A Survey of Balloon Networking Applications and Technologies

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Abstract:

Balloons are used for numerous purposes, such as party decorations, toys, and weather balloons. Another important purpose is to provide wireless networks to the ground through balloons equipped with wireless transceivers in the sky. There are some attempts for that purpose. First, Shibata et al. proposed a new ballooned wireless mesh network system for disasters in 2009. The balloon typically floats around 40-100 m (130-300 ft) in the sky. It provides Internet connectivity over the IEEE 802.11b,g to mobile nodes on the ground. Second, the SkySite platform from Space Data Inc. widens cellular network coverages, and provides private networks over their own radio frequencies via balloons equipped with wireless transceivers in stratosphere. Third, Google officially unveiled Project Loon and launched the first experiments in New Zealand in June 2013. The balloons equipped with wireless transceivers hover at 20 km (12 mi) in stratosphere. They provide Internet access at up to 3G speed to rural and remote areas. The standard wireless protocol for mesh networks and the framework for UAVs (Unmanned Aerial Vehicles) which are able to be applied to balloon networking are described because those two companies do not disclose their main algorithms of wireless mesh networks in the balloon networking. The IEEE 802.11s is an extension to the IEEE 802.11 standard for wireless mesh networks. It integrates mesh networking services and protocols with the IEEE 802.11 at MAC Layer. Additionally, Morgenthaler et al proposed UAVNet, a framework for the autonomous deployment of wireless networked UAVs.

Keywords: Balloons Networking, Google, Project Loon, Space Data Inc., Mesh Networks, Internet, Unmanned Aerial Vehicles, SkySite, Wireless, Disasters, UAVNet, IEEE 802.11s

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1. Introduction

The definition of a balloon is a flexible bag filled with air or gas. It looks a very simple toy for decorative purpose, but it is being used for other a variety of purposes. For example, the balloon is also considerably used to gather weather information such as atmospheric pressure, temperature, humidity and wind speed. A radio equipment attached to the balloon reports those weather information to the ground at a radio frequency of 403 or 1680 MHz.

Besides those purposes, it allows people to communicate with others as well. Historically, in the Three Kingdoms era (220-280 AD), for the military purpose, Chinese used unmanned and small hot air balloons to communicate with allies. [Wiki-Balloon] As the technology has advanced, there have been attempts to provide networks such as Internet or cellular networks since it is much cheaper than satellites. In June 2013, Google launched the first experiments of balloon networking in New Zealand so that it again gets into the limelight. [Wiki-ProjectLoon]

In this paper, three applications and two wireless mesh networks technologies are explained in detail. Section 2 describes Shibata et al. proposal for disasters. Section 3 presents the SkySite Platform from Space Data Inc. Section 4 explains Google Project Loon. Section 5 mentions that two technologies, the standard wireless protocol and the framework for UAVs, in typical wireless mesh networks are able to be applied to balloon networking. Finally, section 6 concludes this paper.

2. Shibata et al. proposal for disasters

The mid of November in 2013, the second-deadliest Typhoon Haiyan struck the central Philippines. Likewise, large-scale natural disasters frequently occur in many places around the world. When they happen, the first response focuses on relief supplies such as water, foods, and medicines. However, such disasters damage network infrastructures such as cell towers and Internet cables as well as power cables so that people in the area cannot communicate with outside world and even within the same area. That impedes supplying those goods and recovering the disaster area.

In Japan, Yosgutaka Shibata et al., 2009 [Shibata09] proposed a new ballooned wireless mesh network system for disaster. It consists of normal rubber balloons and wireless network devices. The balloon typically floats around 40-100 m (130-300 ft) in the sky. Each balloon has two wireless network devices for (1) the vertical network and (2) the mesh network.

(1) The vertical network is for communications between the wireless network node attached to the balloon and mobile PCs or devices on ground. It uses the access method, IEEE 802.11b,g [Wiki-802.11b] [Wiki-802.11g] with the maximum distance around 600 m (2000 ft). That is a standard Wireless Local area network (WLAN) protocol also known as Wi-Fi. It uses a hexahedral antenna because it can cover a ground area of around 100 m (328 ft) diameters from 40 m (131 ft) above the area. (2) The mesh network is for between balloons. It works over Wi-Fi IEEE 802.11j [Wiki-802.11j] with 4.9 GHz transmission frequency, 250 mW power density, and 54

Mbps network bandwidth, which is now incorporated into the IEEE 802.11-2007 standard. [Wiki-802.11-2007] More information is shown in Table 1.

Table 1. Specifications of mesh and vertical network [Shibata09]

	Mesh Network	**Vertical Network**
Standard	IEEE 802.11j	IEEE 802.11b,g
Frequency	2.4 GHz	4.9 GHz
Signal Power	250 mW	10 mW
Trans. Speed	54 Mbps	54 Mbps
Max. Distance	600 m	100 m
Antenna	octagonal plains	co-linear

The wireless mesh network is made up of the balloons by auto configuration functions. This is achieved by electro-magnetic field power density. For example, a balloon tries to find one of its neighbor balloons which has the strongest power density and establish a connection with it. Then, the mesh network eventually has a minimum spanning tree network. If a balloon moves by wind or falls down, the connection between balloons is closed. The neighbor node immediately notices the failure, and tries to find another neighbor node automatically as the same way. This makes the mesh network stable.

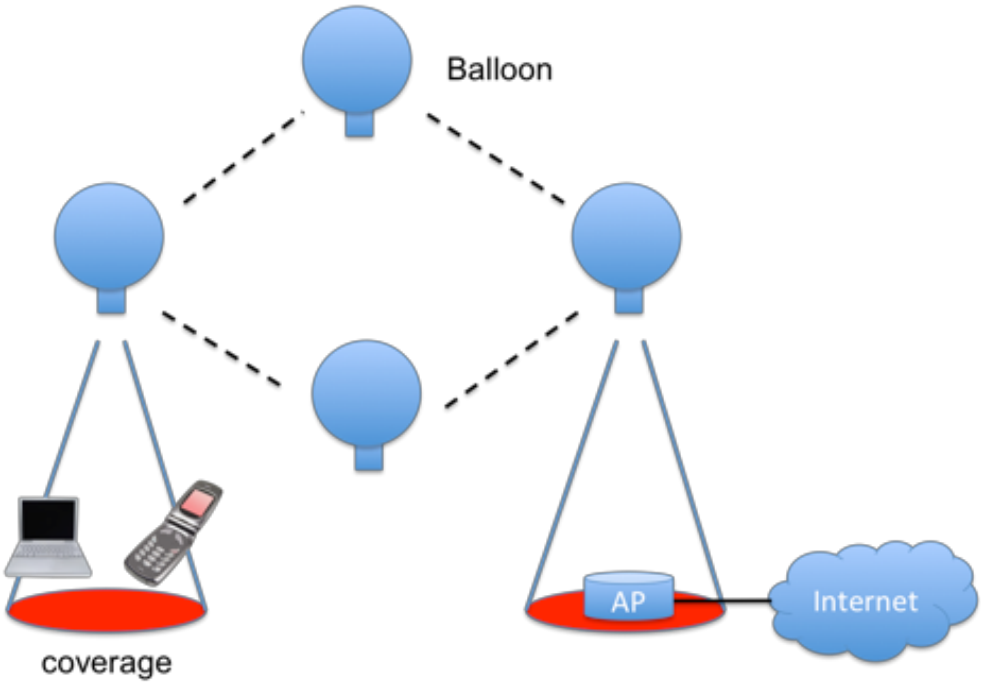

Figure 1. Shibata et al. balloon networking for disasters

If a disaster occurs, some balloons would be launched. One of them, which is the closest to the area which has Internet access, establishes a connection over IEEE 802.11b,g. Other balloons organize a mesh network in the sky through the procedures above. Mobile devices on ground can join the closest balloon network in the sky over Wi-Fi, and communicate with the balloon as shown in Figure 1. The ballon forwards the received data packets from the mobile device to its neighbor balloon through the mesh network. If a balloon, which has an Internet connection, receives the packet, it sends the packet to the AP on ground.

3. Space Data Inc. in the U.S.

According to the Federal Communications Commission [ComputerWorld], in 2012, 19 million people in the U.S. do not have fixed broadband coverage because cellular carriers are not interested in installing and operating cellular towers in sparsely populated area since it cannot make any profit in the areas.

In 2001, Jerry Knoblach, founder and chairman of Space Data Inc [SpaceData01], suggested an idea to widen the cellular coverage for those rural areas in the States. The idea was to have wireless transceivers carried aloft on weather balloons, launched by the National Weather Service. For the past 60 years, the weather service launched 70 balloons twice a day across the country to collect the weather information. The weather balloons are in fact floating above specific areas for about 24 hours at about 30 km (100,000 ft). [SpaceData02] The balloon can be a mini and cheaper cell tower in the sky as shown in Figure 2. [TheRegisterGuard]

3.1 The SkySite Platform overview

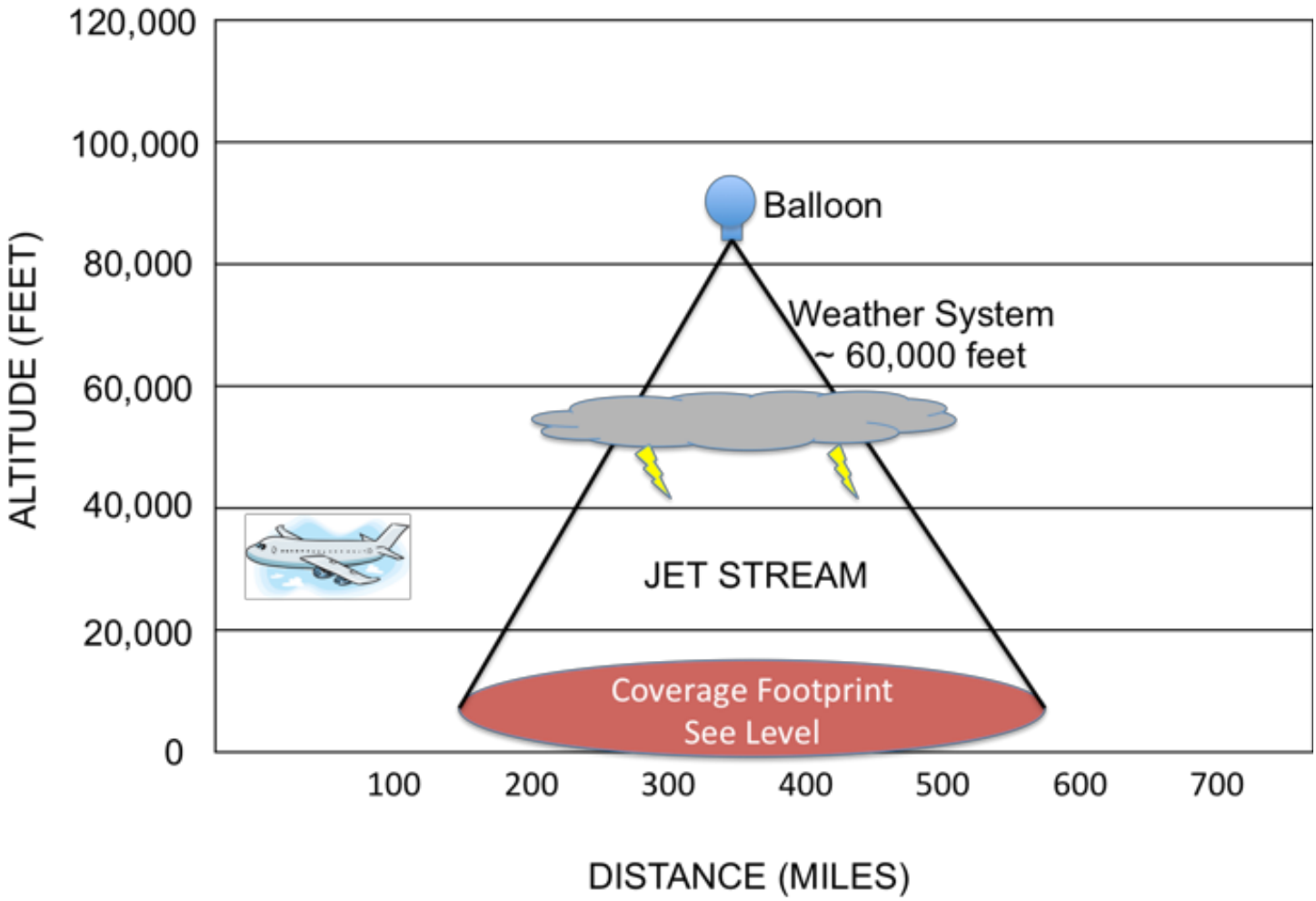

Figure 2. SkySite Platform

His company also started to launch its own biodegradable latex weather balloons and provide private networks. It uses the standard wireless protocol of Motorola 2-way packet data and its own NarrowBand PCS spectrum of 1.7 MHz of nationwide spectrum in 901-940 MHz Band. [SpaceData03] One balloon with a weight of 1.5 kg (3.3 lb), a size of 7.6 m (25 ft) when fully inflated, can cover a 670 km (420 mi) diameter circle below as shown in Figure 3.

The cheap balloons in the sky can remain for up to 24 hours. Before it bursts, the company sends the transceiver a control message to uncouple it from the balloon for the reuse of the transceiver. Afterwards the balloon eventually bursts from the low air pressure and the payload holding the transceiver lands. It has a tiny parachute to land genteelly, and is encased in a small Styrofoam box. Unfortunately, the company cannot estimate where the device would land. Thus, it hires some people with GPS devices to track down them. Most importantly, the company keeps launching new balloons to the sky in order to take over the coverages and provide continuous coverages. Because launching the balloons does not require higher technical skills, it also hires some mechanics at small airports as well as farmers, and asks them to launch the balloons.

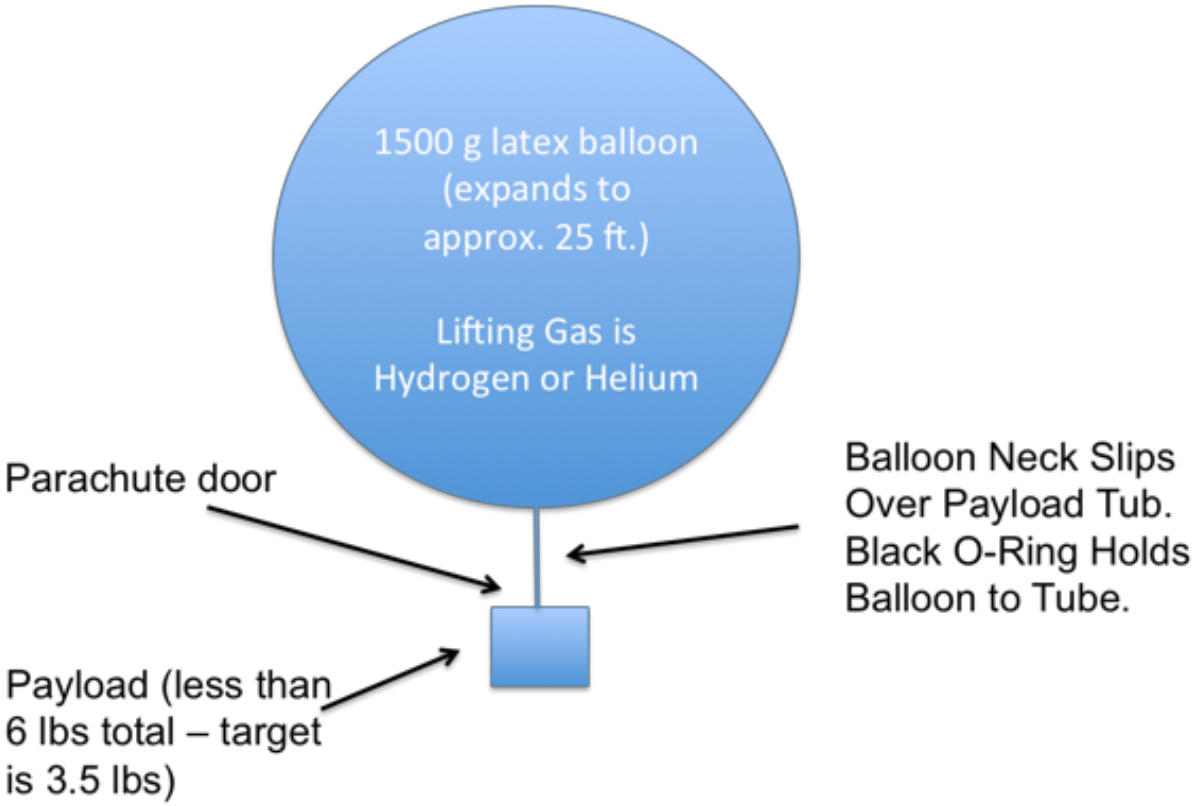

Figure 3. SkySite Balloon

It has numerous fixed telemetry and monitoring applications. For example, oil and gas industries use this network for alarm monitoring, production automation, asset tracking, and cathodic protection. It currently covers the Gulf of Mexico, Texas, New Mexico, and Louisiana, but always looking for opportunities to expand nationwide. It is also used for the military purpose as well. A military balloon carries a repeater that operates in the 225-400 MHz frequency band, stay aloft for about 24 hours as well. It does not need to replace it with another one to provide a continuous coverage because a small military operation lasts only less than 24 hours since the military moves to another area.

The company has partnered with many network companies such as Oceus and Lemko, and is currently working on the balloons to provide LTE. [FierceWirelessTech]

3.2 No potential hazards

Hydrogen is mostly used to fill the balloons instead of helium used in modern balloons or blimps due to the cheaper price. However, Hydrogen is, of course, flammable and dangerous but each balloon has only a little Hydrogen so that the amount of the gas cannot happen any accident like the Hinderburg. [Wiki-

HindenburgDisaster] Another potential hazard is that commercial airliners might crash into the balloons. However, the history proves that there has been no report about any crash even though 1,800 of weather balloons are launched every day around the world. Additionally, the engines of a commercial airliner is designed to resist the ingestion of even an eight-pound bird. Thus, the device on the balloon is acceptable because it is only six pound.

3.3 Usages for disasters [FCC]

Even during Hurricane Katrina, the balloon floating in stratosphere and covering most of Louisiana were operated without interruption. In addition, the company was able to keep launching the balloons in the middle of Louisiana by slightly adjusting the launch schedules even when Katrina whipped through the state. Because the balloons were hovering in stratosphere, they could avoid the adverse weather phenomena, Hurricane Katrina. Most traditional networking and power infrastructures on ground were damaged, but the balloons still provided the connectivity. The company eagerly tried to support the networking to the recovering area, but no one, unfortunately, accepted the offer.

4. Google Project Loon

According the report of ITU (International Telecommunications Unions) [Wiki-InternetUsers], 61 percent of people around the world do not have access to the Internet in 2013, which means two-thirds of the world are not currently living in the global village.The major problem is the cost of an Internet connection. For instance, in the southern hemisphere, the cost is more expensive than a monthâ€™s income due to terrestrial challenges such as jungles and mountains.

Google has begun a research project to provide everyone around the world, especially in rural and remote areas with Internet access over the challenges, called Project Loon. [Wiki-ProjectLoon] [Wiki-ProjectLoon] It was incubated in Google X. [Wiki-GoogleX] Unveiled projects from Google X currently are Project Glass [Wiki-GoogleGlass] and Google Driverless Car [Wiki-GoogleDriverlessCar]. Google unofficially launched the research project in 2011, but they officially announced the project on June 14th, 2013. After two days, they started a pilot experiment in New Zealand. It sends balloons to 20 km (12 mi) in the sky. The balloon networking provides an aerial wireless network at up to 3G speed. [Wired]

4.1 Project Loon overview

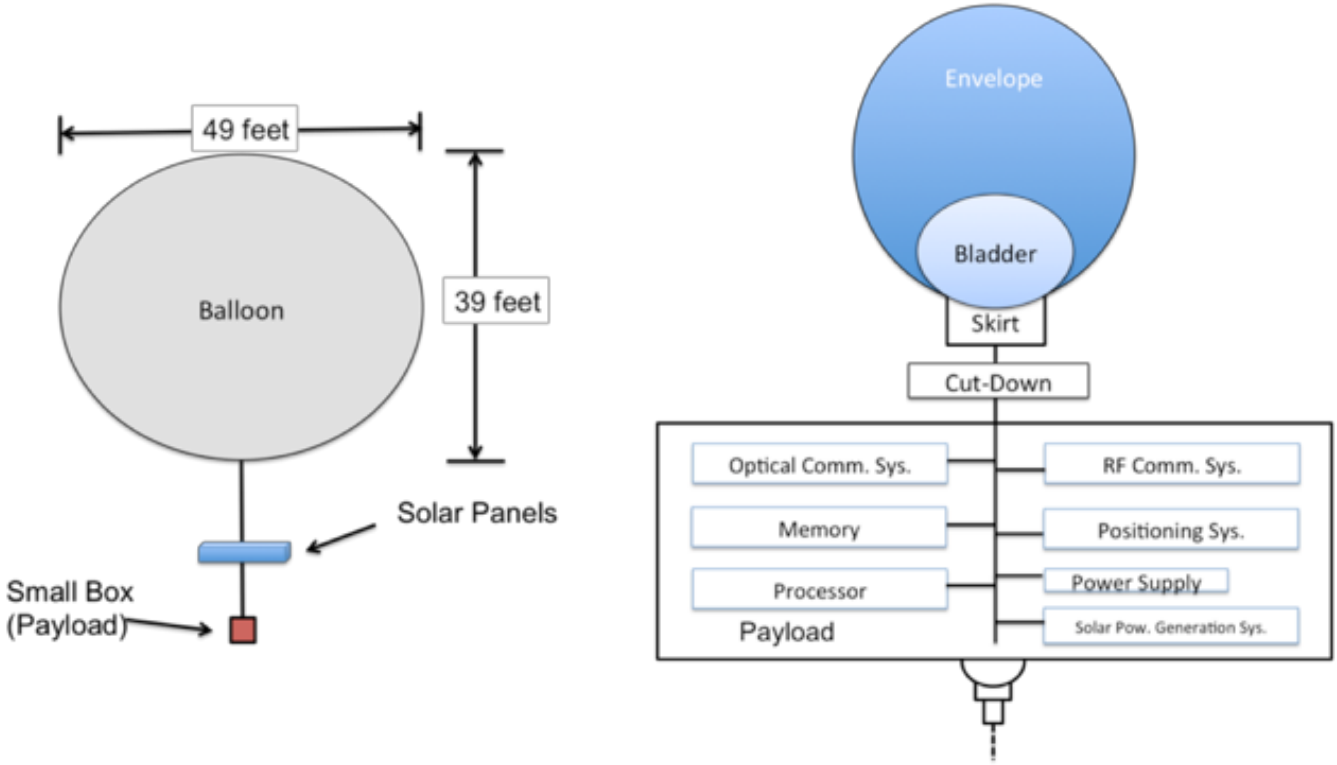

Figure 4. Project Loon Balloon and Payload Architectures

The size of the balloon used in the project is 15 m (49 ft) wide and 12 m (39 ft) tall when it is fully inflated, and it generally consists of a small box (payload), envelope, parachute, and gas.

The small box (payload) hangs below the envelope, and looks very similar to the basket in a hot air balloon, but rather than carrying a burner, fuel tanks, and passengers it holds electronic devices, such as circuit boards, radio antennas, solar panels, batteries, GPS, flight sensors, and devices to monitor weather conditions. The circuit boards control the overall balloon system and radio antennas are for communications.

The balloon powers itself by two renewable energies, sunlight and wind. To operate electric devices, it uses light energy from the sun during the day through an array of solar panels sitting between the envelope and the small box (payload). The panels are able to fully generate 100 Watts, which is enough not only to run all electronics, but also to store the remained solar power in the batteries for use at night. The electronic power is completely not used for the balloon to move in the sky. It is designed to travel by the winds in stratosphere, which is the second layer of Earthâ€™s atmosphere between the troposphere and the mesosphere. The altitude range is about 10-13 km (6-8 mi) and 50 km (31 mi). The balloon will position 20 km (12 mi) altitude. That area brings some engineering challenges. First of all, the air pressure is only 1% of that at sea level. Second, it has temperatures of around -50 Â°C (-58 Â°F). In addition to the lower temperatures, they dynamically changes due to the sunâ€™s rays. Third, there is less protection from the UV light because of a thinner atmosphere. In spite of those challenges, that area is very attractive. First, the winds in the area usually moves steadily and slowly between 8 and 32 km/h (5 and 20 mph). It seems slow and weak, but it is powerful enough to have the balloons flown to other areas. Second, commercial airliners usually fly between 9 and 12 km (5.5 and 7.4 mi) altitude, which means it is high enough to avoid airplane traffics. Moreover, most weather phenomena occurs in the troposphere, below the altitude of the balloonsâ€™ positions (20 km, 12 mi), thus they can also avoid any adverse weather phenomena.

Its envelope is made from sheets of Mylar which is a brand for a thin strong polyester film about 0.076 mm thick.

Such superpressure balloons require Mylar since it strongly keeps from stretching and popping at even high altitude. It is built to resist higher pressures than a normal weather balloon which reaches usually at an altitude of 40 km (25 mi). Inside envelope, there is another chamber, called bladder as shown in Figure 4. To have the balloon descended, a fan powered by the solar energy fills the bladder with air to make it heavier. Likewise, the fan vents air in the bladder, which causes it to rise. The balloon can move up or down a 1.7 km (1 mi) range through the bladder system. This system can help to choose suitable wind currents in stratosphere. It also releases some air inside out of the envelope to relieve pressure. When being out of the service, it releases gas from the envelope and descends slowly to the ground. It rarely happens, but when the balloon drops quickly, it uses the parachute on the top of the envelope.

Figure 5. Specialized antenna at home [Gigaom01]

It can provide wireless Internet connectivity to ground areas at up to 10Mbps (3G speed). There are two kinds of communications: balloon-to-balloon network and balloon-to-ground station or subscribers network. It has specialized radio antennas to support two networks. It currently uses ISM bands specifically 2.4 and 5.8 GHz bands because they are typically unlicensed radio frequencies around the world, which means Google is able to avoid negotiating with local governments to purchase specific radio frequencies. Additionally, these also avoids interferences and reaches much further distances. Because it does not support Wi-Fi, smartphones such as iPhone are not able to establish connections directly to balloons. As shown in Figure 5, it requires users to install a specialized antenna the outside of their home to receive the signal from a balloon near their home and to decrypt the signal. This way is very similar to the usage of satellites.

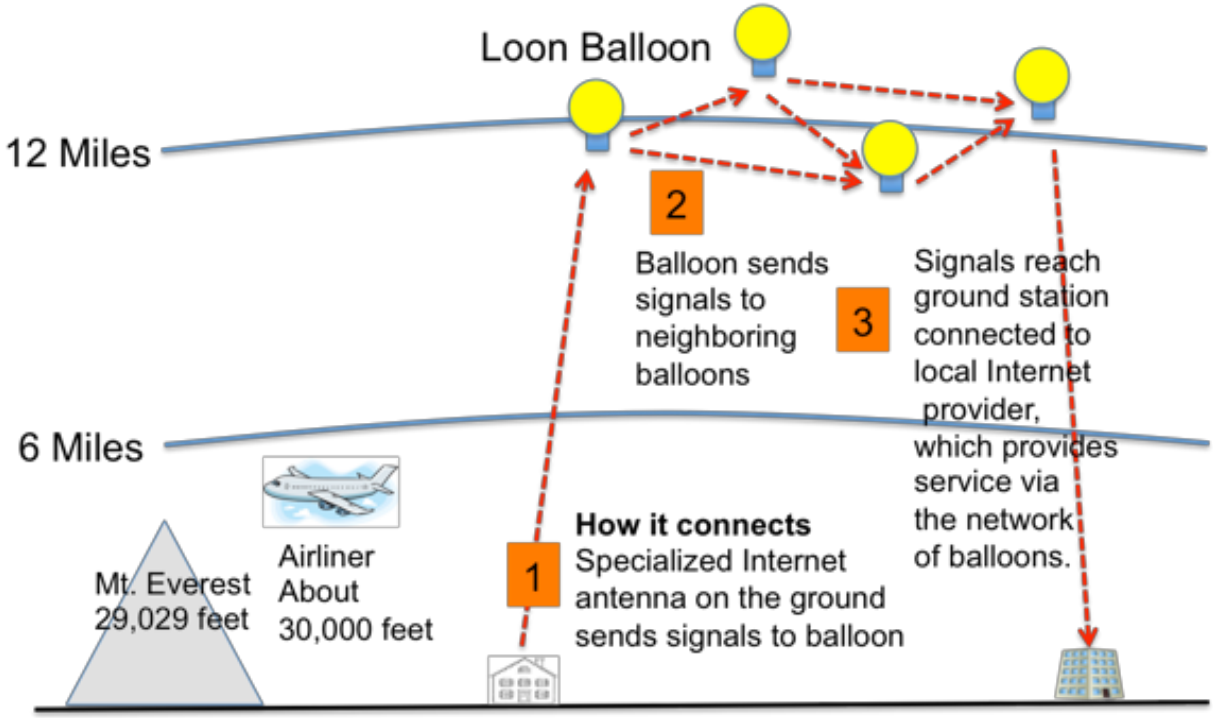

Figure 6. How it connects in Project Loon

As shown in Figure 6, primarily, a user with the specialized antenna sends signals via a radio frequency over ISM bands to a balloon close to him/her. The balloon sends the signals to neighboring balloons. Eventually, the signals reach the balloon which is connected to the local Internet. The wireless mesh network is constantly adjusting as balloons move.

Any balloon is able to connect the Internet to a base station which has Internet connectivity and then receives Internet data and forwards them via balloons in the sky to the destination. Finally, the balloon close to the request user broadcasts the data to the grounds via a radio frequency over ISM bands. The special antenna installed the outside of home receives data and decrypt the data. The wireless mesh network should be constantly adjusting as balloons move.

It covers an area of an around 40 km (28 mi) diameter circle which is twice the area of New York City. Thousands of balloons can cover the whole world. Currently, its lifetime is only a few weeks, but Google anticipates that they can be in the sky hundreds of days in future.

4.2 Reception

This idea is not innovated because Space Data Inc. has been already running this similar network service since 2001. According to The Wall Street Journal [WallStreet], Google was considering teaming up with Space Data Inc in 2008. Both companies declined to comment on the issue.

The company does not unveil the algorithms of how to organizing mesh networks, and the cost of operating this project. [ReadWrite]

Although the project has potential technical merits, it cannot be realized soon. [Fobes] The biggest challenge is not the technical issues, but to find a route of countries unwilling to permit the balloon flights. For instance, in 2002, Steve Fossett was able to finish solo balloon circumnavigation by flying over mostly water in the southern hemisphere because he could hardly obtain approval from many countries. Not every country is glad that

communications balloons operated by an American company fly above countries. In addition to permission, the company should negotiate with countries to purchase or borrow specific radio frequencies.

Besides this project, the search giant is working on related research projects to provide Internet access to rural and remote areas of the world. For example, in 2013, it announced to provide Internet connectivity over TV White spaces in South Africa [GoogleBlog]. Its advantage is that TV white spaces are low frequencies, which means they can travel longer distances. This technology is very suited in rural and remote area because a wireless base station can cover wider area. Having more people online is the Googleâ€™s strategy since more visitors to Internet make more their profits by clicking on Google ADs.[Gigaom02]

Bill Gates also thinks that everyone would have a better life with an Internet connection, but has questioned whether Project Loon is suited for poor people in Africa by stating that â€œ*When youâ€™re dying of malaria, I suppose youâ€™ll look up and see that balloon, and Iâ€™m not sure how itâ€™ll help you. When a kid gets diarrhea, no, thereâ€™s no website that relieves that.*â€ [Huffingtonpost] [Guardian] Additionally, New Zealand where the first experiment is launched is such a good place for the project because people in that country has enough food and clean water. On the other hand, most people in Africa need foods and clean water more than the Internet connections even though Google provides the connections for free, and most of them do not have any electronic devices to use the Internet.

5. Technologies in typical Wireless Mesh Networks

Those two companies do not disclose their main algorithms of wireless mesh networks in the balloon networking â€” e.g. how to organize mesh networks in the sky. In this section, two technologies in typical wireless mesh networks are described; a standard wireless protocol and a framework for UAVs are not used for balloon networking, but are able to be applied to balloon networking.

5.1 IEEE 802.11s

The IEEE 802.11s [Wiki-802.11s] [Kernel] is an extension to the IEEE 802.11 standard for mesh networking. In other words, multiple wireless nodes can communicate with others without the need for an AP between them. It integrates mesh networking services and protocols with the IEEE 802.11 at MAC Layer.

It defines three nodes; (1) Mesh Point (MP), (2) Mesh Portal (MPP), and (3) Mesh Access Point (MAP). (1) A MP establishes peer connections with neighboring MPs. (2) A MPP is connected to both Internet and the mesh network so that it can provide the mesh network with Internet access. Finally, (3) A MAP acts as a traditional AP which is added mesh functionalities so that it provides BSS (Basic Service Set) services.

There are six functionalities in the wireless mesh protocol: (1) mesh discovery, (2) peering management, (3) beaconing and synchronization, (4) mesh coordination function, (5) mesh path selection and forwarding, and (6) intra mesh congestion control. First of all, a wireless node periodically sends beacon frames to its neighboring nodes. Those two nodes are a peer through the peering protocol, and then synchronized via the synchronization and coordination procedures. After that, one of the nodes tries to find ways to different nodes in the mesh networks via a routing protocol like Hybrid Wireless Mesh Protocol (HWMP). [Wiki-HWMP][Wiki-HWMP] It is a default routing protocol, based on a combination of AODV (Ad hoc On-Demand Distance Vector routing)

[IETF-AODV][IETF-AODV] and tree-based routing, but allows to use alternative routing protocols such as RA-OLSR (Radio Aware OLSR). [Bahr06]

5.2 UAVNet

The deployment and maintenance of WMNs (Wireless Mesh Networks) are time consuming and difficult in harsh environments. With that motivation, Morgenthaler et al. proposed a framework for the autonomous deployment of wireless networked UAVs (Unmanned Aerial Vehicles), called UAVNet in 2012. [Morgenthaler12] [Morgenthaler12] It uses Quadcopters [Wiki-Quadcopter][Wiki-Quadcopter] rather than balloons. The wireless mesh node attached to the vehicle communicates with other nodes through an IEEE 802.11s WMN. In other words, data traffic between the end systems is relayed through the IEEE 802.11s. It can be an IEEE 802.11g wireless AP as well. Mobile nodes on the ground are able to connect to the AP. Moreover, administrators also control the vehicles through the AP. The wireless node is Professional Mesh OM1P from Open-Mesh [OpenMesh], and its operating system is ADAM [Staub11], an embedded Linux distribution developed at University of Bern. It provides a platform for wireless mesh networks.

According to their proposal, having UAVs properly located is straightforward. First of all, the first UAV from the starting base station explores the nearest base station. If found, it flies back to the center position of the two base stations, then moves slightly toward the starting base station until a predefined signal strength is reached. The second UAV follows the same procedures above, but it moves slightly toward the first UVA instead of the starting base station. These procedures are repeated until all UAVs are positioned and a ping message is delivered from the starting base station to the nearest base station.

6. Summary

This paper described three applications to which balloon networking are applied: Shibata et al. proposal for disasters, the SkySite platform from Space Data Inc, and Google Project Loon. Moreover, it presented that technologies in typical wireless mesh networks are able to be applied to balloon networking. While it has been shown that using balloons to provide wireless networks has several advantages, unfortunately balloon networking is not being actively researched. This is because only few papers have been published and other works are not unveiled. However, we can anticipate that balloon networking would be a hot and attractive research topic soon if Google starts disclosing their secret work.

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List of Acronyms

ITU: International Telecommunications Unions
UVA: Unmanned Aerial Vehicle
WMN: Wireless Mesh Network
AP: Access Point
MP: Mesh Point
MPP: Mesh Portals
MAP: Mesh Access Point
BSS: Basic Service Set
HWMP: Hybrid Wireless Mesh Protocol
RA-OLSR: Radio Aware OLSR (RA-OLSR)

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