

# **TEAM 1152**

**Problem: The aim of Project Loon is to ensure everyone on the planet has access to the internet, by creating a balloon-powered network.**

## SUMMARY

Based on the area covered by each individual balloon, the total land area of New Zealand, and the air current speeds of various currents that both stream across New Zealand as well as the entire Southern Hemisphere, we have arrived at the conclusion that a total of 1242 balloons (airships) are needed in order to have all of New Zealand's land area be able to receive wireless coverage at all times.

As shown in the previous paragraph, we have decided to change the balloon design from the basic circular shape used by Google in their early prototypes to a more advanced design, the airship, more commonly known as the 'blimp'. By doing so we are provided many advantages which the circular design does not allow for, most important among them greater manoeuvrability and longevity.

Because the reliability of an internet connection is of utmost importance, in our calculations we have also allowed for safety margins within the spacing between individual airships as to ensure that every square meter of New Zealand's land is able to connect to the balloon network.

Due to the variable nature of natural wind and air current flow, we have made slight over-estimations in the values leading up to calculations for the number of airships, as to not generate an end value that is lower than it would be in reality. As such, a perfectly optimised network where all balloons/airships are kept in precise locations would require a slightly lower number of airships, and this is to be expected.

## INTRODUCTION

### **How many balloons would be required to provide balloon-powered internet coverage to all of New Zealand?**

The objective of Google's Project Loon is to allow a constant wireless internet connection from the sky while keeping the costs lower than satellite internet (which can cost more than \$1000NZD a month for a standard 50GB plan)<sup>1</sup> and with faster upload/download rates. The initial aim is to first provide internet access to LEDCs and disaster-stricken zones, and later, all areas of the globe. However to ensure the practicality and usefulness of the internet source the quality of the connection must paramount. With their existing design, Google seems to have taken a single antenna approach, covering a **40km** diameter from an altitude of **20km**. In their 16 June 2013 pilot launch, a **total of 30** gas balloons were launched, providing testers with **approximately 15 minutes** of connectivity before the balloon passed over.<sup>2</sup>

Since Project Loon is still an on-going development, it can be naturally assumed that the aircraft platform will evolve from the current gas balloons to the much more flexible High-Altitude Airships (HAA). With this in mind, we will have to determine;

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<sup>1</sup> Farmside, Satellite Plan Pricing, Retrieved 10 August 2013 (<http://www.farmside.co.nz/Broadband/Satellite.aspx>)

<sup>2</sup> Google Project Loon, FAQ, Retrieved 10 August 2013 (<http://www.google.com/loon/faq>)

- What is the ideal specification for an airship?
- What is the minimum connectivity for an acceptable Wi-Fi connection?
- How can we arrange the airships for the most efficient special packing and coverage?
- How to navigate and guide the airships to achieve maximum circuit efficiency?

## THE AIRSHIP

### What is the ideal specification for an airship?

Despite being very crude and basic, gas balloons are well known for their cost-effectiveness and ease of manufacture. However, through a detailed analysis, we have decided that for a long term scenario, the use of powered High-Altitude Airships (HAA) will be the most effective as the number of benefits easily outweighs the initial costs. These benefits vary from more control to a larger surface area. We will assume that these balloons will be controlled via an on board computer and helium for lift.

	<b>Gas Balloons</b>	<b>High-Altitude Airship</b>
<b>Control</b>	Altitude and basic steering <sup>1</sup>	Altitude and complex manoeuvring <sup>2</sup>
<b>Surface area</b>	Small circular surface area <sup>1</sup>	Large elliptical surface area <sup>2</sup>
<b>Structure</b>	None <sup>1</sup>	Semi-Rigid <sup>3</sup>
<b>Design Life</b>	Temporary (max. 3 months) <sup>4</sup>	At least 10 years <sup>3</sup>
<b>Payload</b>	Vary depending on balloon volume	up to 1800 kg <sup>5</sup>
<b>Reusability</b>	Single cycle, only platform can be reused (in the case of a successful parachute) <sup>6</sup>	Can be landed via mooring mast for refuelling and maintenance <sup>2</sup>
<b>Maintenance/Serviceing</b>	Difficult, requires deflation for descent <sup>6</sup>	Can be done upon mooring <sup>2</sup>

<sup>1</sup> [http://en.wikipedia.org/wiki/Gas\\_balloons](http://en.wikipedia.org/wiki/Gas_balloons)

<sup>2</sup> <http://en.wikipedia.org/wiki/Airship>

<sup>3</sup> [http://en.wikipedia.org/wiki/Zepplin\\_NT](http://en.wikipedia.org/wiki/Zepplin_NT)

<sup>4</sup> <http://www.newscientist.com/article/dn23721-google-project-loon-to-float-the-internet-on-balloons.html#.UgWdBDsyaCk>

<sup>5</sup> <http://www.globalsecurity.org/intell/systems/haa.htm>

<sup>6</sup> <http://www.google.com/loon/how/>

Project Loon has opted for a more advanced helium balloon design, with basic steering and altitude adjustment to move between ‘wind layers’. However, the HAA’s superiority comes from its controllable rudders and thrust mechanisms which allows it to ride on the Ferrell Cells and Jet Streams unpowered, and then uses its own propulsion to switch to a different cell or stream in order to ‘loop back’ and go back to its starting point of the cycle.



Figure 1 An example of a High-Altitude Airship (HAA) by Lockheed Martin ([http://en.wikipedia.org/wiki/File:High\\_Altitude\\_Airship.JPG](http://en.wikipedia.org/wiki/File:High_Altitude_Airship.JPG))

Additionally, a HAA covered with film solar panels benefits from its large surface area so that a greater amount of light energy can be converted and sorted within the on board systems for battery powered night-time flight or temporarily boosting the signal strength of the wireless network. Japan's High Altitude Platform Station R&D Project<sup>3</sup> is comparable to our ideal design for a quasi-geostationary orbit with the power generation at approximately **10kW** at the altitude of **20km**, more than sufficient for the wireless transmitting and receiving needs and suits as an appropriate platform as the upgrade of high-powered telecommunication dish antennas.

Constructed with a semi-rigid structure, a HAA is made to last significantly longer than its gas-based counterpart. The flight duration is more than **3 years**, servicing and maintenance is kept to a minimum and can be moored on an airfield when it is necessary. It is also designed to have a longer life span with at least **10 years**<sup>4</sup>; in some cases, more than **30 years**.

In terms of payload, a typical HAA can hold between **1000-1800kg** of cargo weight which is more than sufficient for the telecommunications equipment.

Therefore, we have decided that the use of a High-Altitude Airship is most suited for this application.

## CONNECTION

### What is the minimum connectivity for an acceptable Wi-Fi connection?

Due to the ambiguous specifications of the antenna used by Google, we approximated their antenna to that of the antenna sited below. (Antenna gain – 25dBi) this antenna is used on both the airship and connected to the user's house and/or workplace.

Because the minimum signal strength required for Wi-Fi connectivity is -10 dBm we were able to calculate the maximum possible separation between the transmitter and the receiver to give both a satisfactory connection of 3G capability, and maximise the area coverage from every individual

<sup>3</sup> Teruhisa Hori: Overview of HAPS R&D Project; Sixth APT Standardization Program Forum, (<http://www.intercomms.net/AUG03/content/struzak1.php>)

<sup>4</sup> Goodyear Blimp, Wikipedia ([http://en.wikipedia.org/wiki/Goodyear\\_Blimp](http://en.wikipedia.org/wiki/Goodyear_Blimp))

airship. This process will effectively reduce the amount of resources required for full coverage and the number of airships needed to cover New Zealand at any instant in time.

After taking into account the decay of the signal caused by the antenna gain of the applied antenna using the Friis transmission equation the separation of the transmitter on the airship and the receiver on the earth's surface should be 10km. signal strength of the transmitter attached to the airship should be i.e. 60 dBm. In the procedure of this calculation the antenna gain of both the receiver and transmitter could be approximated to 25dBi, giving a total antenna gain of 50 dBi.

### Friis Transmission Equation

$$\frac{P_r}{P_t} = \frac{G_r G_t}{F_t} \left( \frac{\lambda}{4\pi r} \right)^2$$

G = the sum of the antenna gain. (Transmitter + receiver)

R = the effective range of the transmitter.

$P_r$  = the minimum signal strength required for Wi-Fi connectivity.

$P_t$  = the signal strength of the transmitter aboard the airship.

Furthermore we are dealing with radio frequency waves of frequency 2.4 GHZ (as stated by Google) which lie in the long wave section of the electromagnetic spectrum so the penetration power of the waves is great enough to pass straight through any obstructions within acceptable estimation. The decay of the signal due to the likes of trees, birds or any other external objects are hence arbitrary, and ignored when calculating the final strength of the received signal.

Another assumption of the model is that the antennas are 100% efficient and the intensity of the signal is not lost as heat in the antenna.

**By adapting the Friis Transmission Equation we can conclude that<sup>5</sup>:**

$$R = \frac{10^{\frac{P_t + \Sigma G + P_r}{20}}}{41.88 \times f}$$

$$R = \frac{10^{\frac{60 + 50 + 10}{20}}}{41.88 \times 2400}$$

$$R = 10 \text{ km}$$

Overall the Friis transmission equation allows us to accurately predict the fall in signal strength from a transmitter of 60dBm over a separation distance of 10km will still provide an appropriate Wi-Fi connection.

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<sup>5</sup> Figure out transmission distance from wireless device specs, Moxa Connection, Retrieved, 10 Aug. 13 ([http://www.moxa.com/newsletter/connection/2008/03/Figure\\_out\\_transmission\\_distance\\_from\\_wireless\\_device\\_specs.htm](http://www.moxa.com/newsletter/connection/2008/03/Figure_out_transmission_distance_from_wireless_device_specs.htm))

## SPATIAL PACKING

### How can we arrange the airships for the most efficient spatial packing and coverage?

Because the signal strength decays exponentially over distance away from the point source, the volume in which the wireless network is viable can be interpreted to be a sphere with the balloon at its centre. Because the original Project Loon is stated to cover a land radius of 20km (diameter 40km) while floating at 20km above sea level, we calculated the maximum effective reach of each balloon's wireless network to be  $20\sqrt{2}$ km (28.284km), which is hence the radius of the sphere about each balloon in which the network signal is strong enough to make data transmission at 3G speeds viable.

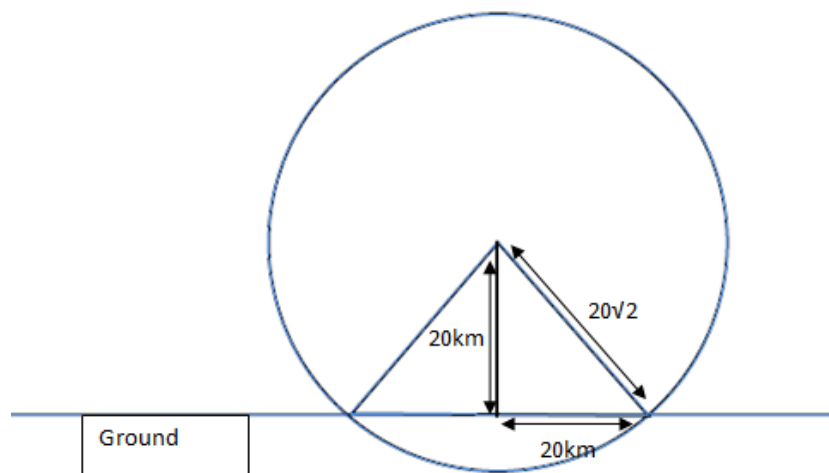


Figure 2 - The original Project Loon dimensions. The circle's centre is the balloon's position \*Not to scale

However, in our case we have instead decided to have our airships float at approximately 10km above sea level while they are over New Zealand, in order to firstly increase the area covered with each airship and also for routing purposes, the reasoning for which is explained in much greater later in this report. If the same wireless transmitters and receivers are used, then the radius of the sphere will of course, remain the same. However, the radius of the ground area which the sphere now covers is greatly increased, with the new ground coverage radius being  $10\sqrt{7}$ km (26.458km). This now allows for a ground area of  $700\pi \text{ km}^2$  (2199.115  $\text{km}^2$ ), while the original Project Loon specifications only allow for an area of  $400\pi \text{ km}^2$  (1256.637  $\text{km}^2$ ).

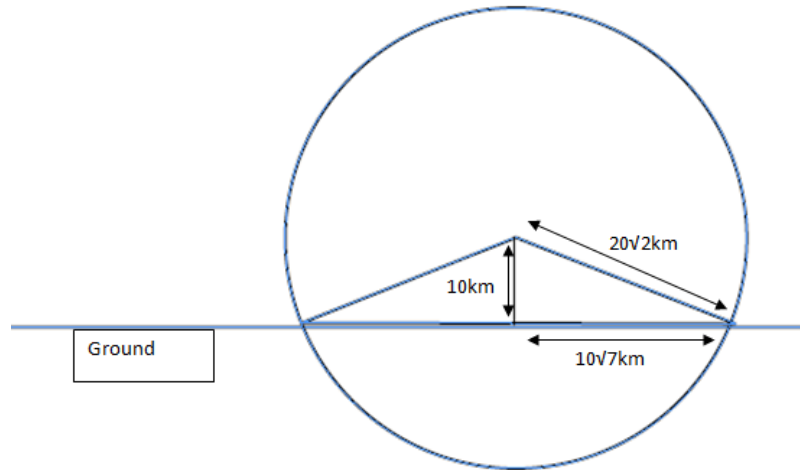


Figure 3 - The new set up, with the centre of the circle (position of airship) being 10km above the ground. \*Not to scale

Because the ground area that each airship is able to cover is circular, the arrangement of airships must inevitably result in the overlapping of adjacent circles as to not create dark spots of no viable wireless reception. We have opted for a **hexagonal packing** arrangement as it produces the most densely packed lattice<sup>6</sup>, with overlapping between adjacent circles to eliminate any empty space.

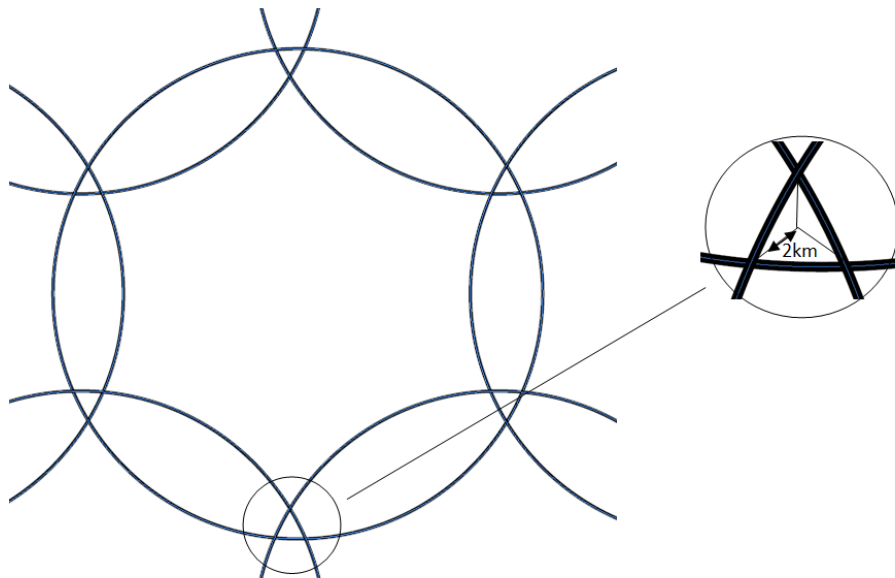


Figure 4 - The arrangement of adjacent airships, showing the overlaps created. \*Not to scale

The reason that we have chosen to have a distance of 2km between the centre and corners of the triple-overlaps is to create a safety margin in case the airships are not exactly in position. Stratospheric airships typically have around 1km position keeping error<sup>7</sup>, but because these airships will be carried largely by northward Ferrell Cell currents, we have decided to double this safety margin in order to guarantee uninterrupted coverage.

<sup>6</sup> Circle Packing, Wikipedia, Retrieved 10 August 2013 ([http://en.wikipedia.org/wiki/Circle\\_packing](http://en.wikipedia.org/wiki/Circle_packing))

<sup>7</sup> Mobile telecommunications via stratosphere, Ryszard Struzak, Retrieved 10 August 2013, (<http://www.intercomms.net/AUG03/content/struzak1.php>)

Under this model, the average area covered by each individual airship is calculated by first calculating the area of the differently shaded regions of the divided circle, by splitting each region into straight edged polygons or a circle segment. Angle ratios as well as the sine and cosine rules are then used to calculate the various areas from the total area of the circle.

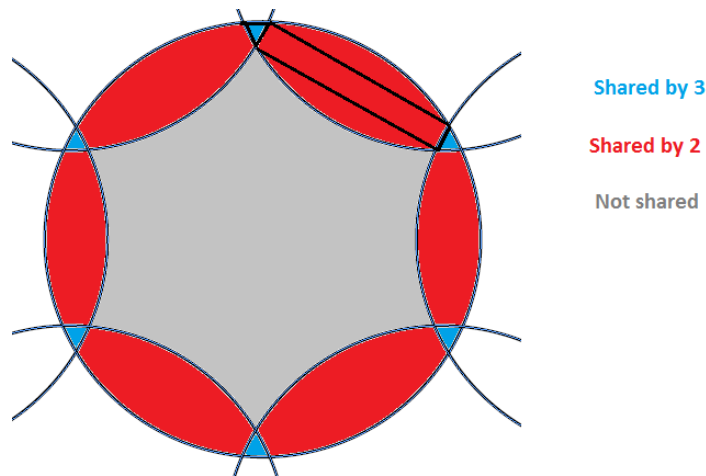


Figure 5 - Splitting used to calculate the average area each individual airship covers. \*Not to scale

From this, the area each blue part is calculated to be  $5.589\text{km}^2$ , each red to be  $166.827\text{km}^2$ , and subsequently the grey being  $1164.616\text{km}^2$  in area. Thus, the average total area of each airship's coverage is calculated as:

$$1164.616 + 3(166.827) + 2(5.589) = 1526.275\text{km}^2$$

As the total area of each airship's raw coverage area is  $700\pi\text{ km}^2$  ( $2199.115\text{ km}^2$ ), this gives a coverage efficiency of **69.4%**.

The land area of New Zealand is taken to be  $267,760\text{km}^2$ <sup>8</sup> and by dividing this value by the average airship coverage we arrive at the conclusion that to **176** (175.433) airships are needed to cover the entirety of New Zealand's landmass. However, because this is a raw calculation that does not take into account the contours in the coastlines. In order to compensate for this, we have taken a rough estimate of the number of additional airships needed to cover the western shoreline of the North and South Island. The straight tip-to-tip measurement of both islands is roughly  $\sim 1600\text{km}$  total<sup>9</sup>. By dividing this by each airship's coverage diameter of  $20\sqrt{7}\text{km}$  ( $52.915\text{km}$ ) we arrive at the figure of **31** (30.237) additional airships needed, bringing the total number for simply covering New Zealand's land area to be **207 airships needed**.

<sup>8</sup> Geography of New Zealand, Wikipedia, Retrieved 10 August 2013 ([http://en.wikipedia.org/wiki/Geography\\_of\\_New\\_Zealand](http://en.wikipedia.org/wiki/Geography_of_New_Zealand))

<sup>9</sup> About New Zealand, Retrieved 10 August 2013, (<http://www.nzs.com/about-new-zealand/>)

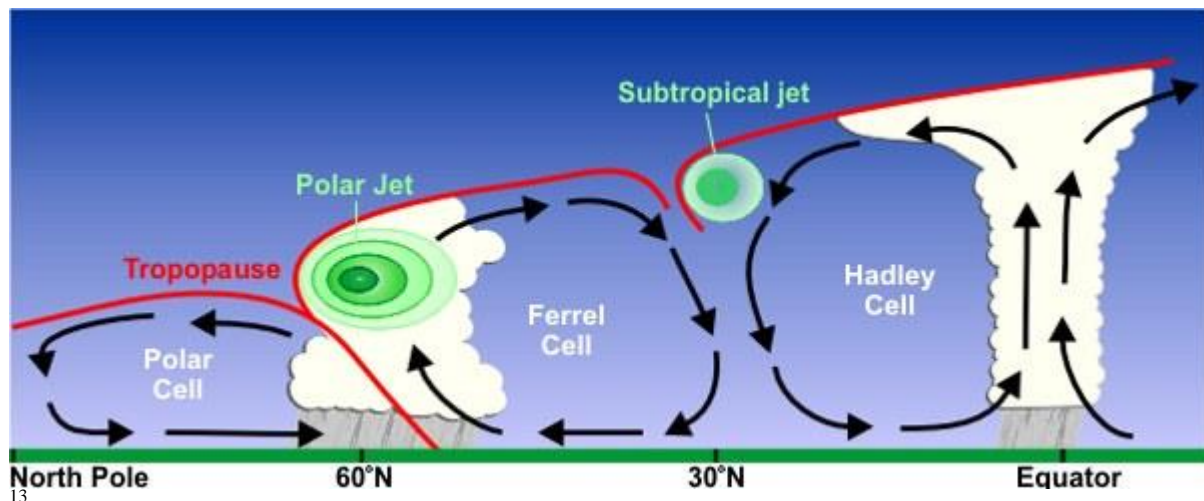


## ROUTING

### How to navigate and guide the airships to achieve maximum circuit efficiency?

Project Loon specifies that the motion of the balloon is to be a quasi-geostationary orbit. This was said to be achieved via opposing wind directions on the different layers within the stratosphere<sup>10</sup>. As such, the balloons will be able to provide constant connection by flying up and down the country as it rides different wind directions by changing the altitude in which it flies in. However, we have not been able to prove that there was such a phenomenon of the opposing wind directions and as such the route in which our airship travels is different to that proposed in Project Loon.

We were, however, able to create a similar route described by using a combination of the **Hadley Cell and Jet Streams** (or more specifically, the southern hemisphere polar jet stream and subtropical jet stream). To put it simply, the airships travel around the world by riding the southern hemisphere polar jet stream located at roughly between the latitudes of 30°N and 60°N and at a height in between **7-12km** above sea-level<sup>11</sup>. As it comes closer to New Zealand, we increase the latitude travelled to be in between **10-15km** above sea-level so that the airship will be under the influence of the Mid-latitude Cell (Farrell Cell) air circulation flow<sup>12</sup>. Therefore this is where we derived the altitude which is required. This will cause the airship to travel from the south island to the north in a diagonal motion as it is being pushed to side due to the jet streams and upwards via Hadley Cell. However, we cannot just ride the Hadley Cell down and then back up again as the polar air flow is so close to the ground that this is not feasible. An alternate method is to continue to ride the Mid-latitude until it decreases the altitude of the airship to be low enough so it can then ride the subtropical jet stream as shown in the diagram below: Because we are using airships, we can are able to move the paths they taking using little repulsion to get them out of either the jets streams and into the motion of the cells and vice versa.



Assuming that the polar and subtropical jet merge (as indicated by Figure 6); The airship will then continue to ride the jet streams until it is back to the point where the jet streams diverge and then travel back up New Zealand.

<sup>10</sup> Google Loon Project, How Loon Works, Retrieved 10 August 2013 (<http://www.google.com/loon/how/>)

<sup>11</sup> Jet Streams, Retrieved 10 August 2013, ([http://en.wikipedia.org/wiki/Jet\\_stream#Polar\\_jet](http://en.wikipedia.org/wiki/Jet_stream#Polar_jet))

<sup>12</sup> Hadley Cells, Retrieved 10 August 2013, ([http://en.wikipedia.org/wiki/Hadley\\_cell#Hadley\\_cell\\_expansion](http://en.wikipedia.org/wiki/Hadley_cell#Hadley_cell_expansion))

<sup>13</sup> Circular Flow image, Retrieved 10 August 2013 (<http://upload.wikimedia.org/wikipedia/commons/3/3e/Jetcrosssection.jpg>)

Motion of  
Airships  
around the  
world

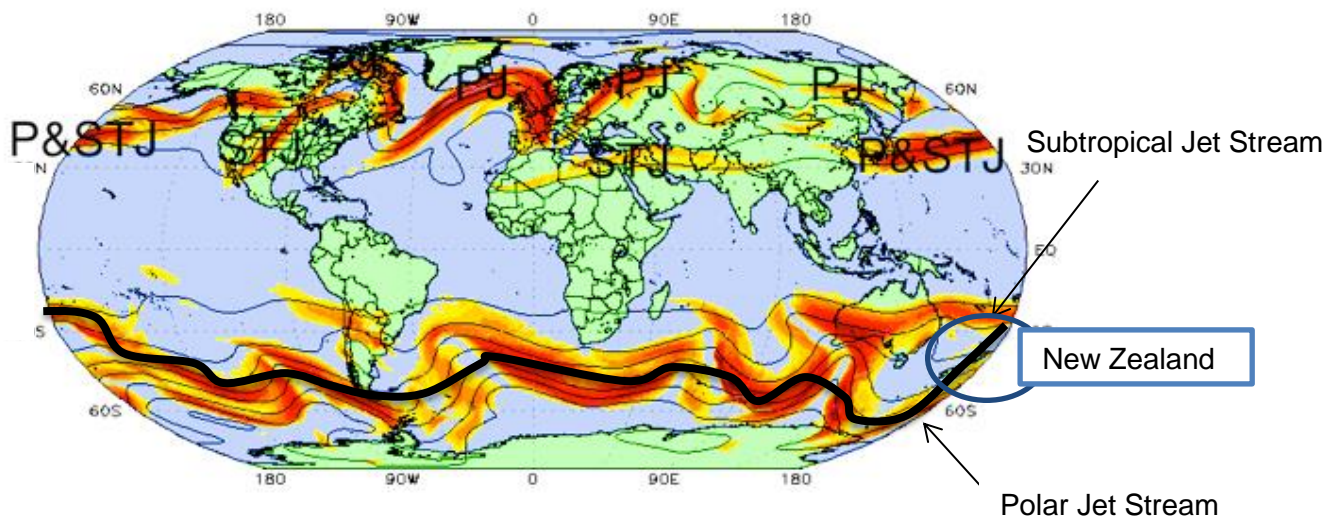


Figure 6 Global Jet diagram showing diversions and conversions of polar and subtropical jet streams, Retrieved 10 August 2013, <http://nwwstatic.co.uk/images/jetstream/jet1.png>

The speed of the wind within the polar jets has a rough average of  $180 \text{ km/h}^{14}$ , we assume that the airship will travel at the speed of the wind due to the fact that without payload it is light than air, and thus greatly affected by wind. The estimated distance to travel is calculated to be  $20,000 \text{ km}$  (using a straight line circumference i.e. averaging the fluctuations of the path, with an earth radius of  $6300 \text{ km}^{15}$ ) therefore the time it takes for one airship to travel round the world without going across New Zealand takes 110hrs. The speed to be able to cross New Zealand  $72 \text{ km/h}^{16}$  and the distance to travel is said to be approximately  $1600 \text{ km}^{17}$  and therefore the time to travel across is 22hrs. Therefore the total time needed to do one cycle is 132hrs which is equivalent to 5.5 days. Therefore, since it takes 5 times longer for one airship to travel around the world than across New Zealand. For every one Airship that leaves the arrangement on New Zealand (which was calculated to be 207) one must be on its way back and to do that there must be five airships around the world ready to replace it. Therefore, the total amount needed in circulation is then equivalent to  $(207 \times 6)$  **1242** airships.

Weather was neglected as the maximum high of the troposphere, where the weather occurs, is **9km** above sea level. Our airship travels a minimum of 10 km above sea level.

## CONCLUSION

Overall, the total number of airships that we have deemed necessary far exceeds the number required to simply cover the land mass of New Zealand. However, by doing so we ensure that regardless of atmospheric currents there will always be airship nodes

<sup>14</sup> Jet Stream Speed, Image, Retrieved 10 August 2013, (<http://www.srh.noaa.gov/jetstream/global/jet.htm>)

<sup>15</sup> Earth's Radius, Retrieved 10 August 2013, ([https://en.wikipedia.org/wiki/Earth\\_radius](https://en.wikipedia.org/wiki/Earth_radius))

<sup>16</sup> Average Wind Speed, Retrieved 10 August 2013, (<https://pangea.stanford.edu/ERE/pdf/pereports/MS/Leaver09.pdf>)

<sup>17</sup> Length of NZ, Retrieved 10 August 2013, (<http://www.nzs.com/about-new-zealand/>)

consistently spaced over all of New Zealand, guaranteeing a stable internet connection. Furthermore, by efficiently utilising the natural atmospheric currents (the Ferrell Cell, the Sub-Tropical and Polar Jet Streams) we minimise the energy input needed to move the airships into place, and because less mechanical propulsion input is needed the longevity of the airships are also greater. Thus, the combination of using airships instead of balloons and the utilisation of atmospheric currents ensures maximum longevity for the airships, allowing each unit's lifespan to last up to 30 years.

Although overestimations are used in our calculations, we feel that this is far preferable to underestimations. Because of the high reliability requirement for such a network, it is always helpful to have redundancies in place, and this way even if a unit were to fail mid-flight, another is able to quickly replace it, thus minimising downtime and productivity loss.

Had we more time and resources, a full simulation of wind currents would have also greatly helped our model of the airships' routing, thus allowing for an even more efficient path to be calculated. Finally, we would have also preferred to explore different connectivity possibilities, beyond the 2.4GHz option currently used by Google, as to perhaps further increase the range of each airship and thus reducing the total number needed.

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