ONWARD TECHNOLOGIES LLC

A Review and Analysis of Alternatives to Fiber Optic High-Speed Internet Access

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Introduction

Dr. Lee is the Chief Technology Officer for Onward Technologies, LLC, a Wyoming USA registered company, whose focus is to the design, production, and market introduction of wireless infrastructure technology. Dr. Lee is the inventor of several lighter than air related patents some of which are specifically intended to dramatically enhance the operational value of an aerostat system when applied as telecommunications infrastructure. Onward's library of issued and pending patents collectively enable an aerostat to operate as wireless telecommunications infrastructure for provision of a high quality and reliable last mile connectivity for Voice, Internet, and Broadcast.

This document will examine certain of the currently available technologies, programs and companies that seek to address the ever present, negative impact of our world's Digital Divide which continues to compromise nearly 50% of the world's population. Several companies are currently in process of researching, developing, and introducing telecommunications infrastructure initiatives capable of delivering telecommunications connectivity from the stratosphere to up to hundreds of miles in space. Among those companies pursuing satellite initiatives the most progressed appear to be SpaceX's Starlink, OneWeb, which has in the past been financially challenged, and Amazon's Kuiper. Among the respective satellite projects presently advancing, this document will direct its review and analysis to Starlink.

This document will provide overview of publicly available information regarding Starlink addressing its advantages, opportunities, and future prospects for purpose of examining the considerable present and future value of Onward's aerostat wireless telecommunications infrastructure to both satellite and terrestrial telecommunications delivery systems.

The Future of Telecommunications Services is Wireless

There is a need for alternatives to modern high-speed Internet powered by fiber optics:

Fiber optics can provide immense capacity, lightning speed, and low latency connectivity. It has significant performance advantages over other competing telecommunication technologies such as 4G and 5G LTE cellular networks, high-speed coaxial cables, Digital Subscriber Lines, microwave links, and various satellite-based Internet access technologies. However, the cost of laying fiber can be prohibitive to undertaking required infrastructure build out in all but the richest countries. Countries such as China due to the rapid pace of industrialization and high population densities enjoy a manageable per capita cost for the buildout of fiber optics infrastructure. Even in some highly industrialized countries, a large portion of commercial buildings still do not have commercial grade high-speed fiber optics connectivity and as result must rely on leasing wired circuits from their landlords, ILECs or CLECs at restrictively high monthly costs. In an urban environment the cost for trenching optical fiber can be excessive even if municipal ordinance does not prohibit it. In suburban and rural settings, the per mile trenching costs are lower, however the lower population density requires laying longer fiber runs often resulting in per capita infrastructure costs even higher than that for an urban buildout.

DS-3 and OC-3 are dedicated lines (or networks), and as such, they are guaranteed by their respective SLA clause to have a certain level of availability and latency, hence they are in demand from businesses requiring dedicated bandwidth for their operation adding to higher cost. Shared networks such as cellular networks, DSL lines, cables and satellite wireless networks, or shared fibers such as Google Fiber do not come with such guarantees and so offer services on a “best effort” basis with no service guarantee which are less costly to operate. Currently 4G/5G speeds are already on a par with dedicated DS-3 or OC-3 lines at roughly two orders of magnitude lower cost. However, they are entirely unsuited for mission critical operations. Shared network connections can be dropped for no apparent reason, and their generally low availability means a certain fraction of their data packets will be dropped and automatically resent via automatic repeat request (ARQ) and may cause random delays in the transport of data, which translates to increases in transmission latency.

Historical Alternatives to High-Speed Fiber Optics Internet Connections

LEO, GEO, VSAT

Owing to their extremely wide area coverage, both LEO and GEO satellite constellations can provide near ubiquitous connectivity. However, since each satellite has a limited mass and power budget, they must rely on higher frequency bands such as Ku and Ka bands to provide sufficient antenna gain without having to deploy large aperture antennas. Higher frequency bands also have more bandwidth available, however, these higher frequency bands are susceptible to radio interference, rain attenuation, atmospheric absorption, dust, mist, fog, or cloud scattering/diffraction/refraction/reflection, etc. In the case of GEO satellites, the roundtrip propagation delays are such that the average latency is close to 0.6 second. Even with Ku, Ka bands, traditional satellite service providers could offer data rates in the range from 2 Kbps to 45 Mbps, meaning slower data speeds and much lower availability than the lower costs of 4G/5G LTE which provide higher data speeds and consistent service availability. VSAT (very small aperture terminal), require dish antennas sized from 75 cm to 1.2m and offer with data rates of only 4 Kbps to 15 Mbps. VSAT service availability is typically about 95% to 99% in tropical regions, and up to 99.95% or more in arctic or desert regions such as ITU-R regions A, B, C and D which are primarily above 45 N^o and 30 S^o in latitude where 99.99% of the time the annual rainfall is in the order of 0.01% the rain rates do not exceed 20 mm/hr.

High Throughput Satellites

More recently, a new class of FSS (Fixed Satellite Service, or GEO) Ka band satellites called “High Throughput Satellites, (HTS) came online. Each such FSS satellite can project multiple spot beams each with a radius of a few hundred Km’s instead of a single wide beam which covers roughly 1/3 of the surface of the earth. Ka bands have higher available bandwidth, and for the same antenna size, can cover roughly ½ the radius of a Ku beam. Viasat-1 has 56 Ka transponders which project 56 spot beams arranged in a familiar hexagonal lattice pattern, like that of a terrestrial cellular network suitable for a 1/7 frequency reuse factor. This allows the net capacity of a single satellite to increase by the factor of 56 x 1/7 = 8. While a classical FSS satellite can provide a maximum of 10 Gbps throughput, HTS satellites such as Viasat or EchoStar can provide more than 100 Gbit/s. Without the 8-fold frequency reuse, the traditional GEO satellites will need to pay over $100 million for a 1 Gbps of throughput, with the frequency reuse, scheme, the same $100 million cost (license fee to FCC) can supply a Gigabit of throughput for 8 times less. Viasat and other HTS service providers can offer their customers with up to 100 Mbps rates for under $100. Future HTS satellites will have even narrower spot beams for even greater capacity limited only by the diameter of the spot beam antennas. Larger diameter spot beam antennas can project smaller spot beams, but since the weight of such antennas grows faster than the physical size of the antenna, soon it will reach a limit beyond which it no longer makes economic sense. The value of the net throughput HTS satellites can provide is offset by their inability to provide carrier class five-nines or even four-nines availability and under 100 ms round trip latency.

SpaceX’s Starlink

More recent developments such as SpaceX’s Starlink constellation and Google’s Project Loon hold promise of improved quality and reliability of services. Starlink intends to deploy as many as 42,000 very low orbit compact satellites at around 540 m altitude to provide gigabit Internet connectivity. According to Starlink’s Founder and CEO, Elon Musk, when fully deployed, each Starlink satellite will provide over 1 terabit throughput. Starlink satellites will be interlinked with multi-gigabit free space optics links to form a global space mesh network of unimaginable total capacity, and AI software will turn the constellation into an instantly re-configurable “Software-Defined-Network” (SDN) which is also a central theme of a future 5G networks.

Starlink’s space laser although still under development recent academic research has already shown the feasibility of terabit throughput using Dense Wavelength Division Multiplexing, (DWDM) similar to those employed by terrestrial fiber optics networks. While much of the research on FSO (free space optics) has focused on terrestrial applications where the FSO systems are susceptible to atmospheric impairments such as fog fade, rain fade, as well as scintillation and beam wandering arising from atmospheric turbulence. Atmospheric turbulence is caused by tiny air pockets of varying air densities at the intersection of cold and warm air. The slight change in the index of refraction of those air pockets acts as a collection of microscopic lenses that cause some portion of the beam to be bent in a random fashion, and to slow more than others. The random slight changes in direction of propagation and slowing cause the wave front to be distorted, resulting in random constructive and destructive interference called scintillation as well as beam wandering and spreading. Scintillation causes arbitrary fluctuations of the received signal, which is called scintillation fade, and can cause the received signal level to dip by more than 40 dB. Thick fog can scatter the laser beam leading to a severe attenuation over a relatively short distance. The fog attenuation could easily be between 40 dB/km to 100 dB/km, and oftentimes even higher. This limits the operational range of the terrestrial FSO system from a few hundred meters to 1 or 2 km.

Starlink will operate in the pristine space environment where there are no air or particulates to impair the propagation of the laser beams, it is theoretically feasible to develop multi-wavelength space-to-space laser links capable of over a terabit of inter-satellite-link throughput with extremely high availability. This means that when fully deployed, the Starlink constellation could become the fastest global Internet backbone, far surpassing the vaulted terrestrial super-speed fiber optics backbone.

In 2020, the global Internet throughput is estimated to be around 650 Tbps (Terabit per second) according to Wikipedia. A 2018 MIT study of OneWeb, Starlink and Telesat, (A Technical Comparison of three LEO Satellite Constellation Systems to provide Global Broadband, Oct. 1, 2018. 69th International Astronautical Congress 2018, Bremen, Germany) estimated that Starlink's max data throughput to be about 21 Gbps per satellite, and the max throughput for a 42,000-satellite constellation is 23.7 Tbps. The reason Starlink's throughput is about ¼ of the theoretical maximum of (4425 x 21 Gbps = 93 Tbps) is that SpaceX's gateway earth stations are a major limiting factor. For the full 42,000 satellite constellation, the net throughput would be around 200 Tbps, roughly 1/3 that of the terrestrial infrastructure by extrapolation. However, if SpaceX's ground segment can be improved upon, it would be possible to achieve a global throughput which surpasses that of the terrestrial fiber.

Perhaps more importantly, if even just a tenth of the Starlink satellites are equipped with a 4-way Tbps laser cross-links, it would be possible for SpaceX to form a global Internet backbone in space with a capacity of 4,200 Tbps, which is about 6.5 times the capacity of the current fiber infrastructure. With further advances in DWDM free space optics technology, even loftier capacity can be expected. Should that happen, most of the Internet traffic could be transported by Starlink's space network.

Since Starlink's ultra-speed optics cross links operate in the near vacuum of space, it can travel at full light-speed, in contrast to light traveling in a single mode fiber, where the light speed is about 40% less. It is potentially possible to achieve a data transport latency which is even smaller than that of terrestrial fiber. This will not be easily achieved. In terrestrial fiber infrastructure, the data to be transported are first separated into local transport and long-range transport. The local data are added or dropped to the main fiber or fiber bundle through an add drop multiplexer (ADM). The newly added signals are pre-amplified with an optical amplifier to equalize the signal level for long distance transport. The optical signals are also amplified at periodic locations to maintain the needed signal/noise level. The optical signals are never regenerated by converting to and from electrical signals while they are transported. Now most satellite laser links are the regenerative type in that the received optical signal is converted to electrical signal so that they can be routed and then transformed back into optical signals to be transported via another laser link. Such process not only increases latency, but it would also require a large data storage to store the temporary data.

With a terrestrial fiber-like ADM architecture, and fast mesh network routing, the latency could be reduce by 30% or more for long haul data, which would be of great interest to financial institutions which might provide Starlink an inroad to population centers (those with more than 2000/square Km.) Note that in parts of population centers such as Tokyo, Seoul, or Manhattan, there could be more than 100,000 people/square Km) which would otherwise be out of Starlink's reach owing to its relatively low throughput per square Km. With a max of 0.7m aperture, their onboard phased array would project a spot which would spread to an area of about 100 square km. With a max of 1 Gbps per beam, it would mean 1 Gbps to share among more than 2000 people, or 100,000 people in high population cities. In the former case, even if 1% of 2000 people are receiving the DL, the average speed shared by 20+ people would be a ho-hum 50 Mbps (the actual throughput is lower because of the transport overhead), and that for just a mid-size city. For some parts of Manhattan, the average data rate would be below 1 Mbps. The trouble is, even if ultra-low latency is in demand from high financial institutions, probably only 2 or 3 finance companies could be served by Starlink owing to their limited bandwidth per cell. Elon Musk conceded as much during a TV interview.

Starlink and 5G

Although Ka bands and V bands are the main FR2 bands for 5G (5G specification defines a new radio interface NR and further subdivide the frequencies into two bands: FR1 [below 6GHz] and FR2 [>24GHz, but mostly mm waves]. FR1 provides limited speed improvement: 700 MHz band will have 30 – 120 Mbps, the larger speed is from massive MIMO with 32 to 128 arrayed antennas per cell. Higher FR1 bands can provide an 8-fold improvement in speed from MMIMO or more, but some advanced 4G services already achieve speeds comparable to that. FR2 relies on beamforming and some cross polarization to achieve limited MIMO to reach speeds as high as 1.8 Gbps over a short range. With FR1 and FR2 combined, 5G can theoretically support 1 M devices per square km, vs 4G's 100,000 devices per square km. This allows the mobile operator to serve high population area such as Manhattan and IoT Massive Machine Type Communication [mMTC]).

Starlink would not be able to take advantage of the enhanced capabilities of full 5G because Starlink's satellites are too far from the surface of the earth. For example, for a simple 4 x 4 MIMO. Both the TX and RX antenna spacing need be at least 58 m apart. Even for earth stations, such spacing is a bit extravagant, but for Starlink's compact satellites, it is all but impossible. Even were it physically possible by using a heavy satellite to accommodate such humongous structure, the satellite would be so big as to block out a large patch of the sky. Massive MIMO (MMIMO) is completely out of the question for Starlink.

For mMTC applications such as vehicle-to-vehicle communications, Starlink might be useful in wide open space due to its wide area near ubiquitous coverage, but since its FR2 beams would only be useful for LOS communications, urban high rises and densely forested areas will cause frequent brief outages as the vehicles are obscured by tall structures and vegetation. Such outages might be acceptable for GPS services or emails, but for future intelligent self-driving vehicles which depend on vehicle-to-vehicle communications to predict and avoid collisions, such outages are most assuredly dangerous.

For the hundreds of millions of suburban subscribers, a rooftop 0.45m mechanically steered dish antenna might be reasonably expected, but unlike fixed satellite services such as from GEO constellations whose customers might only need to point their non-steered dish antennas to the direction of the GEO, or low LEO, the dish antenna must be able to find a large enough opening in the sky to allow the dish to track the fast moving Starlink satellite and to perform quick handover when one satellite is about to disappear and a quick switch over must be performed to point to the new satellite coming into view, a motorized dish must be rotated about 60^o or so and to do so without perceptible interruption of the service is simply impossible. Even a combination of mechanical steering and SpaceX's residential CPE cannot avoid the periodic drop in the satellite signal level during handover. The mechanical steering must be roughly 90^o out of phase with the phased array steering to limit the satellite beam to stay within 30^o of the bore (the normal of the phased array). This leads to a ~ roughly 10 dB dip periodically which might not matter too much except for ITU Regions K, L, M, N, P and Q (half of US is in Regions K, L, M, N). For those Regions, the combination of rain fades and the 10 dB dips can reduce the availability to less than 99% even for Ku bands. In rural and remote areas, potential users might not object to an availability of less than 99%, so all may be well for Starlink.

Starlink may also position itself as a wireless back-haul provider, and certainly its enormous space-based Terabits Internet backbone will be attractive. However, the minimum spot size of their Ka band cells (beams) means they are still throughput limited to attain significant share during the anticipated 5G infrastructure expansion which would be an order of magnitude greater than during the 4G LTE expansion phase. It is expected that much of the expansion will involve replacing slow OC-3 fiber back haul or microwave back-haul to large towers by multi-gigabit fiber back-haul to handle the dramatic increase in the 5G handsets and related devices which would drive the demand on bandwidth by at least an order of magnitude. The less than stellar availability of Starlink's Ka band back haul links will also be a major issue for perspective cellular operators.

A further thought on the upcoming 5G expansion. Presently the thinking is to beef the hell up the large towers by super-fast fiber back-haul and to rely on higher frequency FR2 bands to back-haul the expected large increase in micro-cell, pico-cell and femto-cell miniature base stations with cell ranges as small as 20 m – 200 m. The wide use of such tiny cell sites can greatly multiply the frequency reuse by as much as 10–100 fold. Remember HTS systems simultaneously increases the GEO's data capacities by an order of magnitude, but also reduces the cost of the spectrum by as much as a factor of 10. The wide use of pico and femto cells are the same idea on steroids. However, increasing the deployment of such miniature cells would strain the fiber back-haul for the taller cell towers tremendously. FR2 must rely on those dwarf cell sites to exist since high band mm waves have limited range, hence a cell site which has a radius greater than the range of the high band signals clearly does not work. Now imagine a tall tower is flanked by those dwarf cell sites which could easily number in the 100s, to feed those dwarf cells, an equal number of spot beams would need to be used since feeding so many cells in less than a square km with high-speed optical fiber would be unimaginably expensive. Yet the total throughput demand of such a large number of cells would be huge.

5G devices demand that each small cell must at least be able to support one of the gigabit devices connected to it. Although the max demand of a single small cell is high (1 Gbps or so), an aggregate of such cells might not need to be as high as the total number of small cells times the max capability of any single cell. A good mathematical model of the time varying bandwidth usage of a single cell is a Poisson process. Poisson process is used, for example, to determine how many meteorites greater than 1 meter that strike Earth in a year based on past statistics. More precisely, a model based on the aggregate of Poisson processes called Erlang is appropriate here. In our case knowing that the average bandwidth that is consumed by the 5G devices for a given cell is 236 Mbps with a max capacity of 1 Gbps per cell, one can determine the aggregated back haul throughput needed to feed 100 identical small cells to ensure 99.999% availability for the aggregate. The answer is 35 Gbps. What is amazing is the fact that the probability for the bandwidth demand of any given cell to exceed 600 Mbps is 28%, meaning that for more than 1/4 of the time, the single cell bandwidth demand exceeds 600 Mbps. Naively, one would think that the total aggregated bandwidth needs to be closer to 600 Gbps or so to provide adequate back haul for 100 small cells.

The trouble with feeding 100 small cells from a single tall (30m – 50m) cell tower is that it would be extremely difficult or perhaps impossible to avoid cross interference of those feeder beams, not to mention that it would be near impossible to house 100 high gain feeder antennas on a single mast. To minimize mutual interference, the feeder antennas all must be pointed at different directions, however, since the area covered by the aggregate is likely to exceed a few square km, unless the tower is more than 150 m in height, the majority of the feeder beams travel almost horizontally, which makes it virtually impossible to avoid mutual interference. In addition, replacing OC-3 fiber lines by STM-256/OC-768 (fiber optics line capable of transmission speed of 39.8 Gbps) is an extremely costly proposition.

It would be much less costly to connect into Starlink's multi-terabit Internet in space. Instead of needing 100 feeder antennas to service those 100 or so small cells, a single multi-beam phased array can be configured that each beam can deliver short bursts of data to a subset of cells in turns. For example, a 16-beam phased array, with each beam capable of 2.5Gbps, can deliver up to 50 megabits of data (max burst duration is 2 ms) to a cell and would be capable of providing up to 40 Gbps net back-haul throughput. The max time each cell must wait for its data is 12.5ms which is an acceptable latency for non-time-sensitive tasks. Furthermore, the majority of the small cells are installed on the roof or mounted close to rooftop height, which makes it easy to access them from the satellite compared to accessing them from a 25m to 50m “tall tower”.

There are several challenges associated with the above idea:

1. Neither Starlink's ka nor V band links are capable of 40 Gbps throughput.

2. In regions where rainfall rates can exceed 50 mm/hr 0.01% of the time (ITU Regions K – Q), Starlink's ka or V band availability can drop below 99%, which is too low for 5G back-haul.

3. Starlink's phased array has an estimated aperture of 0.7m, which for 72.5 GHz, can produce a minimum spot size of about 8 km in diameter. Unfortunately, to avoid inter-beam interference, the spot size for each beam needs to be smaller than about 200m, assuming the average cell spacing is 100m. To shrink the spot size to 200m, Starlink's V-band phased array needs to be at least 28m, which, even if it is physically possible, would be way too heavy and costly to build, launch, and deploy. This is really a missed opportunity. Since Starlink will have a global presence, it can directly connect cell clusters globally without needing to be connected to terrestrial fiber infrastructure. Considering that the US market price for OC-3 (155 Mbps) is at least $20,000 a month, although higher bandwidth lines may be cheaper to lease, Starlink could ask for $1M per month for 40 G bandwidth plus the feeder links to the aforementioned cell cluster. This would be a substantial discount perhaps by at least a factor of 10.

Considering the much-anticipated explosive expansion of present 4G infrastructure to 5G, which primarily comprises increasing the number of small cells per tower tenfold or more, it would not be a big stretch to think that a new company with an extraordinarily low-cost solution could take 0.1% of the 5G infrastructure market 6 years from now, or around 1000 small cell clusters, likely generating or annual revenue of $12 billion USD.

As previously mentioned, Starlink's limiting factor for their business model is the ground segment. According to an MIT study, Starlink will need ~123 ground stations and ~3700 gateway antennas to match their 23.7 Tbps system throughput for just 4425 satellites. When the 42,000-satellite constellation is fully deployed, they would need close to 40,000 Gateway antennas and more than 1,000 ground stations. Even though it is theoretically possible for them to deploy Terabit free space optic links for a subset of their satellites, thereby enabling them to greatly surpass terrestrial fiber infrastructure in both capacity and latency, the lack of sufficient space to earth (and earth to space) capacity would greatly diminish their potential revenue while limiting the percentage of earth's population who could benefit from such an immense resource.

Onward's patented system capabilities can address this Starlink deficiency and accelerate elimination of the Digital Divide.

Onward's Enabling IP

Onward's wireless solution employs a tethered aerostat platform that can be positioned at varying altitudes as necessary to maximize the capabilities of its onboard telecommunications payload. Onward's solutions provide a wireless infrastructure that can function either independently or in tandem with other wireless solutions. It can be thought of as the tallest tower in a market. Onward has designed systems to be deployed as high as 1,500m with varying frequency and bandwidth designed payloads and is presently in discussions for provision of systems operating at 300m to 400m altitude carrying a 700Mhz 4G LTE payload.

There are companies other than Onward that look to the use of aerostats as wireless telecommunications infrastructure however, absent Onward's patented and patent pending aerostat operational enhancement systems it is not possible for an aerostat-based telecom payload to provide a meaningful and reliable level of service availability. Every aerostat in the world, except for those equipped with Onward's patented operational enhancement systems, needs to be brought to ground at regularly scheduled intervals ranging from weekly to monthly thereby interrupting telecommunications services. The two primary reasons causing an aerostat to be brought to ground are helium loss and extreme wind and weather.

Onward's patented and patent pending systems will enable its telecommunications infrastructure platform to remain on station for up to six months and is only brought down for regularly scheduled upgrade and/or maintenance or in the event of weather with winds approaching hurricane force. Onward's carrier grade service availability is supported by its patented **O**nward **H**elium **R**eplenishment **S**ystem (OHRS) and its patent pending **W**ind **T**olerance **S**ystem (WTS).

Onward's Aerostat Operational Enhancement Systems

The two most critical factors in flight duration of tethered aerostats are unpredictable variations in wind speed and depletion of lift gas.

Wind **T**olerance **S**ystem **(WTS)**

Onward's patent pending, WTS maintains the force center (CBM) or center of mass and buoyancy in line with the tether attach point (TAP) to maintain a level pitch or within a geometrical polygon defined by the number of support cables to maintain survivability. Filings available for review.

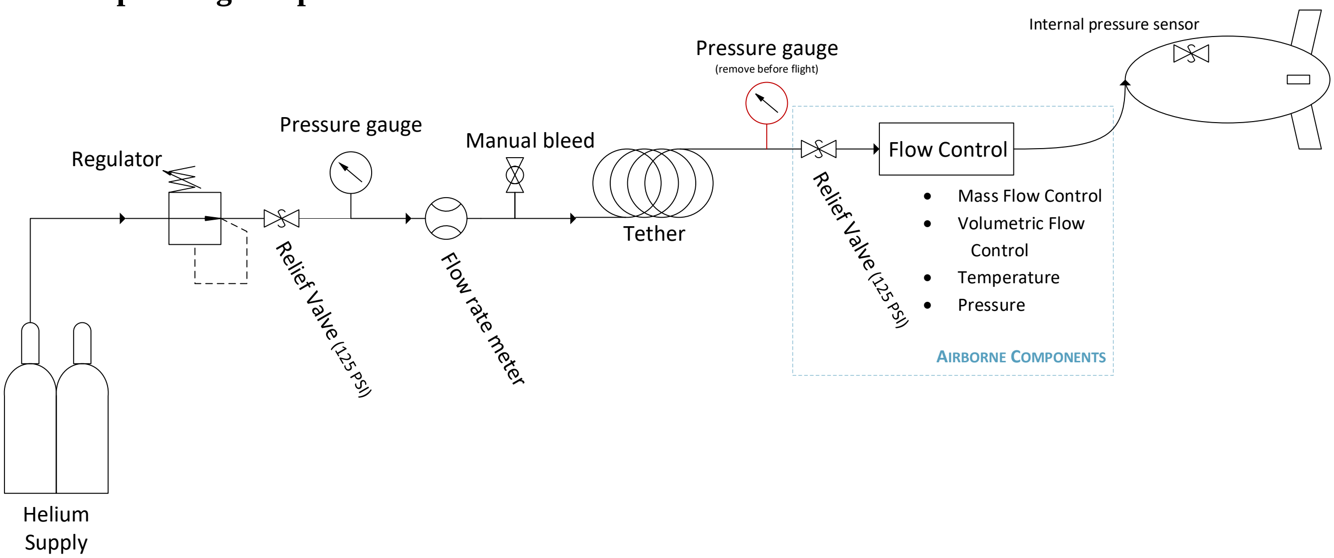
WTS Dual Winch Assembly Differential Assembly includes:

- Cycloidal speed reducer
- Slip Ring for power, optical and helium transfer
- Tether with helium feed tube and power & data cables

Onward **H**elium **R**eplenishment **S**ystem **(OHRS)**

Onward's OHRS monitors and maintains aerostat buoyancy either by predetermined intervals of gas replenishment or by pressure differential in real time thereby keeping the telecommunications platform at altitude to assure continued service availability throughout its defined service area. Filings available for review.

OHRS operating components:



- **Adaptive Harness To Stabilize Aerostats In High Winds and Method**
- Filed October 9, 2018, Utility Patent US # 16/155852
- All 50 Claims Have Been Approved by the USPTO

- **Long Mission Tethered Aerostat and Method of Accomplishing**
- Issued May 4, 2010, US Patent # 7,708,222

- **Slip Ring & Double Slip Ring**
- Issued December 27, 2011, US Patent # 8,083,174

- **Method of Providing Long Duration Tethered Aerostat**
- Issued July 16, 2013, US Patent # 8,485,465

- **Helium Replenishment Tether**
- Issued July 18, 2017, US Patent # 9.708.049

Technical Challenges for Starlink

Owing to their distances from the surface of the earth and limited physical spaces available for radio antennas, Starlink satellites cannot deliver spot (or cell) sizes tighter than 30 km (except that a V-band phased array could deliver spot size as small as 9 km in diameter. This renders their systems incapable of taking advantage of MIMO's ability to drastically increase frequency reuse as well as SNR (signal/noise) improvement. Starlink's ku, ka, and V bands suffer from varying degrees of rain fades and atmospheric absorption which reduce availability, rendering them unsuited for mission critical applications such as financial operations, intelligent vehicle, and robotic factory automation where extremely low latency (< 1ms) and ultra-availability and wireless back-haul is paramount.

Onward's Aerostat System as a Network Concentrator in the Sky for Starlink

A concentrator aggregates multiple streams of data and combines them into a single point of service. It is feasible for Onward to aggregate multiple high-speed links from Starlink satellites into a local cluster of ultra-speed cross linked aerostats to combine and deliver them to the earth's surface using more surface friendly, highly available, and bandwidth efficient 5G massive MIMO/beamformed narrow spot beams. Such spot beams would have a minimum footprint as small as 34m (@72GHz) or 86m (@28GHz). Such spot sizes are well below the average cell spacing of the miniature terrestrial 5G cell clusters. The spot beams can deliver up to 10 Gbps @72GHz and 1 – 2 Gbps @28GHz, which are sufficient for wireless back haul for 5G cell clusters. Onward's patented systems can be configured in a 5-aerostat formation as a sky based super-speed wireless local loop with 40 Gigabit V band MMIMO cross links. The loop is around 5 km in radius to ensure the V band cross links can attain no less than 99.99% availability (ITU-R Availability Criteria for data transmission is 99.99% [unavailable for < 53min/yr] and broadcast 99.9% [unavailable for < 9hr/yr]). In this configuration, the wireless back haul link distances are from 300m to 3 km, carrier grade 5-nines availability is attainable for all but Region Q where 0.01% rain rate is 176 mm/hr! However, by positioning one aerostat right on top of the cellular network, the longest back haul link distance could be made smaller than 1 km which would make even region Q carrier class.

While the majority of the Internet traffic is expected to be non-local and must go through Starlink's super-speed space Internet, traffic for local businesses, factories, offices, massive machine communications, Virtual Reality/Augmented Reality, online gaming, hospitals, emergency responses, drone deliveries, etc. are most likely to be local in nature, and can be handled entirely within Onward's sky local loop. In some situations, one of the aerostats can be connected to a super-speed fiber loop so that Onward's wireless local sky loop can double as an earth station gateway for Starlink. Instead of using just one aerostat to communicate with a Starlink satellite, Onward could use all 5 aerostats to provide superior site diversity during heavy rainfalls. There are two types of rainfalls, the stratiform rains are low to medium in intensity (rainfall rate < 10 mm/hr), wide area, and long duration, while convective rains are high intensity, small area (usually less than 3 km at the low end, and gets progressively smaller for high intensity rains), short duration (usually a few minutes in duration owing to the fast-moving convective nature of the rain). For 0.01% exceedance time, we are dealing with mostly > 100 mm/hr in wetter regions (Region K and beyond), hence the rain cell sizes are only 1 -2 km, and with >10 m/s winds, the duration would be in the order of a few minutes or less. When the aerostats are spaced 5 – 6 km apart, adjacent aerostats would be highly unlikely to be within the same rain cell (where the most intense rainfall takes place), hence Onward's sky loop would have a high availability which is 5-nines or better, as well as max gateway throughput of 200 Gbps (assuming 40 Gbps per aerostat) or better. 5G technology can improve the availability and throughput without increasing latency through the heavy use of fast adaptive modulation/coding/power-control which lowers the effective data rate when environmental impairments are high and increases it when impairments are low to maintain availability and avoid unnecessary ARQ's which drastically increases latency.

Such an arrangement will be mutually beneficial to both Onward and Starlink. Onward is limited by the short range of its V-band cross links (~ 5 km). The range is deliberately kept short to maintain 5-nines availability in all Regions (even Region Q can attain high availability owing to site and temporal diversity and multiple antennas). Onward's Sky Loop or a single Onward platform operating independently of a Sky Loop is inherently an ultra-high-capacity local network, sub-speed back-haul such as LAN or microwave simply do not make sense. However, the anticipated cost of leasing a super-speed fiber back haul would be far higher than the cost of operating an aerostat.

A collaboration between Starlink and Onward would enable Onward to enhance Starlink services ability to get into those low population regions in three ways:

1. It can facilitate the extension of Starlink's ultra-speed space Internet to those regions to attract high tech industry to expand or relocate to less costly real estate; and

2. It can provide low cost 5G network for local customers and rely on Starlink to cover the less populated areas in a seamless manner; and

3. It can provide network redundancy for Starlink's space network when it is included in the Starlink mesh network infrastructure.

A collaboration with Onward would also benefit Starlink in additional ways. By applying Onward's IP and capabilities Starlink can improve its ground segment enormously, it can also compete in the wireless back haul in densely populated city centers and push its uber-speed space network to remote regions. Furthermore, Starlink's claimed latency is 20 ms or more, yet according to a Nokia white paper, smart homes require under 10 ms latency for public safety communications, and smart factory with real time remote control needs under 5 ms latency with 99.99% availability. Telesurgery (AR/VR) in Health care, and autonomous vehicles need 5-nines availability and sub-millisecond latency.

Onward's patented aerostat enhancement systems enable an aerostat platform to support achieving a latency from 2 micro-seconds to 70 micro-seconds, hence it would be possible to control the automated machines in one building from a computer network control center 10 km away, and the commands can be sent half a world away through the space network, in much the same way that a Mars robotic rover is controlled by the onboard computer in the landing craft with commands sent from the NASA Command and Control Center back on earth. Onward platform can also maintain the high level of availability through spatial and temporal diversity and high redundancy of Onward's wireless local loop.

For telesurgery and autonomous vehicles, the only way to achieve sub-millisecond round trip latency is to have a mid-micro-second round trip airtime and minimize the processing time related to the protocol handling and queuing processes at each hop. For a conventional 4/5G cellular network, when you add a hop from car to the small cell antenna with possible delay due to cell to cell handover, and another hop to the microwave back haul, then to the main tower, from there through the fiber back haul to the nearest network switching center, then, if you are lucky, back to the same or different back haul fiber link, back to the tower, then through a microwave link to the final small cell's radio link to the destination meaning the intermediate processing hops will be at least 5, but often a lot more.

It would be extremely difficult to keep the processing delay to under a millisecond, and the 99.999% availability would be hard to maintain since even if all the intermediate links have 99.9998% availability, the combined system latency would be lower than 99.999%. It is achievable in the lab, but probably not in the real world. For Onward, such communications must bypass terrestrial 4/5G network altogether, and instead, rely on Onward's own user links to reduce the intermediate processing steps to just one by positioning autonomous traffic control and vehicle navigation programs within the ground segment of each aerostat or in rare occasions, 2 when handover from one aerostat to another must be performed. There are no handovers while a vehicle is within the coverage of a single aerostat as beam steering/tracking is used instead of beam-to-beam handover as in the case of a fixed beam tessellation arrangement. It is therefore possible for Onward’s platform to achieve a sub-millisecond latency.

Epilogue:

Advances in telecommunications connectivity proposed and to an extent achieved by Starlink in their endeavors are positive gains that with Onward’s value added capabilities Starlink will be better able to seize opportunity to fully embrace the promise of 5G. Onward’s wireless telecommunications infrastructure platform is capable of operation as an independent network and of added value as a supportive and enabling collaborator in projects such as Starlink and OneWeb, Kuiper and others.