positive to most negative.

After all the values above are settled, a total weighted sum of correlation score between customer requirements and engineering specifications is calculated for the corresponding engineering specification. Then we normalized the sum to give a rank order of the engineering specifications to show their order of importance.

Information of the benchmarks are also included in the table. A score from 1-5 is assigned to each benchmark to show how well they meet the customer requirements. Their performance on our engineering specifications are listed at the bottom of the table.

4.4 Engineering Specifications

Engineering Specifications	Unit	Target Value
The Farthest Distance from the User	km	>10
Max Transmission Bitrate	Mbps	>600
Latency in Data Transmission	ms	<10
Precision of Movement	%	>95
Visualization Units in the User Interface	#	>=5
Budget of Our Project	RMB	<5000

Table 1: Engineering Specifications and Target Values

5 Project Plan

We provide a Gantt Chart for our project. Now we are working on step 2&3.
We choose Design Reviews and Expo to be our milestones. Since all design reviews and Expo are very important, there is no difference in priority between them and we will work hard to do them well. Also, we try to divide each team member's work load equally, since we need to finish most of the steps by all group members. Generally speaking, the workload for on board development will be larger than app development since we need to learn more things about 5G and DJI SDK. As a result, we have 3 members work on on board development and 2 members work on the other.

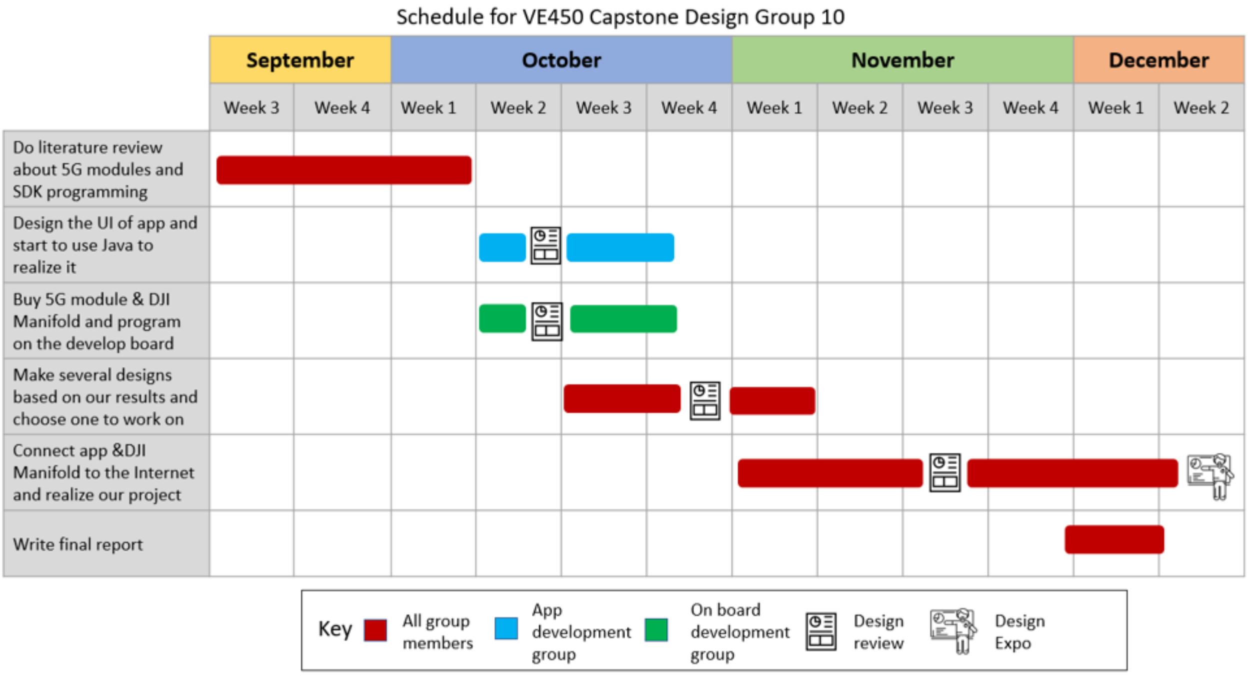


Figure 8: Gantt Chart of Our Project

The budget of our project is also shown as follow. Hopefully we will spend 2,400 RMB in total.

Name	Price
5G Module & Development board	1,800 RMB
Portable Wi-Fi	300 RMB
5G Antenna	300 RMB
DJI Manifold	*provided by the sponsor*
DJI Drone	*provided by the sponsor*
Total	2400 RMB

Figure 9: Budget of Our Project

6 Conclusions

Generally speaking, our work in Design Review 1 can be divided into four parts.
First, we define the goal of our project. We need to make a mobile App, a server and a program in an on board environment so that we can realize the 5G communication between the drone and mobile phone.
Then, we choose two benchmarks: A 5G-Base-Station-Connected Drone and DJI MAVIC Air 2. By comparing with the two benchmarks, we can find whether we do good or not in this project.
Also, we translated the customer requirements into Engineering Specifications to make the Quality Function Deployment.
Finally, we show our Gantt Chart for the project and the tentative budget.

References

[1] S. Zhou, “Design and implementation of 4G network UAV Control”, Chongqing University of Posts and Telecommunications, V249.1;V279, pp. 56-76, 2019.

[2] X. Chen, L. Cheng, J. Wang et al., “UAV information transmission based on 5g network”, Electronic Technology, 2020(18):10-11+5.

[3] R. Muzaffar, C. Raffelsberger, A. Fakhreddine, J. L. Luque, D. Emini, and C. Bettstetter, “First experiments with a 5G-Connected drone,” Association for Computing Machinery, Vol 7, pp. 1-5, 2020.

[4] SZ DJI Technology Co.,Ltd., ”Matices M600 Pro”. [Online]. Available: `https://www.dji.com/cn/matrice600-pro?site=brandsite&from=nav`.

[5] SZ DJI Technology Co.,Ltd., ”Mavic Air 2 User Manual v1.2 cn0”. [Online]. Available: `https://dl.djicdn.com/downloads/Mavic_Air_2/20200615/Mavic_Air_2_User_Manual_v1.2_cn0.pdf`.

Biography

Yanjun Chen

I am Yanjun Chen, a senior student of UM-SJTU Joint Institute major in Electrical and Computer Engineering, and minor in Data Science. I am currently a research assistant in Data Communication and Engineering Lab, SEIEE, SJTU. My research interest includes Mobile Crowdsourcing and Vehicle Routing Problems. I plan to pursue a master's degree in Computer Science after graduation.

Xiangyu Shi

I am Xiangyu Shi, a senior student in UM-SJTU Joint Institute majoring in ECE. My work in this project is using DJI mobile SDK and Android Studio to realize the control of the drone on the mobile terminal. I am expected to begin my master program of Low-carbon Environmental Engineering at SJTU in 2021 fall.

Ye Wei

My name is Wei Ye and I am a senior student of UM-SJTU Joint Institute major in ECE. In this project, I work as a member of the on board development group. I am currently work in the Advanced Network Laboratory as a research assistant and my research interest is about the route planning and task assigning problem occured in mobile crowdsourcing. I plan to pursue a master's degree in Computer Science after graduation.

Yichi Zhang

I am Yichi Zhang, a senior student of UM-SJTU Joint Institute major in Electrical and Computer Engineering and minor in Data Science. I am interested in data processing and algorithms about machine learning. I plan to pursue a master degree in Computer Science to further my study.

Yifeng Kuai

My name is Yifeng Kuai, a senior student of UM-SJTU Joint Institute majoring in Electrical and Computer Engineering. I work as a member of on board development group. My interest and course selection is in circuit design. I plan to pursue a master degree in Integrated Circuit to further after graduation.