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Airborne Internet Providing Tethered Balloon System

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Abstract: In this paper we shall introduce a new system for providing wireless network communication over a specified area using 'lighter than air' balloons. This technology will replace the existing fiber optic network system. This will be done by using a tethered balloon along with the payload (containing a receiver, a transmitter and a radio communication device).This payload will be suspended from the ground at an altitude (depending on the area of coverage required). Users under this area will be able to access this system directly for internet connectivity. This system can be used over large areas like universities, companies and societies to provide internet facility to their users through Wi-Fi or over an area where the user is specified (commercial purposes). Currently Google is working on similar idea called the 'Google Loon' in which they use high altitude balloons which float at an altitude twice as high as air planes and the weather. They recently tested this system over New-Zealand by providing internet to their pilot testers on ground. Their balloons not being stationary, move with directional winds and have to be replaced one after the other to maintain consistency. This can be a huge problem over the areas where upper atmospheric winds are not in favorable direction. We can resolve this problem by using our stationary tethered balloon system which can communicate with the loon balloons to provide internet facility over a desired area. Moreover when our balloon will communicate with the loon balloon it will increase the coverage area as the loon balloon has to communicate to a point which is above the ground. Our system will not only replace the existing fiber optic system but it will also be self-sustaining i.e. It will generate its own power using solar panels.

I. INTRODUCTION

Here we have designed an airborne tethered balloon system to replace the existing optical fiber technology. As an aerospace engineer our focus is mainly on maintaining the height and the aerodynamics of the balloon along with the payload for longer duration (at least a month).Along with this have also considered the benefits of the existing technology in our payload which will be suspended from the balloon system. Our focus is mainly concentrated over the four major uses of this tethered balloon system- point to point data transmission (end to end user), open network for multiple users (universities, companies, rural areas), closed network for commercial purposes and in support of GOOGLE LOON(the places where their balloon is unable to provide the internet facility to the users, our balloon will interact with their balloon to help provide this Wi-Fi facility worldwide by using the Google Loon transmitters and receivers)

Our system is divided into two sections:

1) Airborne Unit: It everything from balloon and its monitoring system to networking components in payload.
2) Ground system: It is consisting of ground control room, servers and tethered system.

II.COMPONENTS OF THE AIRBORNE SYSTEM

Airborne Unit

This unit consists of the balloon, the payload and the parachute (in case of any emergency). Payload will consist of a pressurized helium gas bottle, on board receivers, transmitters for power generation and storage devices.

(a)Balloon Design:

As balloons are made up of elastic materials and have a huge tendency of moving and changing their shape with the flow of wind so here we are introducing our design of the balloon with carbon fiber skeleton over which polyethylene plastic sheets are attached in the form of layers. We use polyethylene plastic sheets and stitch them together over the skeleton to form a balloon in the form of an envelope, we provide multiple layering of same material in order to prevent the leakage of helium from the balloon. Even after multiple layers of polyethylene a small amount of leak from the balloon will take place over time due to which the balloon will lose its lift and gradually come down. So on board we have attached pressure sensors (inside the balloon) which will keep a track of pressure drop and reduction in the gas quantity within the balloon. Once the pressure reaches below the upper limit of the lift, the helium pressurized gas bottle will be fed with a command and then helium will be refilled in the balloon. This entire system will keep the balloon in the air for approximately 30-50 days. This balloon is designed in such a way that it can be refilled and reused.

It is very important that our balloon remains stationary in the air for continuous connectivity with the ground but this becomes difficult as at an altitude of 3-7km, winds are strong and almost continuous at this height hence for this we need a design which provides minimum drag and can stabilize itself in changing winds.

For least drag geometry we experimented with following geometrical shapes and found following results:

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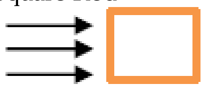
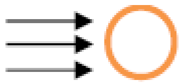
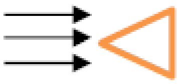
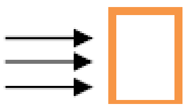
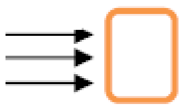
Table 1 Cd of various shapes

S.no	Body	Status	C_D
1	Square Rod 	Sharp Corner Round Corner	2.2 1.2
2	Circular Rod 	Laminar flow Turbulent flow	1.2 0.3
3	Equilateral Triangular Rod 	Sharp face Flat face	1.5 2
4	Rectangular Rod  	Sharp Corner Round Corner	1.3 (L/D=3) 2.5 (L/D=0.5) 0.7 (L/D=4) 1.2 (L/D=0.5)
5	Elliptical Rod 	Laminar flow Turbulent flow	0.6 (L/D=2) 0.25 (L/D=8) 0.2 (L/D=2) 0.1 (L/D=8)

From above we choose the "elliptical rod" this shape will help us to maintain least drag condition and motion but this alone is not sufficient for keeping balloon stationary and hence we devised an experiment in which we generated a hole or a passage in center of the balloon running through its lateral axis which allows air to pass through. Idea was that this will maintain balloon in stationary position for longer period of time as wind will always try to take the path of least resistance i.e. will always try to pass through the passage and hence the balloon will always face towards the direction of wind.

This experiment was setup in a subsonic wind tunnel and positive results were obtained. We have kept the balloon in various orientations, when the wind tunnel was switched on the balloon oriented itself in direction of the wind and further rotation was suppressed. The reason for this rotation and alignment of balloon with the direction of wind was the pressure difference between two different sides of balloon. This is because of the presence of a passage of wind which lowers the pressure at its side by increasing the wind velocity and hence the balloon rotates in the opposite direction to stabilize the pressure.

(b)On board receiver:

This is the main receiver put on board which will receive data from the ground station for distribution. It is the most basic receiver antenna used in optical wireless communication made with very light materials like aluminium. The data speed depends on the user accessing this network having a maximum speed of multi-G bit/sec. In case the use is using the Google loon system, we can use those transmitters on board to interact with their balloons

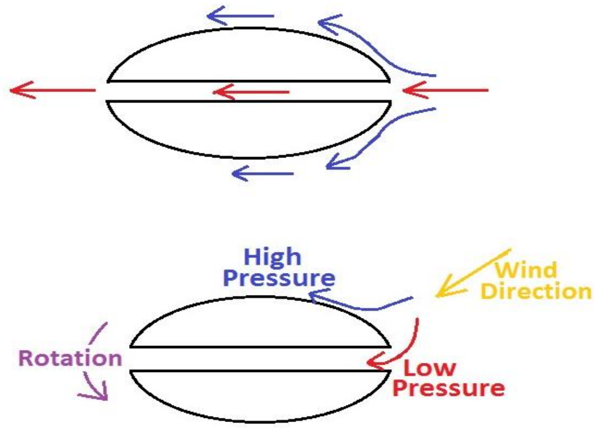


Figure 1 Flow through the balloon cross section

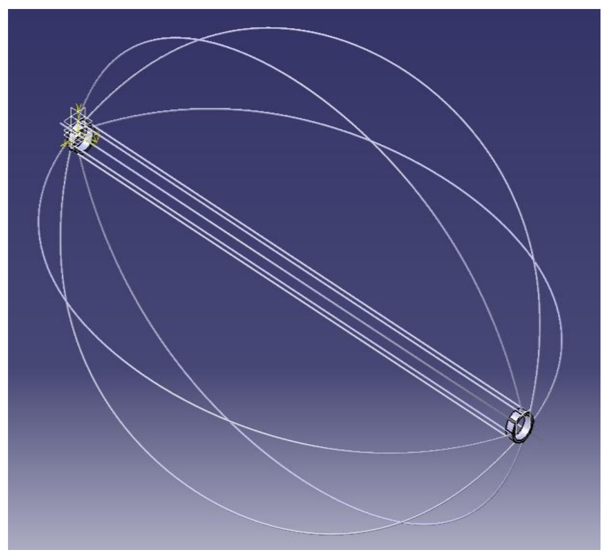


Figure 2 Balloon skeleton

(c)Power unit:

Here we use solar panels to generate electricity on board so that this system becomes independent of power requirements. As weight is a huge issue we use light weight affordable solar panels which open during the day time and close during the night time. A single solar panel has the capacity to generate a power of 120 Watt. The number of solar panels being used will depend on the configuration of the payload. And for the storage of power we use light weight lithium ion batteries.

(d) Parachute:

Approximate Parachute Sizes for payload Weigh of 15 kilograms was tabulated.

Using equation **V=sqrt (2W/ Cd r A);**

Where;

W= weight,

Cd = Drag coefficient,

r = air density, and

A = area of parachute.

Table 2 Diameter for parachute for different descent rates

Descent Rate	Diameter
3 mps	672.84 cm
4 mps	504.63 cm
5 mps	403.70 cm
6 mps	336.42 m

(e) Gimbals:

Gimbal is a device works by making an objected mounted over it independent of its rotation. We attach 3 gimbals in either axis (X,Y & Z) to prevent the rotation of antenna. This is only used in receiver antenna of airborne system and in transmitter antenna of airborne system (only for point to point connectivity).

(f)Weight estimation:

Table 3 weight of components

Equipment	**Weight**
Balloon	4 Kg
Helium refilling system (27CF, 1800psi)	3 Kg
Optical wireless transmitter receiver	0.26Kg
Wi-Fi router	0.26Kg
Point to point transmitter	0.25Kg
Solar panel (120W,7.2apm)	2.10 Kg
Solar panel (60W,3.6apm)	1.15 Kg
Solar panel (28W,1.8apm)	0.45 Kg
Lithium ion battery	0.5Kg
Tethered rope (Kevlar, 450Kg tensile strength)	4.46 Kg per Km
Miscellaneous	0.5 Kg

III. COMPONENTS OF THE GROUND UNIT:

This includes the ground station facility from which all the activities are observed and controlled along with the receivers provided for the users. And a tethered balloon system to maintain and hold the balloon in particular altitude.

(a)Ground station:

This includes the server room, main optical transmitter for communication purposes with the balloon and tethered system for controlling the motion and movement of the balloon. Server room will be any other room which we use at present for provision of internet. For the optical wireless communication we will need an optical wireless transmitter to send data to the air-bone unit (payload) having a tethered system too in order to maintain and change the altitude of the balloon thereby resisting its motion to winds and a refilling room to refill the balloon with helium.

(b) Receiver provided to the user:

These receivers are required by the user connecting to this network in order to communicate or interact with the network. For open Wi-Fi network and close Wi-Fi network, the user does not require a receiver. They can directly connect to the Wi-Fi using the device installed. Whereas for an individual user at a considerably long distance we are providing an optical wireless communication receiver to communicate also we have made communication provision to interact with the Google loon receivers by using their receivers itself.

(c) Tethered balloon system

The tethered balloon has a rope fixed to the ground. After hydrogen is filled in the balloon the payload is attached to it. When the initialization and optimization process has been completed and the balloon is ready to be released to a certain height at a certain speed, a release mechanism is required as the rope which is attached to the ground is usually of a span of 3-4 kilometres and to fix this problem we are using a motor which will be a part of this balloon system. The main objective of this motor will be suspension of the rope in the descent stage as well as coiling and folding of the rope during ascent stage

The tethered balloon system is used for maintaining and controlling the altitude till which balloon rises in the air this contains of rope folding and coiling mechanism attached with a motor for release and retrieval of balloon and payload.

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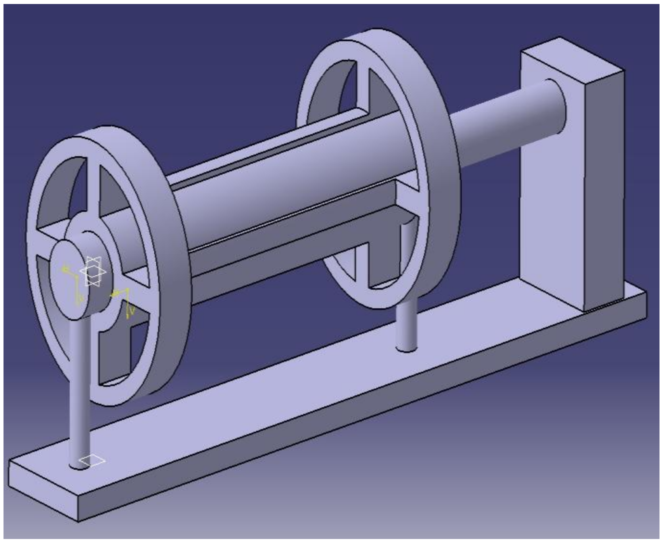

Figure 3 Tethering system

IV. TYPES OF COMMUNICATION CHANNELS

(a)Open network:

Our system can be used as an open network by installing few long range Wi-Fi routers on the payload. The number of routers will depend on the number of user accessing that network. Today wide ranges of such routers are available with gigabits of speed therefore any such router can be used for this purpose. This system can be used over universities, company campuses and over societies to provide internet to the users in these areas. This will not only replace the fiber optical cables but also ensure users the access to this internet facility anywhere in that locality.

(b)Closed network:

This system helps multinational companies (MNCs) to replace their network to wireless. Also it can be used by internet providers for commercial purposes, today we are able access to the internet at our homes either using the phone network or using cable network or small dongles which provide wireless internet are usually expensive. Our system gives those network providers a chance to provide internet connectivity to its users without using wires and cables this will not only cut down the cost of the setup but also grant freedom from failures that occur due to failure in cables and wires. Also this helps in making our streets free from cables thereby making them look neat and beautiful. For this network the user only requires an antenna for receiving the data from their service provider hence developing this system in a more secure manner. Also the data transmission becomes cheaper.

(c)Private network:

This kind of network can be used by any organization which requires security and faster internet speeds for their private networks. These organizations includes astronomical observatories in remote areas which rely on internet connectivity for operating of their telescopes and data transmission to other observatories from the main control room. Army operations can also use this network for easy and fast deployment and better connectivity in remote areas. We can use this kind of network to introduce internet facilities in the remote and rural areas of any country(specially in developing countries) this will not only boost the education level but will also help farmers to understand their crops and predict weather better, hence making them more efficient.

(d)With Google LOON:

Our network can also be used with the Google Loon's network as we are aware of the fact that it is very difficult for Google loon's balloon to stay over a certain position always as their balloon completely relies on wind direction for its motion. We provide a tethered balloon in those areas where it is difficult for Google loon's balloon to stay for a longer duration. They can communicate with our balloon and our system will provide network connectivity on the ground for them. This not only make their system more reliable but also increase the range of their connectivity as now they have to communicate with a point above the ground.

(e)Array of balloons:

This can be used in either of the above cases where this wireless network has to reach a long distance and also to provide this network in the areas it passes over.

V.SIMULATION RESULTS AND PERFORMANCE ANALYSIS

The aim of the wireless design is to get as much internet connectivity as possible from one end to the other in order to receive a stronger signal that would result in higher link margin and greater link availability. The proposed wireless system is designed in such a way that it is able to achieve transmission link distance, transmission data rate and transmission bit rate-distance product over a wide range of the parameters including: power transmitted (PT)=100 mWatt, optical wavelength range (□)=0.85 μm to1. 55 μm, transmitter beam divergence (θ)=100 degree, receiver diameter (DR)=0.1-0.5 m, link distance range=0.1 to 10 Km, receiver sensitivity (SR)=5 μWatt, and transmitter and receiver losses (n)=50 %. Based on these parameters for our wireless design, it is easy to achieve the best transmission bit rates and transmission distances.

We used following equation in order to calculate results:

1) Link budget equation

$$P_{received} = P_{transmit} \cdot \frac{57.295 A_{receiver}}{(\theta L)^2} e^{-\alpha L}$$

2) Total loss coefficient

$$\sigma L = \sigma_{rain} L + \sigma_{fog} L + \sigma_{snow} L + \sigma_{scintillation}$$

For above equation absorption rate can be found using various models available such as Kruse model according to which

$$\sigma_{fog}(Km^{-1}) = \frac{3.912}{V}\left(\frac{\lambda}{\lambda_0}\right)^{-q}$$

$$\sigma_{snow}(dB/Km) = AS^b$$

$$\sigma_{rain}(dB/Km) = 1.076R^{2/3}$$

$$\sigma_{sc}^2 = 4.\left(23.17\left(\frac{2\pi}{\lambda}10^9\right)^{7/6}\right)C_n^2 L^{11/6}$$

3) Power loses during transmission

a) Gaussian beam intensity distribution

$$F_s = 10\log\frac{P_{receiver}}{P_{total}} = 10\log\left(1 - e^{-\frac{2R^2}{w(L)}}\right)$$

b) geometrical loses

$$\frac{A_R}{A_T} = \left(\frac{57.295D_R}{D_T + 100.\,d.\theta}\right)^2,$$

Where AR is the effective area of the receiver lens, AT is the effective area of the transmitter lens, DR is the diameter of the transmitting lens, DT is the diameter of the receiving lens, d is the distance between the wireless optical transmitter and receiver, θ is the divergence of the transmitted laser beam in degrees. Based on curve fitting MATLAB Program, the fitting equations between optical signals to noise ratio (OSNR), the operating signal wavelength for transmitter and receiver, and the wireless link length are:

$$OSNR = 17.35 - 12.27L + 7.05L^2 - 5.87L^3$$

$$OSNR = 3.85 - 10.73\lambda + 2.13\lambda^2 + 9.75\lambda^3$$

The radio frequency transmission response provide the relative loss or gain in a wireless communication system links with respect to the signal frequency. Any signal attenuation due to the wireless communication links can be expressed:

$$Transmission(dB) = 10\log\left(\frac{P_{transmitter}}{P_{incident}}\right)$$

Where Ptransmitter is the radio frequency power calculated at the output of the receiver, and Pincident is the radio frequency power calculated at the input to the laser transmitter. Based on curve fitting MATLAB Program, the fitting equations between transmission response, operating radio frequency, and amplification range are:

1) Without amplification:

$$Transmission(dB) = 10.82 - 2.05f + 7.42f^2 - 4.23f^3$$

2) With amplification:

$$Transmission(dB) = 3.09 + 13.65f - 2.56f^2 + 1.85f^3$$

The Shannon capacity theorem to calculate the maximum data transmission bit rate or the maximum channel capacity for the wireless optical links is as follows:

$$C = B.W\log_2(1 + OSNR), \quad Gbits/sec$$

Then the Shannon bit rate-distance product can be determined by:

$$P_{Sh} = C.\,L \quad , Gbit.km/sec$$

Where L is the wireless link length in km.

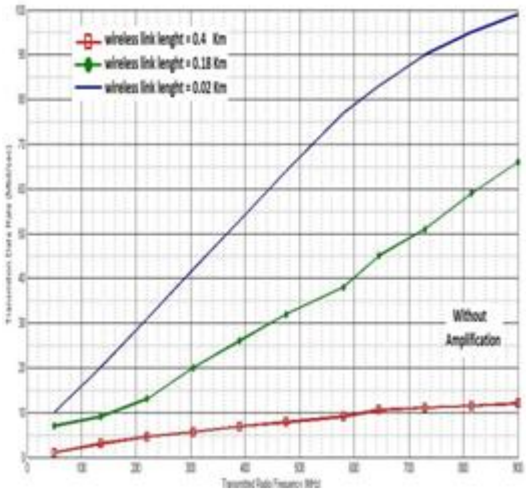

Figure 4 Transmission data rate vs Transmission frequency (without amplification)

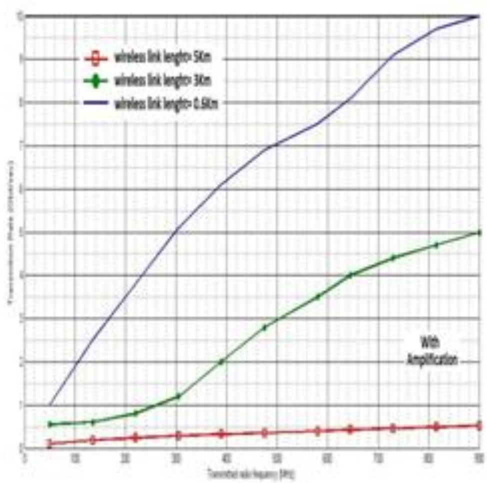

Figure 5 Transmission data rate vs Transmission frequency (with amplification)

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