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Spaceflight Networks – A New Paradigm for Cost Effective Satellite Communications

Jason Andrews, John C. Springmann, Philip Brzytwa, Curt Blake
Spaceflight, Inc
3415 S. 116th St, Suite 123, Tukwila, WA 98168; 206-486-1020
JAndrews@SpaceflightServices.com

ABSTRACT

The use of small satellites has increased significantly over the last 5-10 years, and their popularity and use continues to grow. This is evidenced by the now common rideshare launches, for example the November 2013 launch of 32 satellites on a Dnepr. As the small satellite revolution continues, the challenge has shifted from space access to downlinking payload data in a cost effective and timely manner. To address this emerging market need, Spaceflight, Inc. has launched Spaceflight Networks, a business dedicated to cost effective spacecraft communications services. Spaceflight Networks is deploying a global network of ground stations to enable timely spacecraft tasking, telemetry, and high bandwidth payload downlinking. The network will support UHF, S-, and X-band frequencies, and will be expanded into higher frequencies as required to meet customer needs. The first ground station, located in Tonsina, Alaska (62° N), will be operational Q4 2014, and additional ground stations are coming online in 2015 and 2016. This paper discusses trends in small satellite launches that motivate the planned ground station network, factors such as communications latency that drive the ground station locations, and technical capabilities of the network architecture.

INTRODUCTION

The use of small satellites has increased significantly over the last 5-10 years, and their popularity and use continues to grow. This is evidenced by the now common rideshare launches. For example, the launch of a Minotaur I on November 19, 2013 included 29 satellites, a new record for the number of satellites on a single launch. This record was immediately broken on November 21, 2013 with the launch of 32 satellites on a Dnepr.

While the number of small satellites in use has grown significantly, the available ground infrastructure for small satellite operations has remained largely stagnant. There has been effort to provide ground stations for small satellite missions, such as the Mobile CubeSat Command & Control (MC3) Ground Stations, initially developed primarily for government missions, as well as various ad-hoc ground station networks, but there are very few existing ground station options for small satellite developers, particularly for commercial operators. Existing ground infrastructure that has traditionally been used by large spacecraft operators, such as Universal Space Network, is not amenable to small satellite missions due to high costs. As a result, many small satellite developers and operators are forced to develop their own ground infrastructure for their missions as opposed to using existing, commercially-available ground infrastructure.

Spaceflight, Inc was established in 2010 to enable frequent low-cost access to space for small satellites. It does this by providing ride share opportunities with numerous launch services providers. Spaceflight has launched 36 satellites to date (June 2014) and has 136 satellites manifested to launch. Through working with its small satellite customers, Spaceflight has found that the need for small satellite ground stations is significant, and will be launching Spaceflight Networks – a new ground station network targeted to commercial small satellite operators – to provide ground station services to complement its existing launch services. In this paper, we describe trends in small satellite launches that motivate the need for a ground station solution, discuss ground station siting based on typical small satellite orbits, and describe the planned ground station capabilities. The first Spaceflight Networks ground station will be operational in Alaska in Q4 2014.

TRENDS IN SMALL SATELITE LAUNCHES

Spaceflight maintains a robust small satellite Customer Relationship Management (CRM) launch demand database, which is currently tracking approximately 350 spacecraft (11,000 kg total) seeking launch between 2014 and 2017 [1]. Based on this data, Spaceflight has found a number of trends in the small satellite industry.

The small satellite market is driven primarily by commercial remote sensing missions [1]. This is illustrated in Figures 1 and 2, which show the number

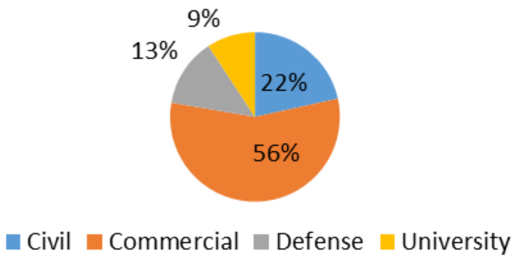

Figure 1. Percent of missions by owner/operator type (2014-2017).

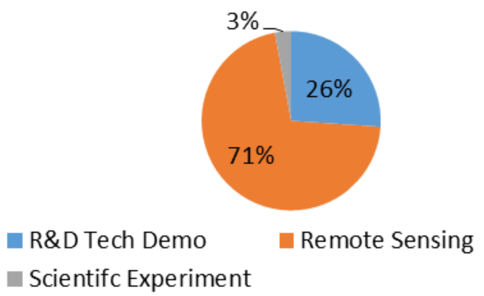

Figure 2. Percent of missions by purpose (2014-2017).

of small satellite missions by owner/operator type as well as by mission purpose, respectively.

Given that a large portion of missions – both traditional large satellites as well as small satellites – are for remote sensing (for which sun synchronous orbits are often desirable), and that ISS logistics provides frequent launch opportunities to 51.6° inclination orbits, a large portion of small satellite launches are to sun synchronous (approximately 98° inclination) and 51.6° inclination orbits. This is illustrated in Figures 3 and 4, which show the expected number of launch opportunities by altitude and inclination between 2014 and 2017.

Given these trends in the industry, a ground station infrastructure is needed to support commercial small satellites in 400-500 km 51.6° inclination orbits, as well as 500-700 km sun synchronous orbits.

GROUND STATION LOCATIONS

Spaceflight Networks will utilize a geographically diverse set of ground stations to minimize the duration between contact opportunities for small satellites in low-Earth orbit. Spaceflight Networks will own various ground stations around the world and is also working with partner organizations to access additional ground stations. The planned ground station locations are based on communications latency with typical small satellite

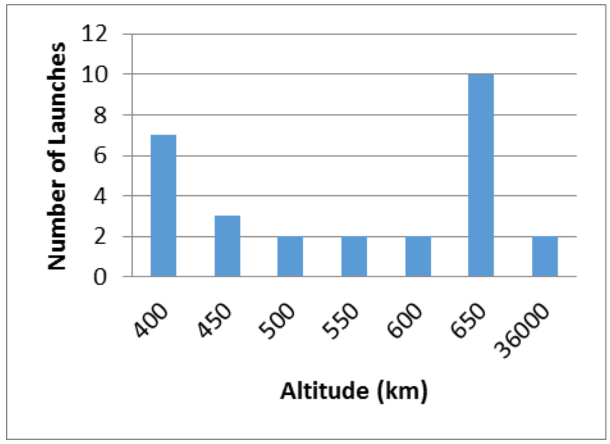

Figure 3. Number of expected launch opportunities by altitude (2014-2017).

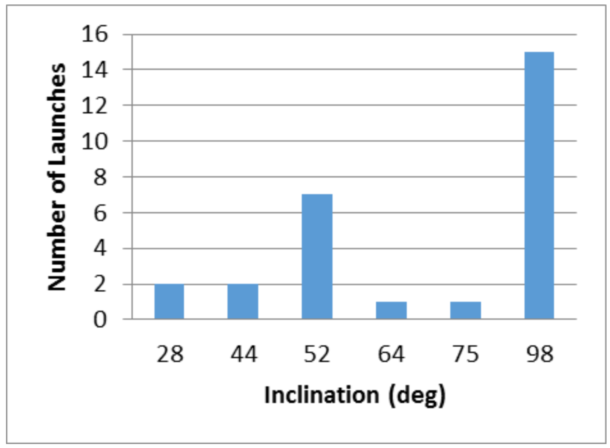

Figure 4. Number of expected launch opportunities by inclination (2014-2017).

orbits. In this section, we describe the methods used to site these stations.

Two primary metrics are used to evaluate ground station locations: Time To Next Pass (TTNP), and Time Since Last Pass (TSLP). Each of these is calculated for a given position in orbit and a given ground station location(s). For a given position in orbit, TTNP is the time from said location until the next communications opportunity. Similarly, for a given position in orbit, TSLP is the time that has elapsed since the last communications opportunity.

TTNP and TSLP are calculated by simulating the satellite orbit in AGI's Systems Toolkit (formerly called Satellite Toolkit), and calculating the time between the mid-point of the contact windows and each satellite location. The satellite locations are then binned into an evenly distributed latitude/longitude grid, and the average TTNP and TSLP for each instance in the bin is calculated. Figures 5 and 6 show the TTNP and TSLP for a satellite in 51.6° inclination 500 km circular orbit and a single ground station located in southern New Zealand. The plots are “heat maps” of TTNP and TSLP, where the color represents the TTNP and TSLP for the corresponding position in orbit.

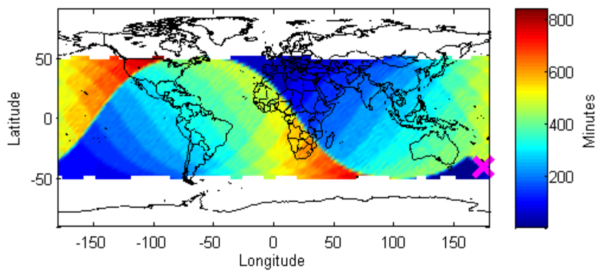

Figure 5. Average Time To Next Pass (TTNP) for a satellite in 51.6° inclination 500 km circular orbit and a single ground station located in New Zealand (ground station location indicated with the X).

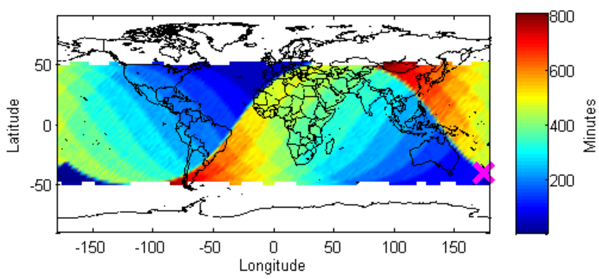

Figure 6. Average Time Since Last Pass (TSLP) for a satellite in 51.6° inclination, 500 km orbit and a single ground station located in New Zealand (ground station location indicated with the X).

As seen in Figure 5, the New Zealand ground station provides excellent coverage (low TTNP) to the Horn of Africa and Middle Eastern regions for satellites in 51.6° inclination orbits. The TSLP is excellent for portions of Western Europe as well as Australia. Using this method, TTNP and TSLP can be calculated for each individual candidate ground station location, or for groups of ground stations. Ground station locations are then chosen such that the TTNP and TSLP are minimized over regions of interest. In the selection for Spaceflight Networks, the goal was to minimize TTNP and TSLP over the entire world for 51.6° inclination and sun synchronous low-Earth orbits.

To select locations for Spaceflight Networks, we first started with a list of 22 candidate locations. These locations are shown in Figure 7. These were used as initial options because they were considered feasible locations – many are locations of an existing teleports, and for others, they are on or near fiber connections in politically feasible locations. From this set of initial locations, TTNP was calculated for each (as in Figure 5), and a ground stations were chosen to provide global coverage with low TTNP for both 51.6° inclination and sun synchronous orbits.

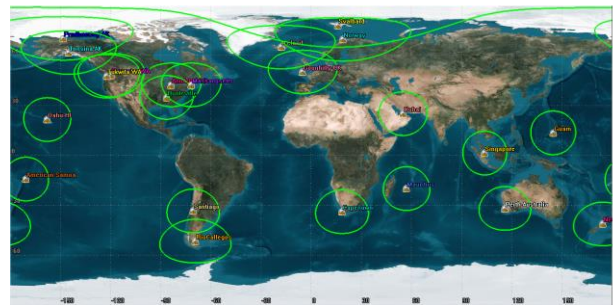

Figure 7. Initial candidate ground station locations used to evaluate different configurations of ground station grouping. The visibility is shown to spacecraft in 450 km altitude orbit.

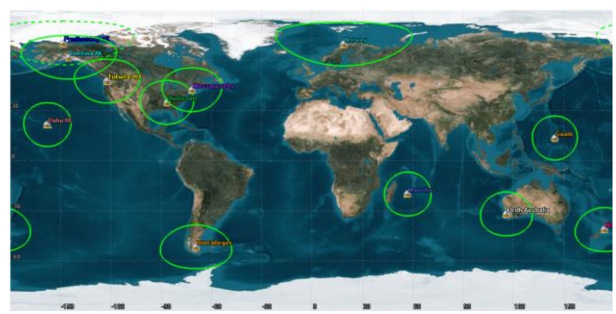

Figure 8. Resulting set of locations for Spaceflight Networks ground stations.

The resulting ground station locations are shown in Figure 8. There are 11 ground station locations: Washington (state), Alabama, Massachusetts, Alaska, Hawaii, Guam, southern New Zealand, western Australia, southern Argentina, Mauritius, and Norway. The resulting TTNP and TSLP for this set of ground stations and spacecraft in 51.6° inclination and sun synchronous orbits are shown in Figures 9-12.

These plots are a convenient way to visually assess ground station effectiveness. As seen in Figures 9-10, the TTNP and TSLP resulting from the ground station configuration for 51.6° inclination satellites is less than 90 minutes for all locations, and for much of the Earth, 20-30 minutes. From Figure 9, we also see that South America is the region with the worst coverage in terms of TTNP. One obvious option for improvement is to add a ground station in Brazil. An additional ground station in central Africa would also be helpful in reducing TTNP over that region.

For a sun synchronous orbit, the ground station configuration of Figure 8 provides 20-40 minute TTNP and TSLP for much of the earth. Ground stations in northern Alaska as well as Norway provide a contact opportunity at least once per orbit for sun synchronous LEO satellites. The northern Alaska location that was initially desired was Prudhoe Bay. However, the current cost of fiber internet in Prudhoe Bay, AK is prohibitively high, so a southern Alaska location has been used in the simulations (Tonsina, AK). Tonsina is the first finalized ground station location and is being installed in fall 2014. Moving to a more northern Alaska location would mitigate the small portion of 90 minute coverage seen in Figures 11 and 12. And of course, an even more northern location, such as Svallbard, would also provide once-per-orbit coverage for sun synchronous satellites.

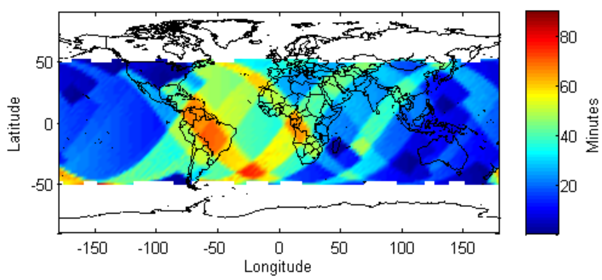

Figure 9. Average TTNP between a satellite in 51.6° inclination 500 km circular orbit and the ground stations shown in Figure 8.

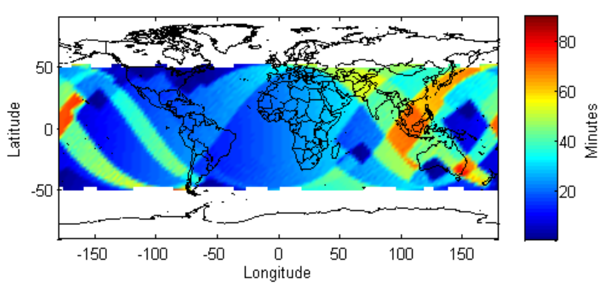

Figure 10. Average TSLP between a satellite in 51.6° inclination 500 km circular orbit and the ground stations shown in Figure 8.

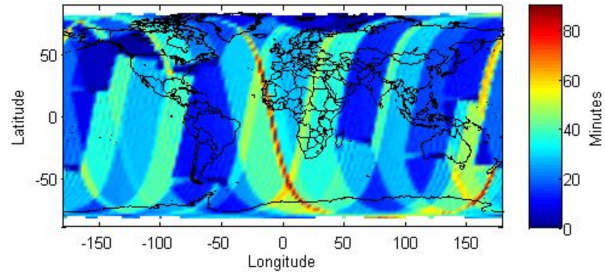

Figure 11. Average TTNP between a satellite in 500 km circular sun synchronous orbit and the ground stations shown in Figure 8.

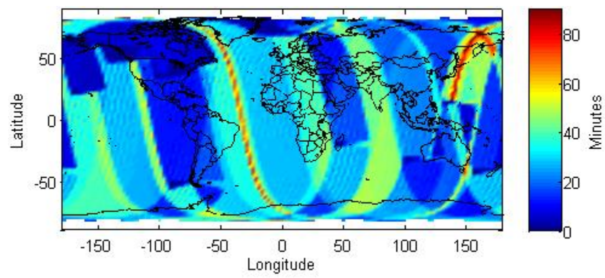

Figure 12. Average TSLP between a satellite in 500 km circular sun synchronous orbit and the ground stations shown in Figure 8.

Although there are some areas for potential improvement, such as the South America coverage for a 51.6° inclination orbit, as well as a northern Alaska ground station to improve sun synchronous coverage, the locations of Figure 8 provide an excellent baseline for Spaceflight Networks ground station locations. With these desired locations in-hand, Spaceflight is working with global partners to select the specific sites, acquire land, and acquire the necessary licenses. As we work the specific site selection, we are also working to improve the baseline locations of Figure 8, for example, by adding a station in Brazil. The first location to be installed is Tonsina, AK. The site construction is in work and the antennas will be installed in fall 2014. The remaining locations will follow, with the intended schedule of a 2015 build for the domestic locations and a 2016 build for the international locations.

GROUND STATION CAPABILITIES

The individual ground stations are being developed to support frequency bands that are commonly used by commercial small satellite operators, which is driven largely by the ability to obtain FCC and ITU licenses for communication as well as by the physical size and power requirements of the spacecraft radios and antennas. Specifically, these frequencies include bands near 400 MHz UHF for downlink, 450 MHz UHF for uplink, 2200 MHz S-band for uplink, and 8000 MHz X-band for downlink. The small satellite industry is also already moving up to higher frequencies such as Ka-band, and Spaceflight Networks is investigating immediate extension to support this band as well.

To support these frequencies, each ground station will include at least one yagi antenna system (one antenna tuned to 400 MHz, a second tuned to 450 MHz) to support UHF frequencies, as well as at least one parabolic dish to support S- and X-band frequencies. Each ground station site consists of the antennas as well as an equipment container to house the RF, computing, security, and other equipment. Multiple antennas, as opposed to a single antenna, will be installed at each site according to market demand. That is, all locations are being designed to accommodate multiple parabolic dishes, and the exact number of dishes installed will be dictated by customer demand. The antenna parameters for the first ground station being installed in Tonsina, AK, are given in Table 1. The X/S antenna parameters correspond to a 3.7 m diameter dish, and the site can accommodate larger dishes if needed.

Software defined radios will be used at the ground stations in an effort to support a wide variety of spacecraft radio and link characteristics with a minimal set of ground hardware. Initially, the software defined radios will be configured to support a specific set of spacecraft radios that are applicable to the small satellite industry. With this approach, Spaceflight Networks will operate much like conventional cell phone networks: spacecraft operators can choose from a list of supported spacecraft radios, and then will purchase a data plan for use of Spaceflight Networks. With the software-defined radio approach, the ground station capabilities can be extended to support additional spacecraft radios with software rather than hardware modifications.

The ground station network will operate in a "bent-pipe" fashion. Each ground station will be connected to the central Spaceflight Network Operations Center (NOC), which will provide connectivity to the ground stations to customers. Each ground station location has fiber connectivity, facilitating data rates on the order of gigabits per second. The interface between the Spaceflight NOC and customers is currently being developed, and will utilize the latest web-based tools to provide convenient access to ground station control/monitoring as well as data flow to and from the stations.

The first Spaceflight ground station is being installed in Tonsina, Alaska (62° N) in Q3 2014 and will be operational by Q4 2014. The antenna and initial ground radio specifications for this site are given in Tables 1 and 2.

Table 1. Antenna specifications for the first Spaceflight ground station.

	UHF	S-Band	X-Band
Rx Freq (MHz)	395-405	2200-2300	8000-8400
Tx Freq (MHz)	435-455	2000-2170	n/a
Polarization	RHCP/LHCP	RHCP	RHCP
Gain (dBi)	16	33.5	45.9
G/T (dB/K)	-10.8	12	24
Tx Power (W)	75	30	n/a

Table 2. Initial radio specifications for the first spaceflight ground station.

<table>
<tr><th></th><th>UHF</th><th>S-Band</th><th>X-Band</th></tr>
<tr><td>Rx Freq (MHz)</td><td>275-475</td><td>n/a</td><td>8000-8400</td></tr>
<tr><td>Tx Freq (MHz)</td><td>275-475</td><td>1650-2400</td><td>n/a</td></tr>
<tr><td>Modulation</td><td rowspan="2" colspan="3">Configurable</td></tr>
<tr><td>Packet Structure</td></tr>
</table>

SUMMARY

Spaceflight, Inc is launching Spaceflight Networks – a new ground station service developed for commercial small satellite operators. The planned ground station locations were chosen to minimize communications latency with satellites in 51.6° inclination and sun synchronous low-Earth orbits, since these are very common small satellite orbits. The first ground station is located in Tonsina, Alaska (62° N) and will be operational in Q4 2014. Spaceflight is currently working with global partners in developing the remaining ground stations, while at the same time refining the planned ground station locations. These stations will be developed over the years 2015 and 2016. The stations will support UHF, S-band, and X-band frequencies, and will be expanded into the Ka-/Ku-band as required to support customer needs. Initially, the ground station radios will be configured to support a specific set of spacecraft radios that are applicable to the small satellite industry. With this approach, Spaceflight Networks will operate like a conventional cell phone network: spacecraft developers/operators can choose from a list of supported spacecraft radios, and then will purchase a data plan for use of the ground network. With the use of software-defined radios, the ground station capabilities can be extended to support additional spacecraft radios as the market demands.

REFERENCES

[1] P. Brzytwa, K. Kelley and C. Blake, "The Small Satellite Launch Dilemma -- Choosing the Cost Effective Launch versus the Optimal Orbit," in *Small Satellite Systems and Services (4S) Symposium*, Majorca, Spain, 2014.