Experiment Design and Analysis of a Mobile Aerial Wireless Mesh Network for Emergencies

Abstract

The development in the field of Unmanned Aerial Vehicle (UAV) allows scientists and hobbyist to develop new applications to use this new emerging technology for civil use. In this paper, we design an experiment to deploy a wireless mesh network in the sky using UAV technology, we study the factors that could affect the performance of the network and we measure each factor effect on the performance to determine the best option of altitude and antenna type to increase the throughput.

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1. Introduction

Aerial wireless mesh is a developing technology in the field of information technology. To prepare for developments in this field we developed an experiment to gauge the efficacy of wireless solutions. These emerging technologies require the investigation of factors such as signal power, transmission schemes, reception, and throughput. One issue that arises with this experiment concerns the altitude of the UAV and choice of antenna types. Particularly, in our investigation we only have control of the transmission system and the altitude of the areal tower. In this paper, we characterize the efficiently of both Omni-directional and Directionally based antennas. With regard to throughput, as these devices may become subject to wind phenomenon such as crosswind, altitude irregularities, and signal absorption, it is important to understand how these influences may affect the performance of the network topology.

2. Experiment Design

We designed the experiment to analyze and measure the throughput (downlink, uplink) in a mobile, dynamic aerial wireless mesh network between two end-points, identify the factors affecting the network throughput and create a proof of concept for the feasibility of aerial wireless networks in emergency situations. In this section, we define the experiment components and the experiment topology.

2.1. Experiment Components

Hardware and software components used in the experiment listed below:

- UAV selection

As we developed our design requirements, we went through several design alternatives to endeavor to develop solutions that can implement immediately in real-world scenarios. Our initial choice was the simple weather balloon for a proof of concept. We observed that some of the difficulties with this implementation were lack of directional control, helium costs, and proper equipment housing. While this implementation had a longer aerial time, the benefits were too asymmetric to adopt. In contrast, we selected the DJI Phantom 2 unmanned aerial vehicle (UAV) [2]. This was an optimal choice for our experiment, as it possesses capabilities such as built-in GPS, wind shear & stable hovering and powerful motors capable of successfully handling our equipment loads.

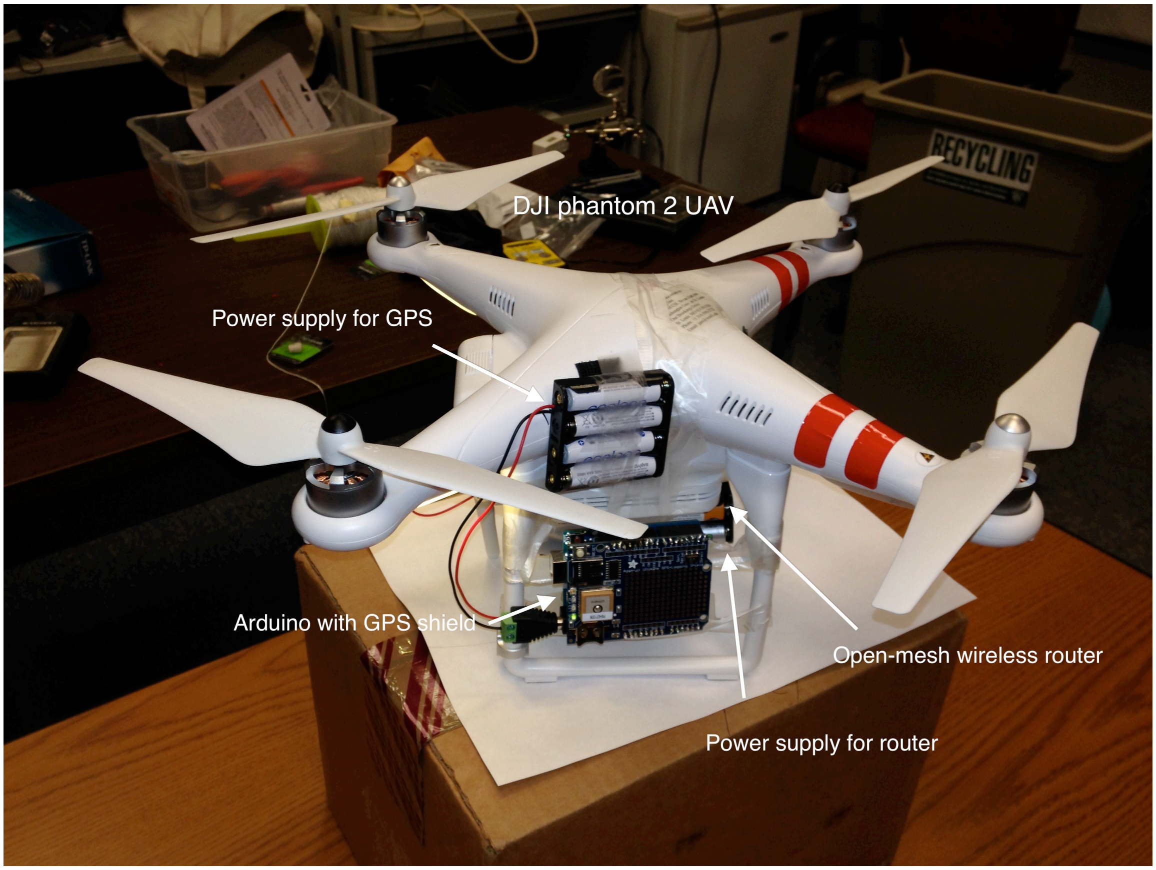

Figure 1: DJI Phantom 2

- Mesh Node

For the selection of the mesh nodes, we decided to go with the standard open-mesh solution already adopted in the field. Our open mesh router is an OM2P mesh node with client connectivity of 802.11 g/n running at 150Mbps with an external Omni-Directional antenna Access Point [3].

- VoIP Server

For the VoIP server, we choose the Asterisk framework which can turns any Linux computer into a telephony switch and provides a private branch exchange service (PBX). Asterisk is an open-source framework and commonly used in the industry [4]. The open-source nature of the framework allows this technology to develop and maintain relevancy in dynamic network topologies.

2.2. Experiment Topology

Our setup consisted of one ground based gateway mesh node connected through a dedicated backbone Ethernet connection to the VoIP server. In the air, we have two aerial mesh nodes (mounted on the UAVs) that provide services to cellular clients spread across some distance. The clients initiate a call by connecting to the mesh node that verifies the cellular credentials by brokering a connection and negotiation with the VoIP server. We have decided to use two mesh nodes to simulate a real world scenario. In an event of an emergency, a response team will setup a base station and release the UAVs to the target area for optimal coverage. The clients will be able to connect to each other and emergency service. This will also allow emergency response teams to use the cellular connection to triangulate the location of the citizens in need within the broadcast radius of the UAV or from the GPS coordinates. Figure 2 shows the experiment topology.

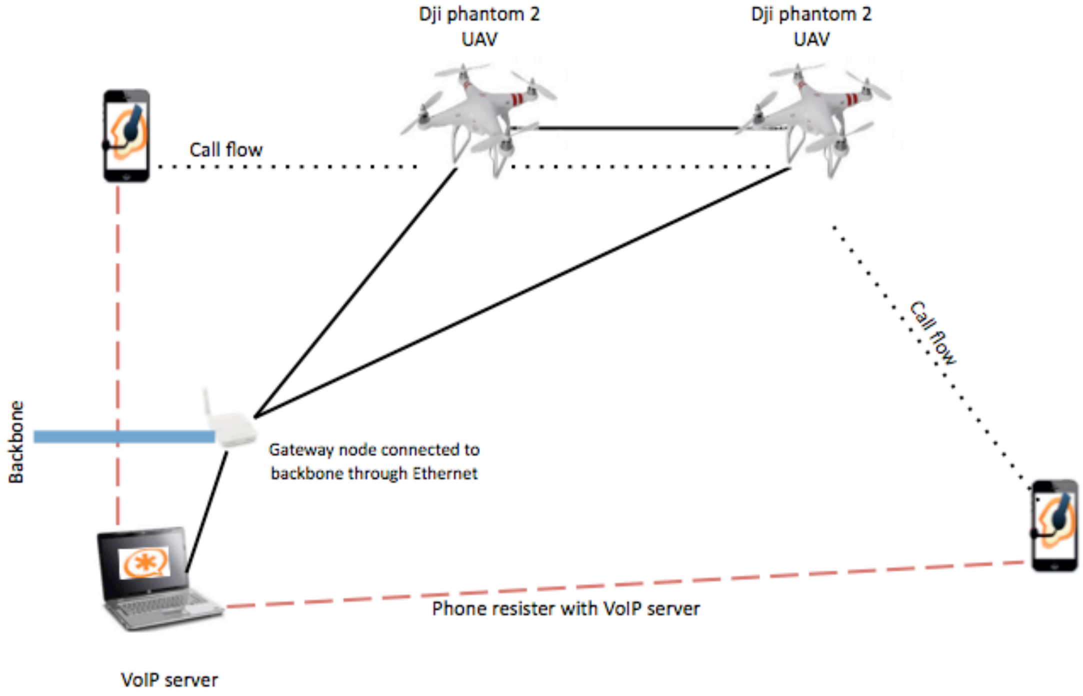

Figure 2: Experiment topology

3. Experiment Analysis

Analyzing the result of the experiment is the most important part of the paper. The analysis will help in defining the effect of the factors on the network. In this section, we define the metrics for the measurements, the factors affecting the network and measure each factor effect.

3.1. Test metrics

Selecting the right metrics in each experiment provides greater accuracy in results as well as precise output. For this experiment, we select the network link throughput in Mbps; however, more metrics are involved in network performance measurement. Network throughput is the average rate of the data transmitted successfully [5]. Hence, in emergencies we are more concern about the message (data in network) delivery. Figure 3 and Figure 4 shows the network downlink and uplink throughput respectively.

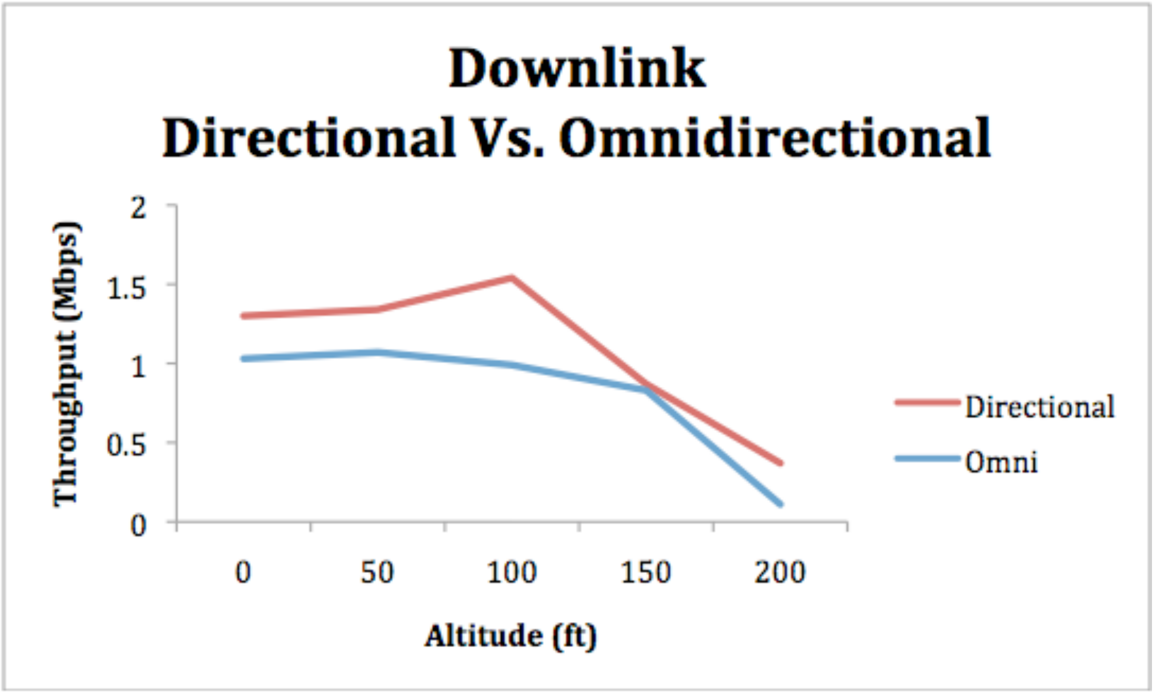

Figure 3: Downlink throughput on different antennas

In Figure 3, we observe the increase in downlink throughput with the Directional antenna up to 100 ft, then a sharp decline recorded, while utilizing the Omni-directional antenna, the downlink throughput is slightly increasing up to 50 ft then starts decreasing slowly up to 150 ft, after that altitude, no throughput was recorded 0 (almost 0 throughput).

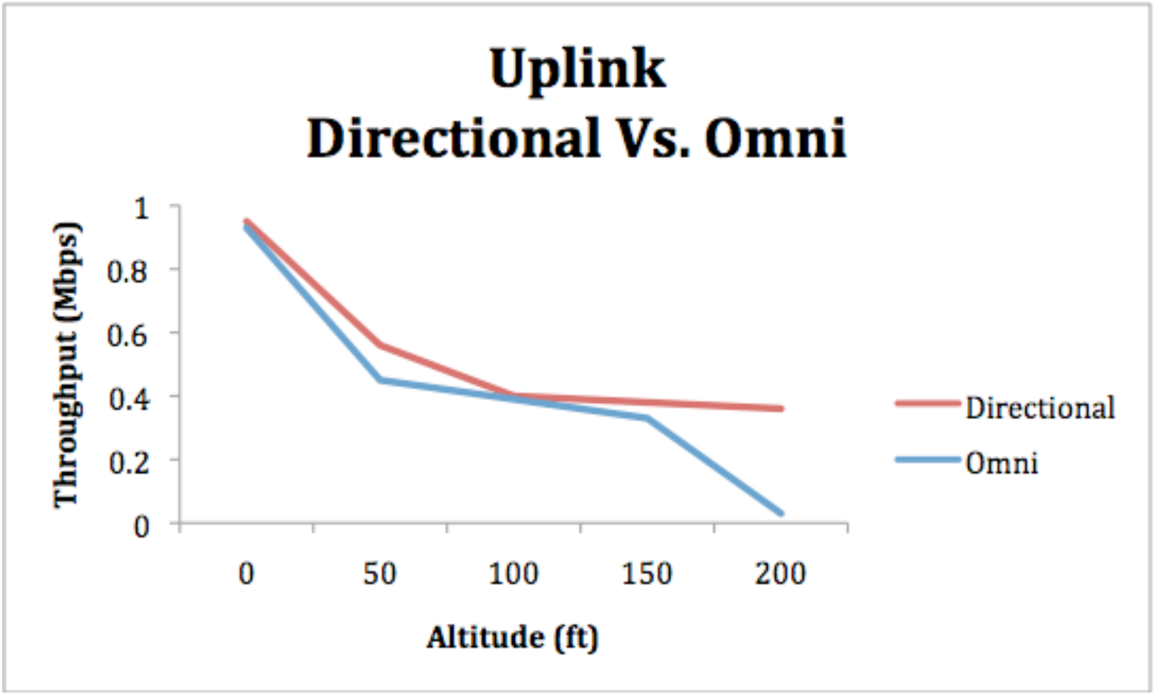

Figure 4: Uplink throughput on different antennas

In figure 4, the uplink throughput on the ground is almost the same on both antennas, when the UAV starts elevating; the uplink throughput starts to decrease in both antennas. On the Omni-directional antenna, the throughput decease up to 150, after that no throughput was recorded. On the directional antenna, the throughput is stable after 100 ft.

3.2. Factors under study

In this experiment, many factors are uncontrollable such as the radio interference, network workload. We conduct the experiment in Danforth campus in Washington University in St Louis, which has a high interference environment and a busy network [6]. Many studies analyzed the effect of interference in wireless mesh networks in different environment [7,8,9]. In our analysis, we study the effect of the antenna and the effect of altitude on the link throughput.

- Downlink

We analysis downlink using two factors factorial design [1], Table 1 shows the factors effect.

Table 1: Downlink Factorial Design

	Antennas				
Altitude	Directional	Omni-directional	Row sum	Row Mean	Row effect
0	1.11	0.99	2.1	1.05	0.23
50	0.99	0.83	1.82	0.91	0.09
100	1.23	0.83	2.06	1.03	0.21
150	0.74	0.76	1.5	0.75	-0.06
200	0.56	0.07	0.63	0.31	-0.49
Col sum	4.63	3.48	8.11		
Col Mean	0.92	0.69		0.81	
Col effect	0.11	-0.11			

An average throughput is 0.81 Mbps. The choice of the directional antenna affects the performance by 0.11 Mbps higher than the average throughput.
The altitude also affect the throughput, for example at 100 ft the throughput increases by 0.21 Mbps more than the average throughput, while at 200 ft it decreases by 0.49 Mbps less than the average throughput.
Next, we estimate the experimental errors in the model. Table 2 shows the estimated model errors.

Table 2: Model errors

	Antenna	
Altitude	Directional	Omni-directional
0	0.05	-0.05
50	0.0347	-0.03
100	-0.08	0.08
150	0.12	-0.12
200	-0.12	0.12

In a good model, the sum of the errors adds up to 0 [1].
Then, we calculate the allocation of variation and table 3 shows the allocation of variation. A denote for antenna and B for altitude.

Table 3: allocation of Variation

Allocation of Variation	Value	% Explained
SSY	23.63	
SS0	19.74	
SSA	0.39	13.39% explained by the choice of antenna
SSB	2.17	73.95% explained by altitude
SSAB	0.26	8.88% explained by the interaction between factors
SST	2.94	
SSE	0.11	3.76% unexplained due to errors in model

From table 3, we observe that 74% of the variation explained by the altitude of the UAV from the ground, 13% explained by the choice of the antenna, 3% unexplained due to errors in the model and 8% explained by the interaction between the altitude and antenna.

Next, we conduct the Analysis of variance (ANOVA) test, which used to analyze the difference between means [10, 1]. Table 4 shows the results of the ANOVA test. Antenna has 1 degree of freedom, altitude 4 degrees of freedom and interaction 4 degrees of freedom. [1]

Table 4: ANOVA

Effect	Mean Square	F-Compute	F-table	
Antenna	0.39	71.11	2.97	Antenna choice is insignificant
Altitude	0.54	98.14	2.25	Altitude choice is significant
Interaction	0.06	11.78	2.25	Interaction in significant
Error	0.005			

We can observe from the ANOVA test that the factors are significant and the interaction is significant. The 3% model errors are due to missing factors, factors like interference [11] and the load on the network has a great impact on the performance, which could possibly causes the errors on the model, more investigation required to analyze these factors (see future work).

Finally, we calculate the confidence intervals for the effects and we use T value at 30 degrees of freedom (ab (r-1)) [1] for 90% confidence. Table 5 shows the effects confidence intervals.

Table 5: Confidence intervals for downlink effects

Parameter	Standard Dev	Confidence Intervals	
Antennas			
Directional	0.023462537	0.091237463	0.138162537
Omni-Directional	0.023462537	-0.138162537	-0.091237463
Altitude			
0	0.046925073	0.191774927	0.285625073
50	0.046925073	0.051774927	0.145625073
100	0.046925073	0.171774927	0.265625073
150	0.046925073	-0.108225073	-0.014374927
200	0.046925073	-0.541725073	-0.447874927

From table 5, we observe that all effects are statically significant.

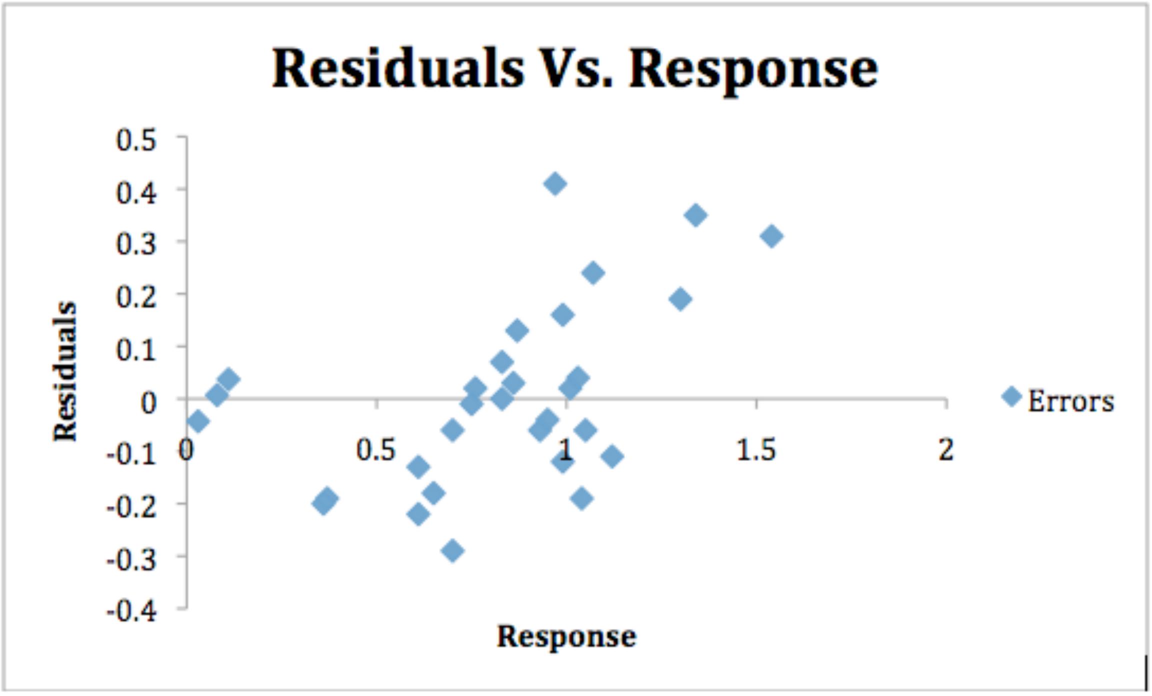

Figure 5: Errors Independency

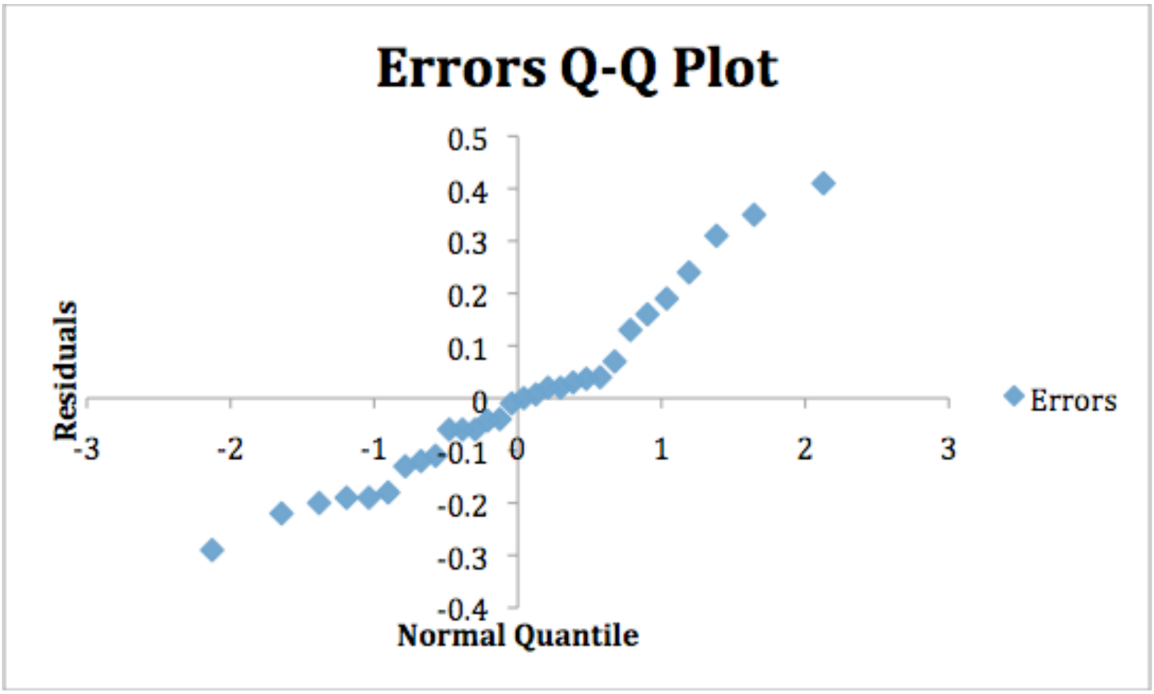

Figure 6: Errors Normality

In figure 5, it is hard to observe any trend that means errors are independent and in figure 6 shows linear relationship between the response and the predictor variable and errors normally distributed, that satisfy the regression assumptions [1].

- Uplink Analysis
The second part is the uplink analysis. Table 6 shows the factors effects.

Table 6: Uplink factorial design

	Antennas				
Altitude	Directional	Omni-directional	Row sum	Row Mean	Row effect
0	0.95	0.93	1.88	0.94	0.45
50	0.56	0.45	1.01	0.50	0.02
100	0.4	0.43	0.83	0.41	-0.06
150	0.38	0.33	0.71	0.35	-0.12
200	0.36	0.03	0.39	0.19	-0.28
Col sum	2.65	2.17	4.82		
Col Mean	0.53	0.43		0.48	
Col effect	0.04	-0.04			

The effect of each factor appears on Col effect and Row effect.
Next, we calculate the model errors; make sure the sum of errors adds up to 0, table 7 shows the model errors.

Table 7: Model errors

	Antenna	
Altitude	Directional	Omni-directional
0	0.03	-0.03
50	-0.007	0.007
100	0.06	-0.06
150	0.02	-0.02
200	-0.11	0.11

In table 8, we calculate the allocation of variation to determine the effect of each factor.

Table 8: Allocation of Variation

Allocation of Variation	Value	% Explained
SSY	9.76	
SS0	6.96	
SSA	0.06	3.16% explained by antenna
SSB	1.87	85.95% explained by altitude
SSAB	0.11	5.39% explained by interaction
SST	2.18	
SSE	0.12	5.48% unexplained due to errors in model

From table 8, we observe that the choice of antenna is affecting the system variation by 3%, while the altitude explain 85% of the variation in the system, 5% explained by the interaction between factors and 5% unexplained due to errors in the model.

Next, we want to see if the effects are statically significant, we use ANOVA to check for factor static significant and the results in table 9.

Table 9: ANOVA

Effect	Mean Square	F-Compute	F-table	
Antenna	0.06	11.52	2.97	Antenna choice is significant
Altitude	0.46	78.32	2.25	Altitude choice is significant
Interaction	0.02	4.92	2.25	Interaction is significant
Error	0.009			

Observing the results from table 9, both factors are statically significant.

Next, we calculate the confidence intervals of the effects on the uplink with T value at 30 degrees of freedom. Table 10 shows the confidence intervals of the effects.

Table 10: Confidence intervals for uplink effects

Parameters	Standard Dev	Confidence Intervals	
Antenna			
Directional	0.024395184	0.023604816	0.072395184
Omni-Directional	0.024395184	-0.072395184	-0.023604816
Altitude			
0	0.048790368	0.409209632	0.506790368
50	0.048790368	-0.025790368	0.071790368
100	0.048790368	-0.115790368	-0.018209632
150	0.048790368	-0.175790368	-0.078209632
200	0.048790368	-0.335790368	-0.238209632

From table 10, we observe that all the effects are statically significant except altitude at level 50ft because it includes 0.

Finally, we perform a visual test to validate the model

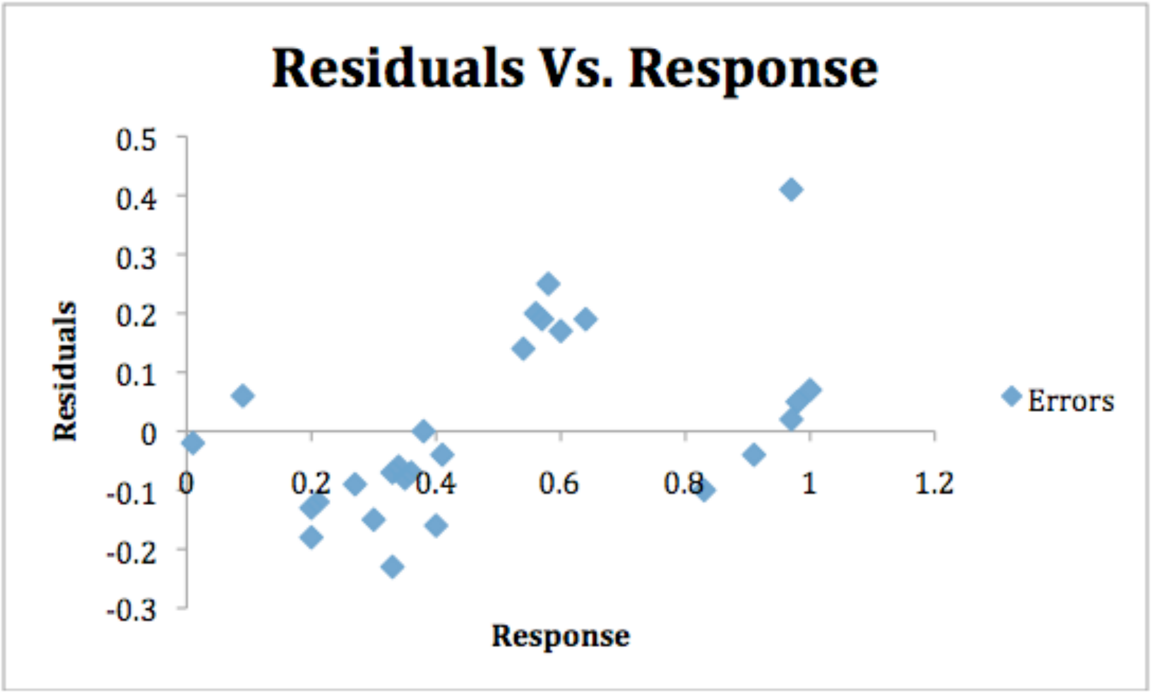

Figure 7: Independency test

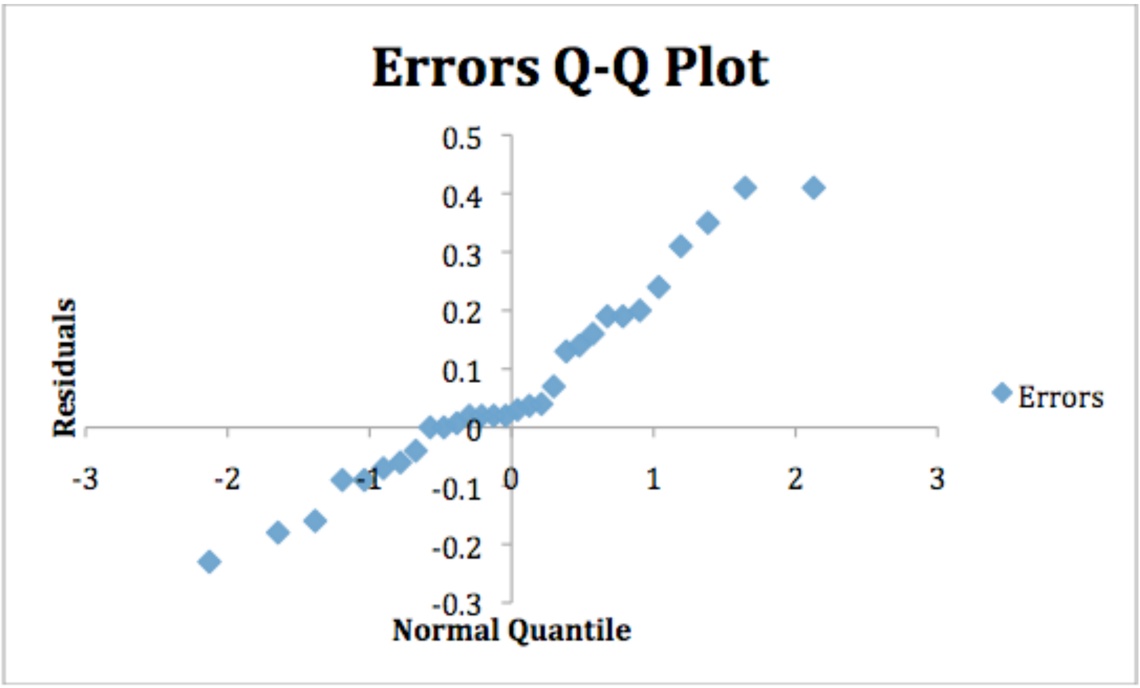

Figure 8: Normality test

In figure 7, there is no trend, which proves errors are independent. Figure 8 shows that errors normally distributed. The errors in the model for uplink analysis due to missing factors from our study, more investigation required (see future work).

4. Future Work

We plan to conduct more experiments to study additional factors (network workload, interference, etc) and try to separate the effect of each factor to have better insight into the network behavior.

5. Conclusion

We conducted two experimental designs to study the effect of altitude and the effect of antenna type on the throughput of aerial wireless mesh network. We observed, on downlink the altitude increases the throughput using directional antenna up to 100 ft, while using Omni-directional antenna the throughput slightly increase up to 50 ft, after 50 ft the throughput was almost stable up to 150 ft.

The Directional antenna proved to be the right choice for aerial mesh networks for downlink communications.

We also observed from the experiment, in the uplink, the altitude decreases the throughput significantly on both antennas. On directional antenna, the throughput became almost stable with slight decrease after 100 ft, while on the Omni-directional antenna, after 150 ft the throughput almost not recorded (very low throughput).

We observe from the analysis of factors, the choice of the altitude is the major factor on the link throughput and at 100 ft altitude the highest throughput recorded on the downlink using the directional antenna, while 50 ft was the best altitude using Omni-directional antenna

We prove that using directional antenna will give significant result at different levels of altitude.

6. References

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7. Appendices

A. Asterisk Setup

1- Download Asterisk framework from: http://www.asterisk.org/
2- Install Asterisk on a Linux based server. See installation steps here.
3- Install freePBX manager for Asterisk from: http://www.freepbx.org/
4- Restart the server and find Asterisk server IP using **ifconfig** command**.**
5- Enter Asterisk IP in a browser of you choice to access freePBX to configure Asterisk.

6- In freePBX web GUI, click freePBX administration, you will see login screen (**default username is** ‘admin’, **password** ‘admin’).
7- After login, select admin menu and go to administrators to change username and password.
8- From here, go to admin menu and select module admin to update and install the necessary modules (for this experiment all necessary modules are installed).
9- Go to application menu, select extensions to add extensions to allow calls between the extensions.
10- From extension screen, select generic SIP device and click submit.
11- In User Extension, enter the user extension number (e.g. 2000), enter the display name (e.g. 2000), in secret enter the password for the extension (e.g. a1a2a3) and click submit then apply changes to Asterisk.
12- Add another extension.

B. Zoiper Setup

1- Download Zoiper from Google play or apple store on clients.
2- On cell-phone open Zoiper, go to setting and select accounts, add account.
3- After select add account, select SIP account, enter account name, in domain, enter Asterisk server IP, in Username, enter extension number and in password enter the password then select register (remember to be in the same network as the Asterisk server).

C. Arduino with Adafruit GPS shield Setup

1- Download and install Arduino IDE from: http://www.arduino.cc/
2- Connect Arduino board to you computer using USB cable.
3- From tools, select your board and select your serial port.
4- For GPS shield, download this library: https://github.com/adafruit/Adafruit-GPS-Library
5- Uncompress the library, place the folder in Arduino libraries folder.
6- Restart the IDE, then open file menu, select examples; from examples select **Adafruit_GPS** and select **sdlog_shield** to log GPS data to the SD card.
7- Insert the SD card in the slot.
8- Upload the file to the board by click the upload button.