`2008 IEEE Region 10 Colloquium and the Third International Conference on Industrial and Information Systems, Kharagpur, INDIA December 8 -10, 2008.

Paper Identification Number: 308

Low Cost Wireless Internet Access for Rural Areas using Tethered Aerostats

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***Abstract*— ICT plays an indispensable role in the overall development of rural areas, especially in developing economies. There is an urgent need to bring the rural areas into the mainstream by providing them last mile connectivity, especially during natural disasters and calamities, when other modes of communications are severely hampered. This paper describes a low cost innovative solution for providing internet access to rural areas using tethered aerostats, which can easily be relocated. The total cost of this relocatable system was found to be nearly half of that of a conventional fixed tower based system.**

***Index Terms*—ICT, Internet, P2MP, Rural areas, Tethered Aerostat, Wireless Communication**

I. Introduction

Lack of infrastructure in rural areas and high installation costs as compared to urban areas are the two major hindrances in building a wireless network which would cater to needs of rural community, especially when other modes of communication are disrupted. The objective of this project was to develop an easily re-locatable Wi-Fi based low cost communication system in rural areas, for knowledge sharing and community participation. The feasibility of the system was established through experiments and a field trial. Large scale deployment of the developed system can play a major role in bridging the gap between distant communities which are beyond the range of present communication towers.

Wireless bridges can provide connectivity up to 10 Km. The conventional approach is to mount antennae (typically directional) on a high tower which is then connected to the wireless bridge. These antennae look at client side antennae through line of sight (LOS) connectivity for internet access. It is the cost of these high towers (50 to 100 meters) at the base station which makes deployment of such wireless networks expensive. Further, these towers, once erected, are not re-locatable to other areas where communication needs may arise.

This paper describes an innovative concept using tethered Aerostats as a platform for raising wireless communication payload, which overcomes the two main limitations of high towers listed above. Tethered aerostats are an outcome of Lighter-Than-Air Technology, where static lift production mechanism is based on the Archimedes Principle [1]. An aerostat does not require any additional energy to reach to a certain height. For a given volume of envelope that contains the lighter than air gas, displaced weight of air creates a vertically upward buoyant force that leads to the lift. One or more ballonets are provided inside the envelope to adjust the buoyancy. The envelope volume is large enough to ensure that the displaced air should be able to produce sufficient lift, under the entire range of operating conditions, to balance all the weight groups of the aerostat system, viz., envelope, fin, nose battens, ballonets, pivot mechanism, payload, tether, recovery system, gas filling ports, and safety valves.

Aerostats are used all over the globe as a platform to house high-resolution sensors for applications such as aerial surveillance, regional atmospheric data collection and balloon-barrage system. Depending on the payload, range of surveillance, and operational time, these aerostats can be launched to any desired altitude from a few meters above ground level to as high as 5000 m above ground level. Of course, the payload carrying capacity of an aerostat is reduced as the operational height is increased.

Aerostats can easily be deployed at high altitudes, ensuring

Manuscript received June 15, 2008. This work was supported in part by One World South Asia Organization through EGIFT Fellowship under Project code no 06 IU 012

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disturbance free LOS for the communications payload. Once they are deployed, there is very little recurring additional expenditure to keep them afloat, except in the form of small amounts of lighter-than-air gas, just to top-up for the leakages through the fabric over a period of time. Due to its

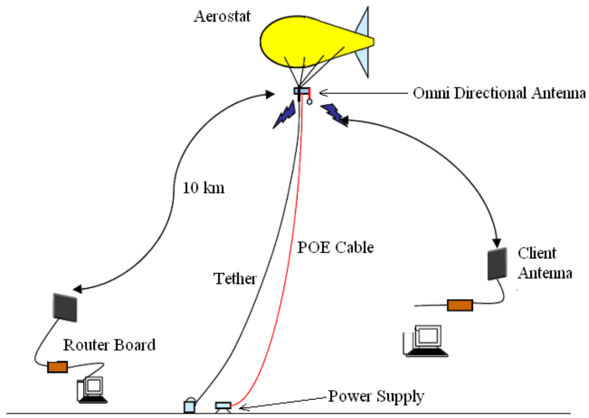

Figure 1. Conceptual Sketch of the overall system

aerodynamic shape as well as provision of fins, an aerostat can remain fairly steady even in strong winds and hence can provide stable line of sight connectivity. An omni-directional antenna mounted below the aerostat leads to a relaxation in the antenna direction alignment requirement.

A conceptual sketch of proposed communication system is shown in Fig. 1. The PoE cable carries data as well as power from ground to the router box mounted below the aerostat. The receiver antenna at client location which may be in the range of 10 to 30 km from the aerostat spot location can easily receive these signals.

Section II of the paper focuses on the networking part of the proposed model. Section III describes the procedure for arriving at sizing of Aerostat. Experimental details and field trial are included in Section IV. Cost Analysis is provided in Section V followed by conclusions in Section VI.

II. Wireless Communication

Wireless infrastructure can be built for very little cost compared to traditional wired alternatives. Using inexpensive off-the-shelf equipment, high speed data networks can be built for connecting remote areas together. The primary technology used for building low-cost wireless networks belongs to 802.11x family of protocols, also known as Wi-Fi [2].

A. IEEE 802.11b Standard

802.11b [3] uses the ISM (Industrial Scientific Medical) band from 2.400 to 2.495GHz. Due to the ubiquity of equipment and unlicensed nature of the 2.4 GHz ISM band, our work is focused on building a network using 802.11b. It makes use of Direct Sequence Spread Spectrum (DSSS) modulation and has a maximum rate of 11 Mbps, with actual usable data speeds up to about 5 Mbps. 802.11b can be used in a point-to-multipoint configuration, wherein an access point communicates via an omni-directional antenna with one or more clients that are located in the neighborhood of the access point. Typical indoor range is 30 m (100 ft) at 11 Mbit/s and 90 m (300 ft) at 1 Mbit/s. The overall bandwidth is dynamically shared across all the users on a channel depending on the individual demands. The protocol with few modifications can also be used to achieve a range of several

kilometers by using high-gain directional antennas when line of sight connectivity is available in fixed point-to-point

TABLE I Wireless Router Specifications

WLAN support	Two 802.11 a+b+g Wireless miniPCI cards
Processor	266 MHz NSC SC1100 system on a chip CPU (Intel Pentium MMX architecture)
RAM	64MB SDRAM SoDIMM
Ethernet Ports	Two 10/100 Mbps using the NSC DP83816
Flash BIOS	2 Mbit on board
Flash Memory	Compact Flash 64MB
USB connector	1.0 version
PoE Standard	802.3af
Operating Temp.	-20°C to +70°C
Weight	209 g
Board Size	105 mm x 215 mm (4.13 inch by 8.46 inch)

TABLE II Antenna Specifications

Specifications	Omni-directional Antenna	Directional Antenna
Frequency	2.4 GHz	2.4 GHz
Gain	15.4 dBi	19 dBi
VSWR	1.5 : 1	1.5 : 1
Polarization	Vertical	Vertical
H. Beamwidth	-	18º
V. Beamwidth	-	18º
Cross Polarization	-	>30 dB
Max. Input Power	100 Watts	100 Watts
Impedance	50 Ohms	50 Ohms
Windage	200 kmph	-
Connector	N-Female	N-Female
Dimensions	1780 mm (height)	394 x 394 x 28mm
Weight	1.16 kg	1.8 kg

arrangements.

B. Building a 802.11b wireless network

We are using Mikrotik's RB/KAO [4] outdoor router packages at the base station and client end. The router board consists of a 266 MHz processor with 64MB RAM. 802.11b base station device is operated in master mode (also called AP or infrastructure mode). The wireless card creates a network with a specified SSID (Service Set Identifier) and channel, and

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offers network services on it.

C. Software

All configurations were done using *Winbox* software tool [4]. The *Winbox* console is used for accessing the MikroTik Router configuration and management features, using graphical user interface (GUI). Four *Winbox* utilities viz., *Traceroute*, *ICMP Bandwidth Test*, *Packet Sniffer* and *Ping* were used to analyze the link performance during experimentation.

III. AEROSTAT DESIGN

A. Aerostat Design Methodology

A methodology for sizing of a tethered aerostat has been developed by Raina et al. [5]. This methodology arrives at geometrical dimensions and mass breakdown of an aerostat that meets certain user-specified operational and performance related requirements. The methodology was used for sizing of an aerostat meeting the requirements and assumptions shown in Fig. 2

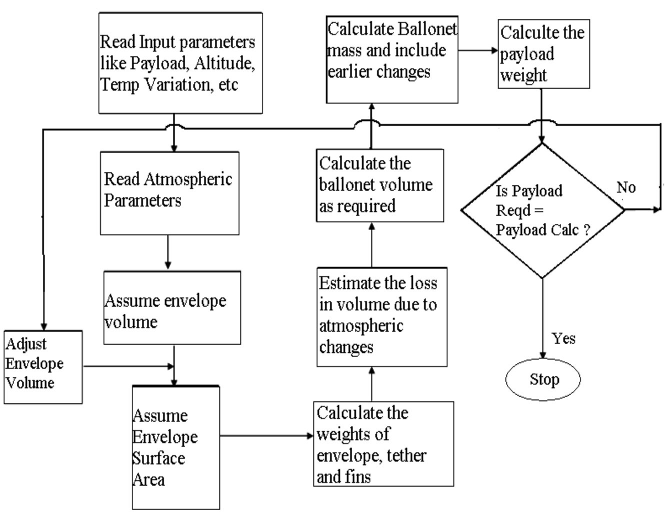

Figure 2. Flow Chart of the aerostat design methodology [5]

Depending on the payload requirements, operating altitude, temperature variation and other atmospheric input parameters, the envelope volume is assumed at the start, using a thumb rule. The surface area and other parameters like weight of envelope, tether and the fins are then estimated. Once the weight breakup is obtained, the volume and hence mass of the ballonets are calculated. Since the value of net lift available is known, the payload capacity of the aerostat can be estimated. The envelope volume is iteratively adjusted till the payload capacity of the aerostat matches the requirement specified by the user.

B. Aerodynamic Stability

Once the aerostat has been deployed it is mainly subjected to wind loading. The fins are the main directional stabilizers for the aerostat, as they prevent the aerostat from re-orienting itself. We also determined the tether profile under various wind loading conditions, as depicted in the Fig. 3, using the approach suggested by Wright [6]. In our case, an omni-directional antenna was mounted below the aerostat; hence blow-by was not of much consequence. A swivel coupling can be used to ensure directional stability in case of directional antennas.

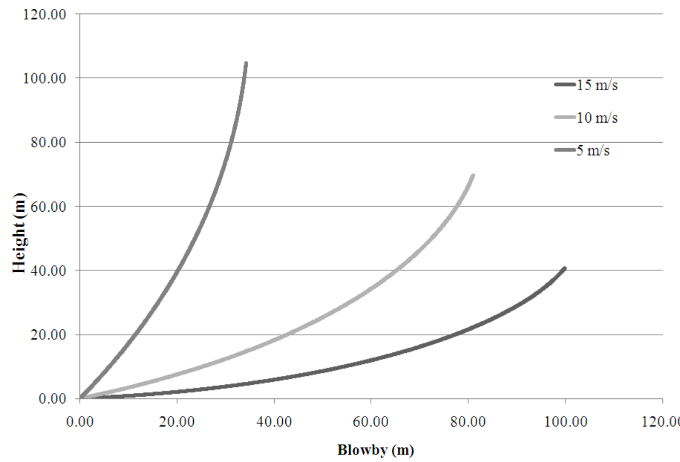

Figure 3. Tether profiles for various wind speeds from the mooring point

TABLE III OUTPUT FROM AEROSTAT DESIGN CODE

Output Parameters	**Unit**	**Value**
Envelope Volume	m^3	188.38
Envelope Surface Area	m^2	185.10
Envelope Length	m	16.19
Envelope Diameter	m	5.06
Drag on Aerostat Envelope	N	91.40
Mass of Envelope Group	Kg	71.78
Mass of Fin Group	Kg	36.74
Mass Tether Group	Kg	35.15

C. Output

A typical output derived from the methodology has been illustrated below in Table III. Critical parameters like envelope dimensions and the weight breakup of various groups of the aerostat system are generated based on the aerostat design methodology [5].

The methodology also generates the geometrical profile of the Envelope and the Fins, as shown in Fig. 4.

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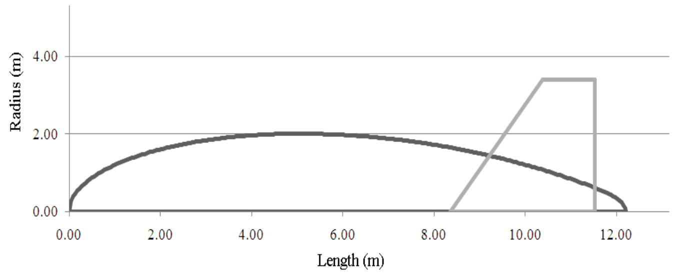

Figure 4. Geometrical Output obtained from the aerostat design methodology

IV. Experimentation and Results

Initial experimentation was carried out within the campus of IIT Bombay. Wireless link was set up between one access point (AP) configured in infrastructure mode and two clients placed at an approximate distance of 1.2 Kms from the AP, as shown in Fig. 5.

TABLE V IP ASSIGNMENT

Router Box	Wireless Interface	Ether Interface
Access Point	192.168.7.1	10.107.170.190
Client 1	192.168.7.2	192.168.8.1
Client 2	192.168.7.3	192.168.9.1

TABLE VI ACCESS POINT ROUTING TABLE

Destination	Preferred Source	Gateway
10.107.0.0/16	10.107.170.190	--
192.168.7.0/24	192.168.7.1	--
192.168.8.0/24	--	192.168.7.2
192.168.9.0/24	--	192.168.7.3
0.0.0.0/0	--	10.107.250.1

TABLE VII CLIENT ROUTING TABLE

Destination	Preferred Source	Gateway
192.168.7.0/24	192.168.7.2	--
192.168.8.0/24	192.168.8.1	--
0.0.0.0/0	--	192.168.7.1

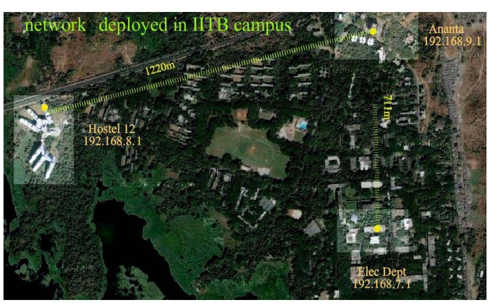

Figure 5. Wireless network setup in IIT Bombay campus

IP addresses were allotted to ethernet and wireless interfaces of the routers, access point routing, client routing details are listed in Table V - VII. Access point was wired to IIT Bombay LAN. A data file was downloaded from LAN to *Client 1* using FTP application to check the wireless link performance. Average data rate of 700 Kbps was observed. The signal strengths observed for received and transmitted signals is provided in Table VIII.

A field trial using Aerostat was conducted at Dr. Babasaheb Ambedkar Technological University (BATU), located in Raigad district of Maharashtra, which is around 160 km from

TABLE VIII OBSERVATIONS

Within IIT Bombay Campus	
Base Station	Rooftop, Electrical Department
Client	In Hostel 12
Distance between BS & Client	1.2 Kms
Max Tx/Rx Signal Strength	-64/-65 dBm
Min Tx/Rx Signal Strength	-80/-80 dBm
At BATU Campus Using a Spherical Balloon	
Base Station	Mechanical Workshop, BATU
Client 1	Staff Quarters
Distance between BS & Client	1.5 Kms
Max Tx/Rx Signal Strength	-75/76 dBm
Min Tx/Rx Signal Strength	-82/-84 dBm
Minimum Ping Time	2 ms
Average Ping Time	10 ms
Client 2	Temple
Distance between BS & Client	2.5 Kms
Max Tx/Rx Signal Strength	-90/-90 dBm
Min Tx/Rx Signal Strength	
Minimum Ping Time	2 ms
Average Ping Time	18 ms
At BATU Campus Using Aerostat	
Base Station	Mechanical Workshop, BATU
Distance between BS & Client	7.0 Kms
Max Tx/Rx Signal Strength	-81/-82 dBm
Min Tx/Rx Signal Strength	-92/-92 dBm
Minimum Ping Time	3ms
Average Ping Time	85.3ms

IIT Bombay, off Mumbai-Goa highway. One of the reasons for choosing BATU campus as a venue for flight testing was because the Air Traffic Control prohibits testing of any type of aerial vehicles within 45 nautical miles (approx 90 km) of the commercial airspace. The climate at BATU campus during the period of trials was hot (40-43^{o}C) with uncertain winds throughout the day. Further, BATU is surrounded by hills which made it a suitable place to operate the aerostat to observe its vulnerability. Two sets of observations were made, one using a spherical balloon and another using a tethered aerostat.

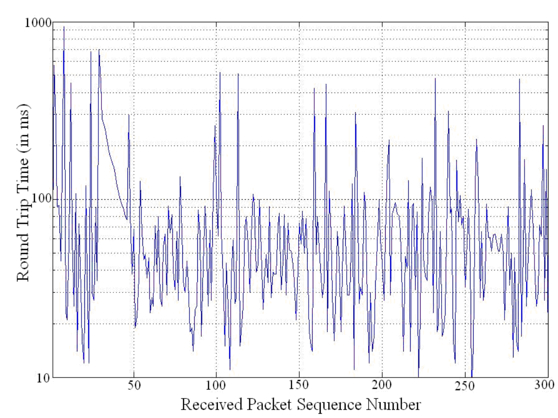

Figure 6. Round Trip Time as a function of Received Packet Sequence Number. The graph shows the ping statistics for packet numbers 0 to 300 sent over 7 Kms link between BS and Client.

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Omni-directional antenna and access point were mounted on the aerostat/balloon and were sent to a height of around 100 meters above the ground. At the client end 19dBi directional antenna was used. Distance between client and access point was varied from 1.5 Kms to 7.0 Kms and observations like received signal strength, round trip time for ping packets and packet losses were made as shown in Fig 6.

Routers at both the Base station and the client end are operated at 5 Volts and the max power input required for the antennas on both BS and client side is 100 watts. The router boxes are powered from a typical 230 V supply with the help of an adapter.

V. Cost Analysis

A detailed cost analysis of the proposed system is shown in Table IX. It can be seen that the one time expenditure involved in setting up the infrastructure is INR 15,00,000

TABLE IX Cost Breakdown Of Aerostat Based System

System Component	**Cost (INR)**
Wireless Equipment	
Routers + Antennae + Cables & Connectors	1,50,000
Aerostat Components	
- Hull	7,00,000
- Tether	1,20,000
- Winch	30,000
- Initial Gas filling	5,00,000
Total	**15,00,000**

which includes the wireless equipment of INR 1,50,000. The aerostat envelope loses LTA gas due to permeability of the fabric, which can be assumed to be 1% of envelope volume per month of deployment. Further, additional operating costs towards transportation of LTA gas, maintenance of the system and manpower have to be incurred. For a three year operation, the total operating costs are estimated to be around INR 10,00,000 hence the lifecycle cost of the system over a three year period would be INR 25,00,000. On the contrary, the setting-up cost for a fixed tower is around INR 35,00,000 comprising of land lease, tower construction and telecom equipment [7]. The operating cost of a tower based system is mainly dependent on the cost of maintenance of the equipment, and is estimated to be INR 5,00,000 annually [7]. The total cost of setting up a fixed tower is thus estimated to be around INR 50,00,000 for a span of three years. It is seen that the cost of this Aerostat based system is nearly half of the tower based system, over a life cycle of three years.

It must be kept in mind that an aerostat based wireless communication system is re-locatable; hence fewer installations will be needed to provide wireless coverage over a given area, for disaster management.

VI. Conclusions

The proposed system having a central base village providing internet connectivity to neighboring villages has been studied extensively for its technical and economical feasibility. The use of aerostats results in considerably reducing the overall system cost. Setting up of several point-to-point links will certainly distribute the available bandwidth but most of the rural areas don't demand high speed connectivity, so using Wi-Fi with point-to-multipoint setup is a feasible solution.

The proposed system can also be deployed at a short notice to serve emergency situations like floods, earthquakes and other natural disaster affected areas where connectivity is worst hit. Also relocation of the system to anyplace within operational range is possible with very less launching area requirement.

Acknowledgments

The authors would like to thank *One World South Asia* for providing financial support in funding this study. Help and assistance rendered by Mr. Amol Gawale, Mr. Sanjay Mohite, Mr. Sharanappa Sindole and the following personnel from Dr. BATU, Lonere during the field trial is also greatly acknowledged; Prof. M. S. Tandale, Head, Dept. of Mechanical Engg., Mr. Gerald Sequeira, Mr. Kaviresh Bhandari, Mr. R. M. Chavan and Mr. P. S. Shrivardhankar.

References

[1] Khoury G. A., Gillet J. D., Eds., "Airship Technology" Cambridge Aerospace Series: 10, ISBN 0 521 430 737, Cambridge University Press, 1999.

[2] R. Flickenger, *Wireless Networking in the Developing World,* 2nd ed. December 2007.

[3] IEEE 802.11b Standard http://www.ieee802.org/11/.

[4] Routers and Wireless Systems. http://www.mikrotik.com/systems.php.

[5] Raina, A. A., Gawale A. C., Pant, R. S., "Design, Fabrication and Field Testing of Aerostat system", National Seminar on Strategic Applications of Lighter- Than- Air (L-T-A) Vehicles at Higher Altitudes, Snow and Avalanche Study Establishment, Manali, India, 12-13 October 2007.

[6] J. Wright, "Computer programs for tethered-Balloon System Design and Performance Evaluation," Report No. AFGL-TR-76-0195. Air Force Geophysics Laboratories (LCB) Hanscom AFB, Massachusetts 01731, August 1976.

[7] Choksey, K. R., "Tower sharing: A strong value proposition for Telecom Sector", Weekender, KRC Research Report, 23rd July 2007.

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