Team: 1141 **10/08/13**

PROJECT LOON

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

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

Summary

Project Loon is being developed by "Google". It is a research project being constructed in order to provide internet access to every single person on the planet; especially people living in isolated areas. Using solar powered balloons placed high in the stratosphere (at an altitude of around 20Km), a world-wide wireless network is hoped to be achieved. The ground surface area that each balloon covers has a diameter of 40Km.
We have been asked to find out how many balloons will be needed to provide internet coverage for the whole of New Zealand.

Our interpretation of the question: We are finding out how many balloons will be needed over New Zealand at any instant in time for there to be enough internet coverage for everyone.

The surface area that each balloon provides internet cover for, is circular in shape. This means that all of the balloons in the stratosphere will have to be close enough together that their internet signals overlap. Our final number of balloons needed to provide internet for the whole of New Zealand, reflected on this key idea. After copious amounts of research, we also found that there would need to be more internet coverage over densely populated areas such as Auckland and Wellington, than over isolated areas, as the demand for internet would be larger. This meant that the coverage areas of each balloon would need to overlap even further over populated areas than isolated areas.

It was decided that every part of the country needed to be covered by internet from at least four balloons. To achieve this, we overlapped the second balloon to the mid-point of the first balloon as seen in figure 2. The urban areas needed even more coverage as there would be greater demands for internet.

After calculating the area of New Zealand and the Chatham islands combined, (combined area = 417 904.43 Km^2), and the surface area of the Urban area of New Zealand, (5078 Km^2 (including the Chatham Islands), we found the area of New Zealand that had lower populations densities. This came out at 412826 Km^2. This meant that the number of balloons needed to cover this area is 1033 balloons. (The working out for this answer is shown in body paragraphs).

We later found that the number of balloons needed for the more densely populated areas is 51 balloons. This meant that the total number of balloons needed over New Zealand at any point in time is 1084 balloons (1033 + 51).

Introduction:

The internet: one huge global network consisting of staggering amounts of information about every topic imaginable. This relatively new invention has changed the face of the planet forever. For most people in the Western world, the internet is taken for granted. But for 2/3 of people world-wide, it is something they have to live without. Now, "Project Loon" is making it possible for everyone to access the internet no matter where you live. Using solar powered balloons placed high in the stratosphere (at an altitude of around 20Km), a world-wide wireless network could be achieved. The main problem, is figuring out how many balloons will need to be ejected into the sky to give internet coverage to every part of the earth. This document contains the answers.

Interpreting the question: Our team is finding out how many balloons will be needed over New Zealand at any instant in time for there to be enough internet coverage for everyone.

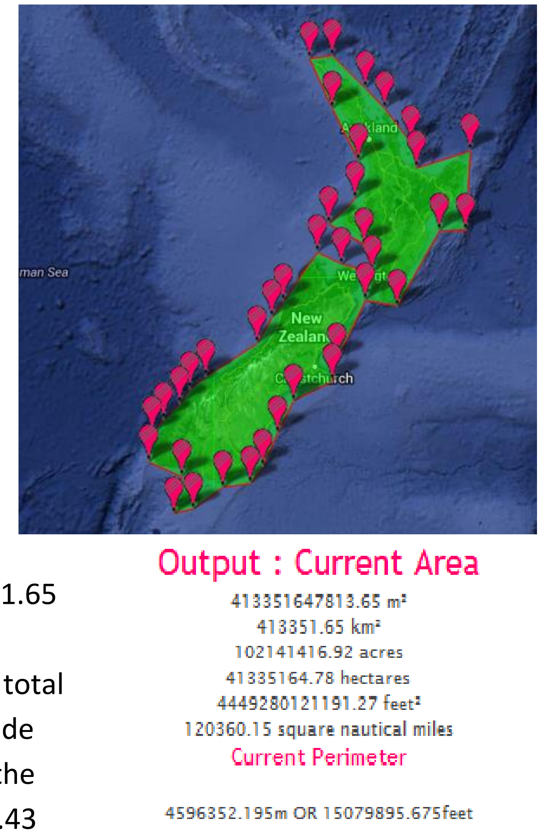
A few assumptions were made in order to come to an accurate answer. One assumption we made was based on the fact that the balloons were 20 Km above the earth's surface. In the stratosphere, winds are relatively slow moving. They start at speeds of around 8Km per hour, and can reach wind speeds of 32.2 Km per hour. The prevailing wind travels from West to East in the Stratosphere, and any balloons in the Stratosphere will be pushed along by the winds. The problem is that different parts of the stratosphere will have winds travelling at different speeds.

In order to accurately give the earth proper internet cover, there will need to be balloons covering the oceans so that when the winds in the stratosphere blow the balloons towards the East, the balloons that were transmitting internet connection over the oceans would now be transmitting internet connection over a country.

To ensure that the balloons stay in the correct mesh structure, they all have to move with the Stratosphere wind at the same rate. The different layers of the stratosphere provide different wind speeds. In order to keep the balloons travelling around the earth together, it will be necessary to differ the level at which they travel in order to reduce/ increase their speed to keep up with the other balloons. To do this, they will need to lower or raise the balloons within the stratosphere. This is easily achieved. There are two parts to the balloon. One is dark, and one is light. The solar panels found underneath the balloon are used to power the rotation of the balloon. When the balloon needs to be raised, the balloon rotates in order to face the dark side towards the sun. The black colour absorbs the sunlight making the gases within the balloon expand causing the balloon to rise. This is because the absorption of sunlight heats up the gases. If the balloon needs to be lowered, the white/light side of the balloon is rotated into the sun. The sunlight is reflected off the white surface which stops the gases from expanding and makes the balloon lower itself. This is essentially how the balloons are controlled in the upper atmosphere. It is assumed that the balloon will cover the same diameter along the ground (40 Km) even if it changes its position in height within the Stratosphere.

Because it is possible to control the positioning of one balloon against another, it is therefore assumed that there will always be the same density of balloons over a given area.

Because New Zealand is surrounded by water, and is very thermally active due to its position on a fault line, there are many islands in the surrounding waters that are classed as part of New Zealand. Some of these include: The Chatham Islands, White Island, Stewart Island etc. Because all of these islands are classed as New Zealand, it is important to incorporate them under the balloons over New Zealand. When we calculated the area of New Zealand with which the balloons had to cover, we included a small amount of surrounding ocean so that all of the offshore islands would have internet provided.



Using "Google Maps Area Calculator", we calculated that New Zealand (including the surrounding oceans and the Chatham Islands) had an area of 417904.43km^2. In the photograph to the right, the area that was calculated is shown. You can see that a small portion of ocean is also included in our calculations. The area is shown in the screen shot to the right. Area= 413351.65 Km^2

The area for the Chatham islands is shown in the screenshot below. Area= 4552.78Km^2

The area of New Zealand (413351.65 Km^2) + the area of the Chatham Islands (4552.78Km^2) equals the total area of balloons needed to provide complete internet coverage for the whole of New Zealand = 417904.43 Km^2.

When calculating the area that the balloons needed to cover, we assumed that people would want to access the internet anywhere in New Zealand so we didn't neglect areas with low populations in our calculation.

We were told that each balloon covers a radius of 40 Km. We assume that this means that the circular pattern the balloon covers has a

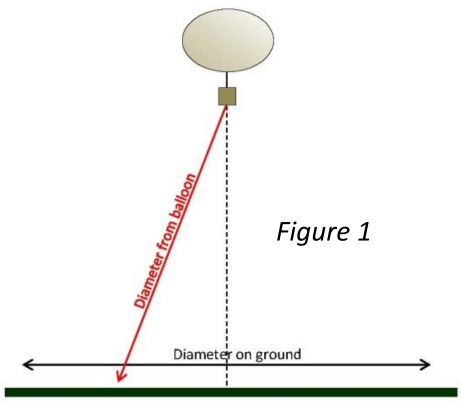


Figure 1

ground diameter of 40 kilometres; not the distance between the balloon and the ground equalling 40m. (See figure 1)

The Loon:

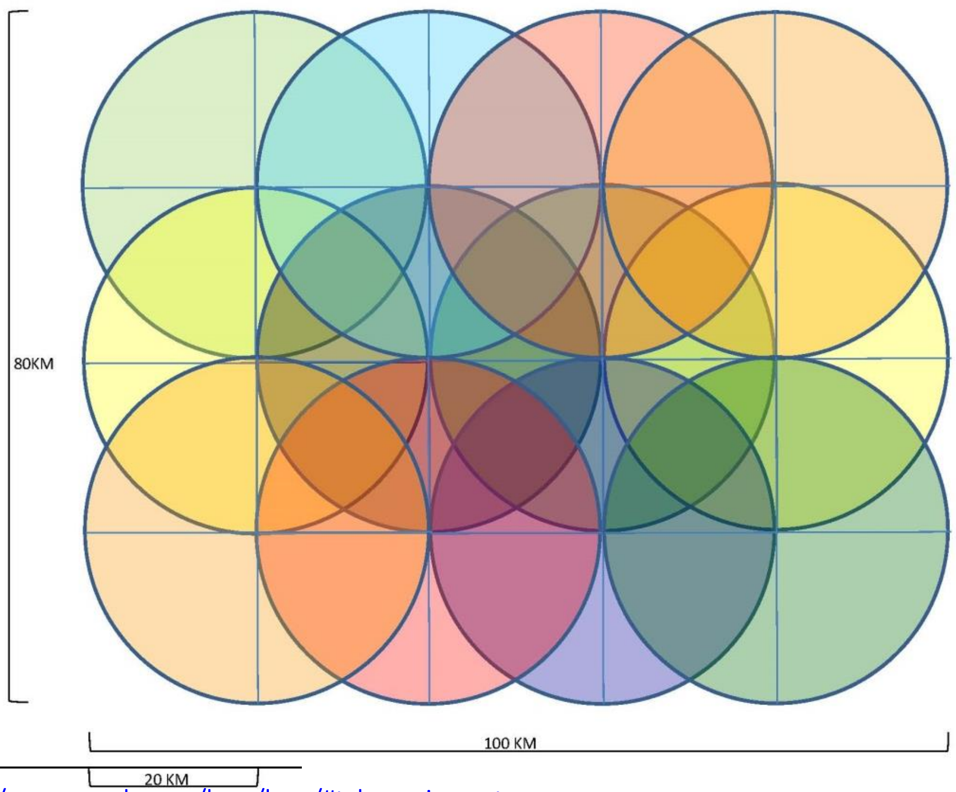
The loon is a large balloon, (approx. 15m by 20m) which is filled with helium gas. The balloon envelope is made of polyethylene sheets which is strong, allowing the balloon to withstand the harsh conditions of the stratosphere.

Hanging under the balloon envelope is a small box which contains all the loon's electronic equipment. This includes circuit boards that control the system and radio antennas to communicate with other balloons and with internet antennas on the ground and batteries for storing solar power to be used at night. [1]

The loon communicates with ground with a radio frequency of 2.4GHz and 5.8GHz. It connect with antennas on the ground and then connects these antennas with a ground station which connects them to an existing internet network. This is much like normal wireless networks, except it will allow the internet to be transmitted much further and to much more isolated locations. The antenna is connected to a consumer grade router which will provide that location with internet.

Our final answer is also based on the idea that every internet transmitting balloon is working, and that every balloon's electrical equipment is working to its full potential, and delivering internet to people at a range of 40 m in diameter along the ground.

Calculations:



[1] http://www.google.com/loon/how/#tab=equipment

A low density system can be created by having a 50% overlap of each balloon coverage area. This creates an average of 1.5 balloons covering any one point on land.

Figure 2

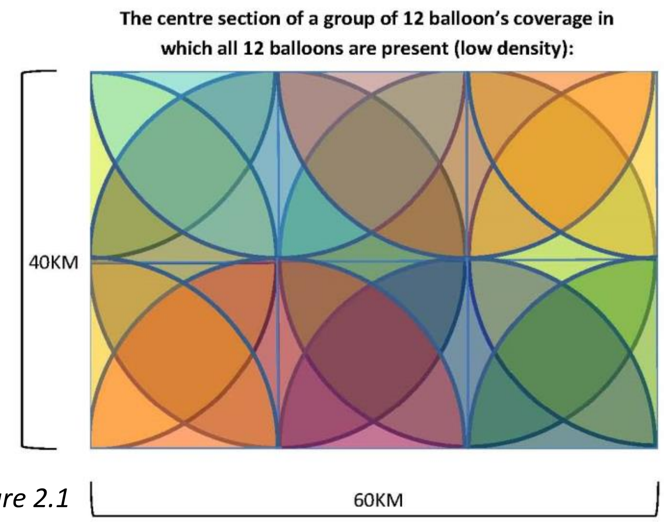


Figure 2.1

In this diagram (figure2.1) there are:

- 4 ¼ of balloon coverage areas
- 6 ½ of balloon coverage areas
- 2 whole balloon coverage areas

⇒ 4/4 + 6/2 +2
= 6 whole balloon coverage areas

Therefore for every 40 x 60km section of land, there are the equivalent of 6 balloons.

⇒ 40 x 60 = 2400km2

Now to find the equivalent size of the area per balloon:

⇒ 2400 ÷ 6 = 400km2 per balloon

Then to find the number of balloons needed to cover new Zealand, the total area of New Zealand needs to be divided by the area per balloon:

⇒ 417,904.43 ÷ 400 = 1044.761075

= 1045 balloons (4sf)

However due the urban areas needing a higher density of balloons, this low density would only be to cover non-urban areas. Therefore the calculation would be the total area of non-urban areas divided by the area per balloon.

- Urban areas = 5078km2

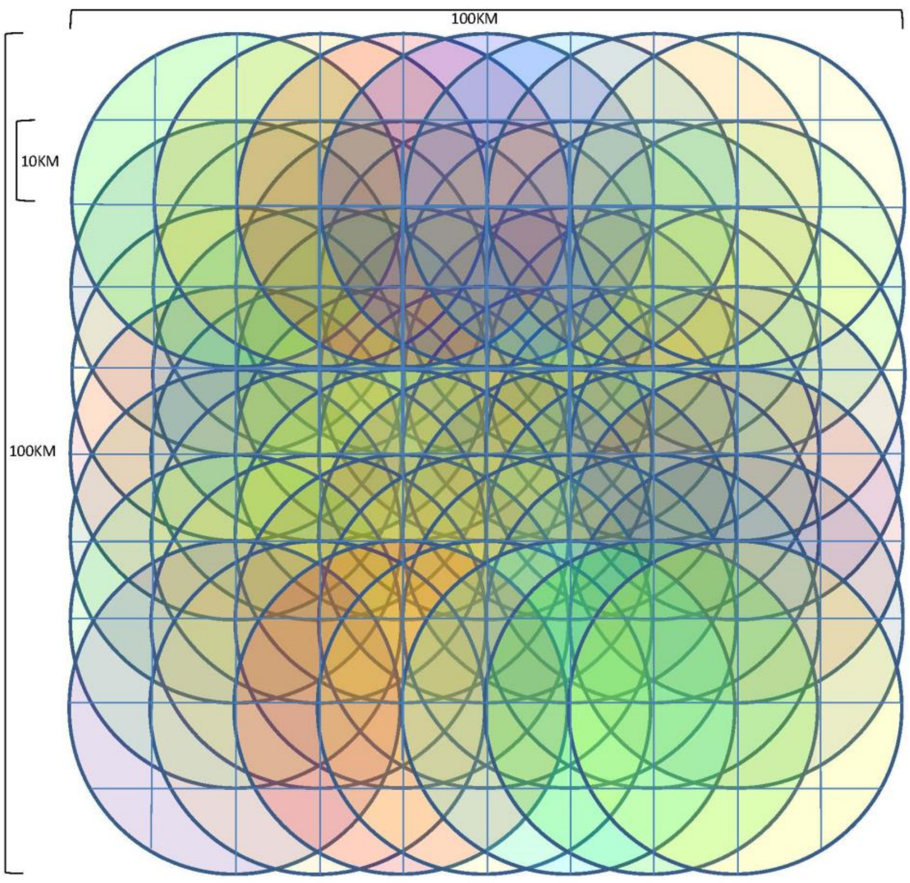
⇒ 417,904.43 – 5078 = 412826km2
⇒ 412826 ÷400 = 1032.065

= 1033 balloons (4sf)

Therefore 1033 balloons would be needed to cover non-urban areas.
This concentration of balloons in non-urban areas guarantees the coverage of internet for everyone living in these areas.

As certain areas of the country, such as large urban environments, have higher population densities than others, this would mean that the amount of balloons in these areas needed to be increased. Having a larger amount of balloons over these particular areas would allow for the wireless network to be more reliable and to accommodate the increased proposed usage. The interconnected "mesh" of balloons over these areas would contain more balloons within the same area as over the non-urban areas "to help meet the higher bandwidth demands that are typical in urban areas, (therefore the) balloons may be clustered more densely (over urban areas)." The amount of overlap in the urban areas will also be increased substantially, from 50% of the ground area covered by each balloon to 75% overlap. The amount of land claimed to be "high density" by Statistics New Zealand was deemed to be 5078 Km^2 (approximately 1.9% of the total land area), so this was the figure used in our calculations. By removing this value from our overall coverage area for the greater New Zealand area and its dependants, as to avoid doubling up on land area covered by any calculations, separate figures for both the "High" and "Low" density areas were able to be calculated. Where any given point in non-urban areas would be covered by an average of 1.5 balloons, the higher density areas would be covered by an average of 12. This will allow the wireless network to meet any higher usage demands by ground users and allow individual balloons to be less likely to reach their full bandwidth potential which would produce less stress on their capacity to function and the network as a whole.

How the High Density area was calculated:



By having an array of circles with 75% overlap of radius (as shown in the diagram), the number of balloons in the high density area could be calculated with respect to how much area the average balloon covered.

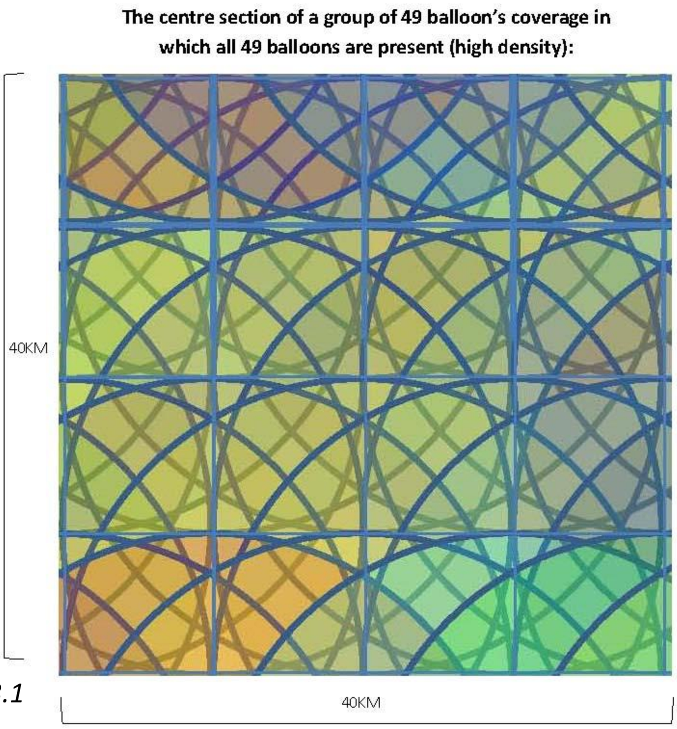


Figure 3.1

As is shown on the diagram, there are many different combination of how different part of a circle can be a part of this idealised part of a circle. In order to calculate the number of circles representing parts of coverage for individual balloons, it was necessary to calculate several complicated areas of sectors of circles.

For the calculation of the 1/16th of a circle, where area q = area x + z,

Where radius of the circle = 20 km,

$\theta = 30°$

Using the calculator at planetcalc.com, the area of segment z is 4.72 km^2, and the chord length is 10.35 km. See figure 4.

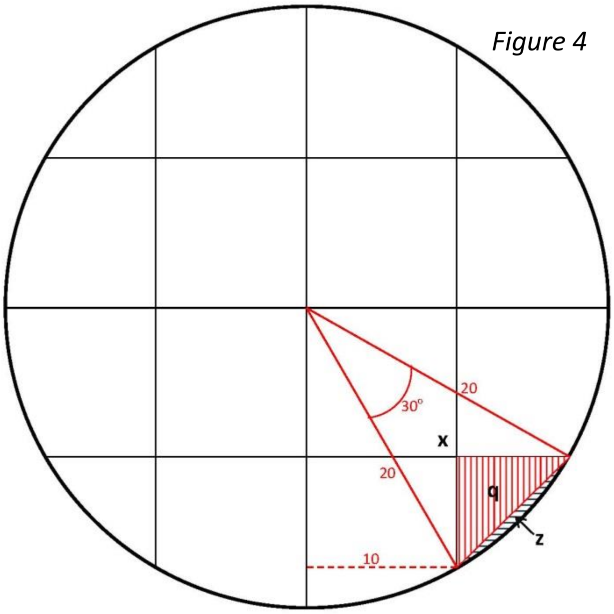


Figure 4

In order to find the length of the other 2 sides of the isosceles triangle that encompasses x, we use the hypotenuse of that triangle which was the chord length we calculated before.

Using Pythagoras Theorem,

$l = \sqrt{(\frac{10.35^2}{2})}$

$l = 7.3186\ km$

Finding the area of the triangle, and adding it to the value of z we found earlier, we get the total area of q.

$$\frac{7.3186^2}{2} + 4.72 = 31.5\ km^2$$

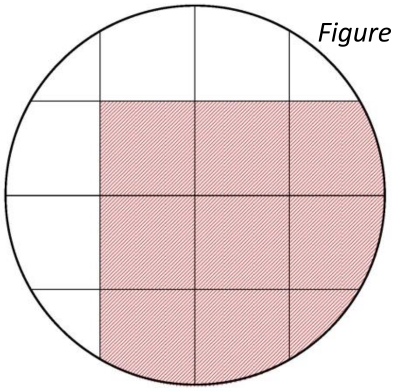


Figure 5

Which we calculated to be a proportion of 0.025 of the total circle's area $(31.5/(\pi \times 20^2))$.

Similar calculations were carried out for other proportions of the circle in various proportions.

Proportion of Circle	Number of instances	Proportion of Whole Circle	Totals:
1	1	1	1
1/4	4	0.1956	0.7824
1/4	4	0.25	1
1/16	4	0.025	0.1
3/16	8	0.1661	1.3288
3/4	4	0.8044	3.2176
9/16	4	0.6383	2.5532
1/8	8	0.0977	0.7816
3/8	8	0.4023	3.2184
1/2	4	0.5	2
		TOTAL NUMBER:	15.982

The total number 15.982 was rounded to 16.

This value of 16 was then divided by the number of square kilometres represented in the original diagram, namely 1600 km^2. This gave us a value for the density of the high density balloon areas of 1 balloon per 100 square kilometres.

This concentration of balloons in urban areas guarantees the coverage of internet for everyone living in these areas.

Based on the working shown in the previous paragraphs, we came to the conclusion that 1084 internet transmitting balloons would be needed to provide the whole of New Zealand (including the surrounding islands) with internet access. This is the number of balloons that would constantly need to be above our country, with higher densities of balloons over the larger cities. As calculated in the low density calculations, 1033 balloons are needed to provide for all of the rural areas in New Zealand. As calculated in the high density calculations, 51 balloons were needed to cover all of the urban areas. This proves that we will need 1084 balloons in total (1033 + 51).

Mathematical model of the situation in Excel: (See Appendix)

The situation of the movement of the balloons can be modelled in excel. This can be done by finding the x and y values of a balloon at a given time, and by then finding how they interact with each other because of it.

The first thing to do was to set up a starting point for the balloons. This was done using the balloon array that we decided would be used in the lower population density areas, namely with 1 balloon per 400km^2. In this system, there is a distance of 20 km between each balloon (assuming that the balloons are in a square grid as explained above). Starting x and y for positions of balloons were inputted into Excel to model ideal "starting positions".

The next thing to do was to calculate the random component of the wind that would affect the movement of the balloons. In order to do this, we calculated that after 15 minutes, assuming the values for stratospheric wind given by Google[2], the average balloon would have moved by ±8 km to ±32 km. Therefore, by simulating this random movement of the balloons, and calculating by how much the balloons will "bounce back" due to their being likened to a spring[3]. In order to simulate this, I used the following formula in Excel:

=(D13+INT(RAND()*(15)-8))

Where the simulated wind effects are assumed to give a random movement to the balloon, of maximum magnitude $\pm$ 0.25 hours * 32 = $\pm$8 km.

With D13 representing any x or y value relating to the position of one of the balloons (only in the horizontal plane), thereby simulating the random wind that might affect the balloons in that 15 minute time period.

The next stage was to analyse the difference in values between multiple balloons.

=F16 + (0.5 * ((F16 - F18) + (F16 - F14)))

This formula means that in the y axis, the balloon moves slightly towards or away from the other 2 balloons in the y axis surrounding it, by calculating the difference between the values, summing them, multiplying them by a half, and then adding these to the original value for the y position of the balloon. The same is repeated for the x axis. This was repeated 3 times, the results of which are demonstrated here for one of the experiments.

The result of this exercise was that there was not a significant change in the positions of the balloons over time. Looking at the values that were generated in the third and final round of analysis after 45 minutes, the values are not too much different from the original values that were given, for example, on the spreadsheet, balloon (5, 5) has changed its y position from the original 120 to 134. Therefore, it can be said that the arrangement of the balloons that we decided upon for low population density areas is good enough to allow for reliable coverage of low population areas in this simulation. This represents a worst case scenario, in which the movement of the balloons is completely random. In real life, the amount of adjustment of the balloons height would be much more targeted, in that the knowledge of where the wind currents in the stratosphere are and which altitude to move towards is known. Therefore, it can be said that our density of balloons in New Zealand is appropriate for low population areas in order to provide reliable internet access.

[2] www.google.com/loon
[3] Patent - Relative Positioning of Balloons with Altitude Control and Wind Data US20130175391, 2c).

CONCLUSION:

Our calculations only included the use of area covered by the overlapping balloons which incorporated the average amount of balloons covering a single given point. This did not include the edges of the greater reception area which would only have individual balloons that sit on the exterior of the collective group connecting to the ground area, which are only partly overlapped and therefore provide less effective signalling to the surface beneath them. However, as we considered the waters immediately surrounding New Zealand in our calculations of the overall area that needed to be covered by Project Loon, we already accounted for any usage on or just off the shores of the country. Therefore, the areas with lower signal strength from lack of overlapping balloon signals would hardly be used anyway and would not cause a problem for any users off shore. This extra area is also helpful in accounting for the movement of the balloons due to wind, as they will be moved around despite corrections done from ground bases and/or super node balloons. Even though the main area of balloons we have calculated may shift, there will still be a slightly larger amount of signal surrounding that, albeit not as strong or reliable. Reference Figure 6.

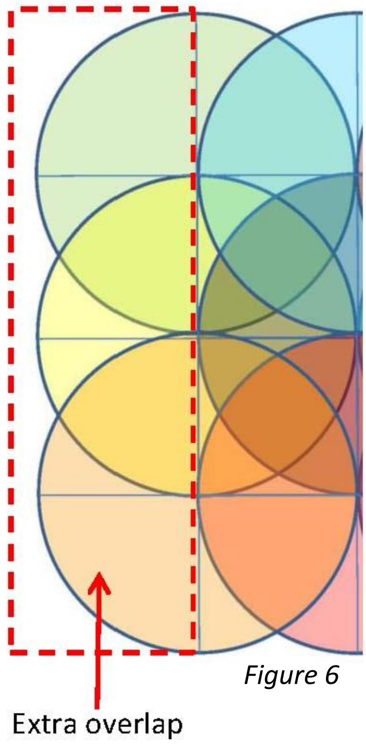


Figure 6

If we had had more time, we would have calculated the wind power, and how it would change the distribution of the balloons over New Zealand. This would have given a more accurate description of the coverage.

We would also investigate different models as to the different densities in different parts of the country to accurately distribute the coverage according to the areas of higher/lower internet usage.

We found that 1033 balloons for non-urban areas in New Zealand, and would need 51 balloons for urban areas. With more time, we could have separated these numbers into more refined categories. But we found that in order to guarantee internet access to everyone in New Zealand, our models would be sufficient, making the total number of balloons needed 1084.

Appendix:

Balloon on X axis		1		2		3		4		5		6		7		8		9		10	
		x	y	x	y	x	y	x	y	x	y	x	y	x	y	x	y	x	y	x	y
	Balloon on Y axis:																				
	1	0	180	20	180	40	180	60	180	80	180	100	180	120	180	140	180	160	180	180	180
Random Change		3	185	12	184	45	186	61	174	84	186	98	172	117	182	137	183	166	181	180	183
	2	0	160	20	160	40	160	60	160	80	160	100	160	120	160	140	160	160	160	180	160
Random Change		2	160	21	161	33	155	63	153	76	162	102	153	117	160	142	161	160	165	176	157
	3	0	140	20	140	40	140	60	140	80	140	100	140	120	140	140	140	160	140	180	140
Random Change		-7	143	19	142	46	140	54	138	84	135	100	143	114	140	144	140	164	137	182	145
	4	0	120	20	120	40	120	60	120	80	120	100	120	120	120	140	120	160	120	180	120
Random Change		4	121	22	114	41	123	54	112	85	114	103	125	116	122	143	114	160	116	181	126
	5	0	100	20	100	40	100	60	100	80	100	100	100	120	100	140	100	160	100	180	100
Random Change		-5	98	23	97	34	104	62	96	85	103	92	106	118	93	139	98	165	95	177	96
	6	0	80	20	80	40	80	60	80	80	80	100	80	120	80	140	80	160	80	180	80
Random Change		-7	85	24	76	44	82	63	76	86	73	98	84	112	81	138	85	155	86	185	85
	7	0	60	20	60	40	60	60	60	80	60	100	60	120	60	140	60	160	60	180	60
Random Change		-4	66	24	63	35	62	54	65	76	55	94	56	121	63	139	61	160	65	175	64
	8	0	40	20	40	40	40	60	40	80	40	100	40	120	40	140	40	160	40	180	40
Random Change		-4	34	17	45	40	45	56	35	86	45	106	34	118	33	139	42	163	34	182	42
	9	0	20	20	20	40	20	60	20	80	20	100	20	120	20	140	20	160	20	180	20
Random Change		-2	26	14	18	42	12	56	22	72	14	101	22	116	13	134	20	155	24	181	17
	10	0	0	20	0	40	0	60	0	80	0	100	0	120	0	140	0	160	0	180	0
Random Change		-3	-7	14	-6	40	-8	64	0	73	-1	101	-4	121	-5	134	-4	160	-7	174	-1

FIRST ANALYSIS AFTER 15 MINUTES

	X Number	2		3		4		5		6		7		8		9	
	Y number	x	y	x	y	x	y	x	y	x	y	x	y	x	y	x	y
	2	26.5	164.5	20.5	153	68.5	147.5	68	171	105	145	118.5	163	143.5	159.5	155	171
Random Change		28.5	156.5	24.5	146	64.5	141.5	63	172	110	144	111.5	162	149.5	164.5	147	177
	3	16.5	142.5	55	140	49.5	138.5	87.5	129.5	97.5	148.5	111.5	138.5	145.5	141.5	168	131.5
Random Change		12.5	138.5	50	134	45.5	134.5	81.5	123.5	89.5	143.5	113.5	137.5	147.5	138.5	173	137.5
	4	23	106	42	133	50	105.5	85.5	109.5	110	132	116	124.5	144.5	109	155.5	112
Random Change		28	110	45	132	48	111.5	88.5	105.5	114	126	115	118.5	143.5	101	159.5	114
	5	23	93	25.5	111.5	65.5	88.5	84.5	105	83.5	114	122	84	137.5	102	172.5	93
Random Change		18	89	20.5	108.5	65.5	91.5	89.5	103	82.5	112	122	78	129.5	108	178.5	94
	6	24.5	68.5	53.5	88	68	74.5	91.5	66	103	91	104.5	77.5	137	86.5	147.5	87
Random Change		16.5	64.5	53.5	92	64	75.5	93.5	60	104	85	97.5	77.5	143	79.5	147.5	82
	7	27.5	62	28	60	48.5	71.5	66	49.5	86	53	127	67.5	139.5	58	161	67.5
Random Change		23.5	65	27	52	49.5	64.5	59	53.5	85	45	125	65.5	139.5	56	163	59.5
	8	15	50.5	41.5	50	57	25	98	55.5	114.5	29	117.5	28	141.5	50.5	168.5	26
Random Change		19	50.5	33.5	49	56	25	104	61.5	118.5	24	110.5	27	139.5	52.5	173.5	22
	9	12.5	17	44	4	52	31	64.5	6	98.5	30.5	112.5	5	131.5	21.5	148.5	29.5
Random Change		13.5	9	49	6	46	37	58.5	-2	102.5	32.5	114.5	6	128.5	19.5	153.5	22.5

SECOND ANALYSIS AFTER 30 MINUTES

	X Number	2		3		4		5		6		7		8	
	Y number	x	y	x	y	x	y	x	y	x	y	x	y	x	y
	3			65.25	131.5	34.75	140.25	87.25	108	67	156.5	113.75	134	148.5	139.5
Random Change				62.25	124.5	38.75	139.25	91.25	108	68	149.5	113.75	126	154.5	142.5
	4			54.75	153.25	40.5	104.25	91.5	92.25	142	140	112.25	123.5	148.5	85.75
Random Change				52.75	152.25	42.5	100.25	89.5	96.25	146	139	106.25	125.5	146.5	82.75
	5			-8.25	126.75	75	77.25	88	104.25	56	133.5	137.75	46	115.75	130
Random Change				-4.25	132.75	78	71.25	84	103.25	58	129.5	132.75	51	116.75	134
	6			83.25	114	70.5	75	112.75	39.75	124.25	101.25	71.5	72.75	151.5	79.25
Random Change				89.25	111	65.5	67	114.75	37.75	123.25	95.25	63.5	71.75	152.5	82.25
	7			10.5	39.25	39	76.25	19.25	52.25	58.75	30.5	146	80.5	137.75	49.5
Random Change				14.5	43.25	31	77.25	19.25	45.25	61.75	22.5	147	85.5	136.75	45.5
	8			29	60.25	64.25	-5.25	149.25	98.5	143.25	3.75	101.25	15.75	145	80.5
Random Change				31	62.25	65.25	-2.25	149.25	92.5	149.25	2.75	93.25	20.75	140	72.5

THIRD ANALYSIS AFTER 45 MINUTES

	X Number	4		5		6		7	
	Y number	x	y	x	y	x	y	x	y
	4	26.625	76.25	91.375	72.875	229	167.125	89.25	140.125
Random Change		28.625	70.25	88.375	77.875	228	170.125	90.25	135.125
	5	102	24.5	65.875	106.125	-18.625	181.875	180.625	-29.75
Random Change		98	23.5	61.875	107.125	-17.625	186.875	177.625	-34.75
	6	76.5	59.625	177.875	-5.625	186.625	135.75	-12.875	54.75
Random Change		77.5	63.625	171.875	0.375	180.625	138.75	-16.875	47.75
	7	-3.375	110.25	-93.5	40.625	-12.75	-20.375	215.625	137
Random Change		-10.375	103.25	-91.5	38.625	-19.75	-15.375	219.625	141

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Please Note: All sources were found and used on the 10th of August 2013.

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