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White Paper:

Comparison of GEOs and LEOs, and the Planned Aurora IV and OneWeb Systems, for Alaska

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Abstract

The socioeconomic benefits of broadband are well established.[1] To compete in the modern economy, broadband services are essential. Populations with high broadband penetration generally excel and those with limited access decline.[2] As such a robust, cost-effective, broadband infrastructure that can serve all of Alaska is vital.[3]

Currently, Alaska has significant gaps in its broadband coverage, particularly in rural and remote areas where adverse topographical and weather conditions make terrestrial network buildout not economically viable. As a result, a significant portion of the population in Alaska has no access to broadband, or has broadband that is deemed by the US Federal Communications Commission to be inadequate. Despite heavy federal subsidies to Alaska's carriers to extend their terrestrial networks, many Alaskans will remain unserved or underserved after the subsidies expire 10 years from now.[4]

This paper considers the use of a new generation, high throughput satellite as a complement to the existing terrestrial network, to create a complete, seamless Alaska broadband solution.[5] Fortunately, there are a wealth of case studies across the globe from which Alaska can benefit, many of which involve similar challenges as those faced by Alaska, such as a highly non-uniform and widely dispersed population spread across challenging geographies, often with extreme weather conditions. In all these cases, satellites have played a major role in reaching the portion of the population that cannot be economically served by other means.[6]

We review the global literature regarding holistic broadband offerings, and then analyze the satellite component. We discuss the key differences between satellite offerings including the next generation of high-throughput geostationary (GEO) and Low-Earth-Orbiting (LEO) satellite systems. We compare both the key technical and business aspects of the Aurora IV GEO HTS system currently under development by the Alaska-based Pacific Dataport, Inc. ("PDI"), with the planned OneWeb global LEO system being developed by the Virginia-based company WorldVu Satellites Ltd.

Our findings are that both Aurora IV and One Web coexisting and competing in the marketplace is not only beneficial, but essential to secure a competitive, reliable and affordable broadband future for Alaska.

Comparison of Key Aspects of HTS GEO and LEO Systems

Continuous advancements and innovations in satellite technology, including higher throughput satellites, antenna design and performance and high-volume manufacturing capabilities, have resulted in a renewed interest in leveraging the unique characteristics of this capability, whether through next generation GEO high throughput satellites or global constellations of satellites in LEO. The following table and discussion provides a high-level comparison of key aspects of both.[7]

	GEOs	LEOs
Coverage and Capacity:	Only one GEO is necessary to provide consistent, uninterrupted, high capacity service to a target market	Hundreds of LEOs with overlapping beams in a highly organized constellation. The need for low-cost satellites drives single-string less reliable designs than GEO. Individual Satellite outages cause periodic gaps in coverage until replaced
Network Stability:	Static geometry of GEOs, i.e., fixed, high powered beam delivering consistent high throughput capacity, is better for stability of services	LEOs are mobile systems; as such, user experience is similar to wireless mobile even in fixed installations. Certain applications may suffer due to frequent handoffs between satellites and a high degree of traffic variability
Latency:	Impact of latency is application dependant. Latency has very little effect 95% of broadband applications, and most media and mobility applications.	Closer to the Earth than GEOs, so lower latency. Some advantage over GEOs for time-critical applications, such as gaming and high speed trading
Efficiency:	A single GEO can focus its capacity permanently on a given market where the capacity will be used	Since LEO satellites are constantly moving around the Earth; as such, more than 80% of their time is spent over water and uninhabited regions with little or zero revenue producing traffic making it very difficult to achieve profitability
Complexity:	GEOs remain fixed over the same geographic area and require a relatively simple ground segment, including low-cost, readily available fixed-site antennas	LEO constellations are operationally complex, and require costly ground antennas that track and hand-off signals between satellites as they move overhead. The current generation of LEO broadband systems are the most complex space undertakings ever attempted
Cost:	A single GEO has built-in redundancy, longer lifetime (typically lasting 18+ years), lower ground segment cost and can deliver capacity exactly where its needed	Economies of scale for volume manufacturing, offset by need for 100s of satellites and gateways, higher deployment and user terminal costs and less efficient use of capacity
RF Spectrum:	GEOs typically secure an orbit location and associated RF spectrum, with priority of use once coordinated, that is sufficient to meet their anticipated service requirements	Coordination of RF spectrum for LEOs is difficult, as they must avoid causing interference to GEOs in most cases, and must share their spectrum with other LEOs
Time to Market:	A single GEO can begin generating revenues over its target market as soon as it completes in orbit testing. If more capacity is required, additional GEOs can be deployed	A significant portion of the LEO constellation, including satellites and gateway earth stations, must be deployed before it can begin generating revenues over any region
Market Focus:	GEOs can focus their capacity on specific geographic areas where demand is clearly identified and sales efforts can be targeted to maximize economic returns	Global LEO constellations, with their capacity spread worldwide, and significantly limited in any given area, require broad market access, and rapid buildup of paying subscribers from countries all over the world

Coverage and Capacity:

Only one GEO satellite is required to provide 24x7x365 uninterrupted high capacity service to a target market. On the other hand, hundreds of LEO satellites with overlapping beam patterns in a highly organized constellation are required to provide seamless coverage over a given region of the Earth, with capacity spread evenly across all regions of the Earth rather than concentrated in target markets where it is needed.

Network Stability:

The static geometry of a GEO, i.e., a satellite in geostationary orbit with a high-throughput spot beam permanently focused on the same geographic location, is excellent for stability of service.

In contrast, a LEO constellation is essentially a wireless mobile system in which the users can be considered as fixed and the cells are moving. All cellular users have experienced spotty cellular coverage which manifests itself as blocked calls (calls that cannot be placed), or dropped calls (calls that are interrupted and require a redial). Many of these irregularities of service occur due to cell handoffs where the user transitions from one cell to the next. In the vernacular of LEO satellite systems, cell handoffs are analogous to beam-to-beam handoffs and satellite-to-satellite handoffs. With hundreds of satellites circling the globe every 90 to 100 minutes or so, these handoffs can occur as frequently as several times per minute in some systems. Each handoff represents a potential connection anomaly. As such, LEO systems can suffer from inconsistency of service both in the form of transmission speed and service availability.

Latency:

Latency is the time it takes for a message, or a packet, to travel from its point of origin to the point of destination. This is a simple definition, but it can be misleading. Broadband systems contain multiple elements contributing to the overall transmission time. It is important to understand the contributors to latency and the factors that dictate their performance. These are:

<u>Transmission delay</u>: the time interval required to push all the packet's bits into the link, which is a function of the packet's length and data rate of the link;

<u>Propagation delay</u>: the amount of time required for a packet to travel from the sender to receiver;

<u>Processing delay</u>: the time required to process the packet header, check for bit-level errors, and determine the packet's destination; and

<u>Queuing delay</u>: how long the packet is waiting in the queue until it can be processed.

The total latency of the system is the sum of the aforementioned delays. Transmission delay is dictated by the available data rate of the transmitting link and has nothing to do with the physical distance between the sender and receiver. Propagation delay is generally a constant factor of the speed of light depending on the medium through which the signal travels.

The time required for the speed of light to transit from the surface of the earth to a satellite and back is a factor in satellite systems. Because GEO satellites orbit at a much higher altitude than LEO satellites GEO latencies are higher.

From a user experience standpoint, the effects of latency are very much application-dependent. 95% of internet traffic is video transmission-related and for this type of data latency is virtually transparent to the end user.

Real-time services can exhibit a degradation of user experience over networks with high latency. High-speed financial trading is particularly sensitive to latency followed by applications, such as gaming. Other real-time applications that are less impacted include Voice Over Internet Protocol (VOIP) and videoconferencing. While users can perceive the additional propagation delays, GEO satellites have been successfully serving this need for more than 50 years and they continue to be instrumental for services such as cellular backhaul today. Indeed, many of today's mobile telephone calls pass through satellite networks transparently to the end user.

In summary, much is made of latency because it is a facet where GEO and LEO satellite systems differ. Latency can negatively affect user experience in time-critical applications, such as online gaming, high frequency electronic trading, but these applications make up less than 5% of internet usage.[8]

Efficiency:

A single GEO satellite can focus its capacity permanently on a target market where its capacity is sure to be used, and then efficiently focus its efforts on the ground in the same market utilizing the appropriate sales and distribution channels as well as the requisite inventories of affordable user terminals. In contrast, since LEO satellites are constantly moving around the Earth, most of they spend most of their orbit over oceans and other uninhabited areas. This geographical inefficiency translates to economic inefficiency, i.e., a LEO company will need to adopt a strategy of global market access, i.e., gaining access to the markets of as many countries around the world as possible on a case by case basis. Each market has its own regulatory, political and economic challenges, and then the LEO company must find local distributors to sell equipment and services, in order to achieve the revenue requirements to drive the economics of the LEO system.

Complexity:

A single GEO satellite, once in its designated orbit location, will remain fixed over the same geographic area for the duration of its 18+ year lifetime. It will require a relatively simple ground segment, including low-cost, readily available fixed-site antennas, in order to provide high quality broadband services throughout its coverage area.

LEO constellations, on the other hand, are operationally complex, and require costly ground antennas that track and hand-off signals between satellites as they move overhead. The original "Big LEOs", such as Iridium and Globalstar, had 66 and 48 satellites in their constellations, respectively. The current generation of planned LEO broadband systems, such as OneWeb, will have hundreds if not thousands of operational satellites in their constellations. This has never been attempted before and comes with its own unique set of risks.

Cost:

GEO satellite costs more than a single LEO satellite, but it has built-in redundancy, longer lifetime (18+ years), lower ground segment cost and can deliver capacity exactly where it is needed. Further, if more capacity is needed, an additional GEO satellite can be deployed into a nearby orbital slot with available frequencies (with 2 degrees of spacing or more between the satellites) and focus its spot beams on the same coverage area.

In contrast, although LEO constellations can take advantage of high-volume manufacturing for economies of scale, the economic benefit is offset by the need for hundreds of satellites, more launches and higher cost to deploy them, with more frequent need for replacement (average lifetime is five to seven years). Further, the ground segment for LEOs is far more expensive, with the need for tens or hundreds of gateways, depending on the system, and far more expensive UTs. In addition, in order to increase the capacity of the system, significantly more satellites and / or an entirely new constellation must be deployed.

Radio Frequency ("RF") Spectrum:

GEOs typically secure an orbit location and associated RF spectrum, with priority of use once coordinated, that is sufficient to meet their anticipated service requirements. The same RF spectrum can be re-used over the same coverage area by as many other GEO satellites as necessary as long as their orbit locations are spaced at least two degrees apart from each other.

In contrast, coordination of RF spectrum for use by LEO constellations is difficult, as they must avoid causing interference to GEOs in most cases, and must share their spectrum with other LEOs. Such sharing is extremely difficult from technical and operational standpoints and can have a major impact on the amount of capacity available to the affected LEOs.

Time to Market:

A single GEO can begin generating revenues over its target market as soon as it completes in orbit testing. If more capacity is required, additional GEOs can be deployed.

In the case of LEOs, a significant portion of the constellation, including satellites and gateway earth stations, must be deployed before it can begin generating revenues over any region. Implementation of a LEO constellation like OneWeb, with more than 680 operational satellites in 18 orbital planes, can literally take several years from the time of the initial launch to commercial revenues. The critical path includes deploying the entire constellation of satellites with multiple launches (each with its own risk of failure), drifting the satellites into their designated orbital planes, testing them for functionality, and then going through the same deployment rigors with the 55 to 75 regional gateways. Only then will the system be ready to commence service.

Market Focus:

GEOs can focus their capacity on specific geographic areas where demand is clearly identified and sales efforts can be targeted to maximize economic returns.

LEO constellations, on the other hand, have their total capacity spread globally, making capacity significantly limited in any given area. In addition, they require market access to many countries located all over the world, in order to match demand to available capacity, and only then can they begin rapidly securing a sufficient number of paying subscribers in order to service their debt and meet equity returns expectations.

Comparison of Key Aspects of Planned Aurora IV and OneWeb Satellite Systems

The following discussion provides a detailed comparison of technical and economic aspects of the Aurora IV GEO HTS system, designed exclusively for the provision of broadband service to Alaska, and the OneWeb LEO system, which by physical necessity is global in design and focus.

Business Risks:	Aurora IV	OneWeb
Access to Radio Frequency (RF) Spectrum:	No RF spectrum constraints. Has all of the Ka-band spectrum needed to meet capacity / service requirements	OneWeb's access to Ku- and Ka-band spectrum could be limited by ITU regs to avoid interfering with GSO satellites and to share spectrum with other LEOs
User Terminal Availability and Costs:	UTs for the Aurora IV system are readily available at pricespoints of less than $350 USD each	Technology for consumer UTs not yet available; OneWeb not planning to fund R&D or production. If OEMs don't up, supply and cost of UTs could be affected
Market Access:	There are no issues or impediments to securing the necessary licenses for commencement of broadband satellite equipment and services sales in Alaska	Licenses required from each country to be served. Very difficult to secure in some countries. Indonesia, China, Russia moving to block OneWeb from market access
Distribution:	Aurora's principal founder, Microcom, hase 34+ years of distribution experience with direct to consumer and wholesale sales to carriers and businesses	OneWeb relies on Softbank for distribution agreements with 3rd parties worldwide. If Softbank fails, or 3rd parties fail to secure subscribers, OneWeb fails
Competition:	No GEO HTS systems planning to cover Alaska. Several LEO systems have announced intent, but only OneWeb and O3B next gen (mPower) announced implementation plans; mPower does not cover Alaska.	OneWeb faces global competition from GEO HTS operators and LEO competition from O3B / mPower system, which will attack OneWeb's markets ± 50 degrees north and south of the Equator
Launch Risk:	Single launch on SpaceX Falcon 9 or Ariane V, each with very successful track records	20+ launches of 30 satellites each to deploy initial constellation over 2 to 3 years. Likelihood of at least one failure is (statistically) > 70%. No track record for Virgin Galactic or Blue Origin, so can't evaluate viability
Schedule Risk:	The satellite technology is proven and the construction and launch schedule is predictable. No regulatory issues and capital acquisition requirements are manageable. Consumer-grade UT equipment is widely available.	New technology required; mega-project with large, interdependent, concurrent, development programs; global regulatory morass; UTs, market access and distribution partners in 190+ countries are real issues.
Gateway Operations:	Aurora IV will not require more than 2 or 4 gateways for the full-up system, all to be owned and operated by PDI. The technology for each of these is well developed, and the performance and costs are well known	Functionality of constellation depends on 55-75 gateways, to be owned / operated by 3rd parties. If any gateway not in place or properly operated, would negatively impact OneWeb performance
System Cost:	There is very little risk that the system cost will increase beyond current estimates. The key components of the Aurora IV system are well known	$2 to $4 billion in CAPEX for OneWeb's gateways and other ground components not included in space segment cost
Funding Strategy:	Aurora IV will be financed by private equity, capacity commitments and debt. Total equity investment, which will be offset even further by upfront payments for bulk wholesale capacity, is less than $40 million USD	OneWeb's funding strategy includes mix of financing. OneWeb plans to use Softbank capacity contract to support $3.5 billion in ECA project financing. If Softbank defaults on capacity contract, ECA financing at risk
International Business Risk:	None; Aurora IV is dedicated to coverage of Alaska	Most of OneWeb's service area is outside the US. There is significant regulatory, political and economic instability in many of the countries where OneWeb needs to provide services to achieve economic viability.
Collision with Space Debris:	There has never been a loss of a GEO satellite due to a collision. Probability is less than 0.0041	Collision risk is much greater in LEO than GEO, especially with intersecting polar orbits and 100s of sats drifting between planes. Collision debris can threaten whole constellation. Russian and Iridium sats collided in 2009 creating debris field that continues to threaten LEOs
Network Security:	Information security ("IS") per US best practices. Network security is robust by design with only one satellite and a closed network architecture of 3 to 4 gateways	IS with OneWeb system will be subject to large number of foreign entities, many in developing world. Network security uncertain with gateways managed by foreign governments / operators. Cyber-threat significant

Mission:

The Aurora IV satellite system is focused exclusively on Alaska, with the goal of bridging Alaska's digital divide with US quality of service standards.[9]

In contrast, OneWeb's stated mission is to enable affordable Internet access for everyone, connect every school on Earth by 2022, and bridge the global digital divide by 2027.[10]

While achieving either of these mission objectives would be an extraordinary accomplishment, it seems that the likelihood of success is greater with a mission focused exclusively on Alaska's broadband requirements, as opposed to one that attempts to satisfy the broadband requirements of every country in the world. One reason for this is simply the magnitude of the effort. Another is that the approach taken by PDI with its Aurora IV system is based on technology that is proven, readily available and affordable, all created within a well-known and manageable business and regulatory environment.

The OneWeb system, on the other hand, despite its undeniably grand objectives, is based on a highly complex system, with technology still in development, user terminals that are not yet available, and the need to successfully navigate the business and regulatory environments of 194 different countries around the world.

Space Segment and Coverage:

The Aurora IV satellite system will consist of a single satellite located in geostationary orbit and a supporting ground network, with high powered spot beams focused exclusively on Alaska and surrounding ocean areas. The Aurora IV satellite will be located in the geostationary arc at or about 150 degrees West Longitude, and have the ability to maintain its position at this location, which is an optimal location for coverage of Alaska, for the entirety of its 18+ year design life.

In contrast, the OneWeb system will consist of an initial constellation of more than 680 satellites, operating in 18 high-inclination planes (87.9 degrees circular at an altitude of 745 miles above the Earth) of 36 satellites each.[11] The overlapping beams of these satellites will provide coverage of the entire planet. OneWeb's ability to maintain this global coverage will be dependent upon continuously ensuring the full functionality of these satellites, by a complex strategy of station-keeping, incremental replenishment at the time such satellites reach the end of their useful life, and in some cases, by statistically expected pre-mature failure.

Implementation Schedule:

Vendor selection for the Aurora IV satellite is scheduled for January 2018, with satellite construction to be completed within 26 months thereafter, with satellite deployment and commencement of service in 2020.

OneWeb plans to begin constructing satellites in 2018, with launches beginning in 2019, and a goal of having the initial global constellation of hundreds of satellites in place and operational by 2022.[12]

Capacity:

Aurora IV is designed to provide at least 20 Gigabits per second ("Gbps") of capacity for broadband services to Alaska, with the concentration of such capacity mapped to Alaska's population and data density requirements, to ensure maximum usable capacity where it is needed.[13] If needed, additional capacity can be added by launching a second satellite into an adjacent orbit location.

According to OneWeb, the theoretical global capacity for the entire constellation is approximately 5 Tbps.[14] However, most of this capacity will be unusable, because two thirds of the constellation will always be operating over ocean regions,[15] and additional capacity will be constrained due to ITU requirements for LEO systems to avoid causing RF interference to GEO systems[16] and spectrum sharing requirements with other LEO systems.[17] With respect to Alaska, the amount of OneWeb capacity actually available for use is estimated to be ± 12 to 18 Gbps, based on the assumption that at least three OneWeb satellites will have full or partial coverage of Alaska at any time, but with footprints that constantly vary in the amount of overlap.

Launch Services:

The Aurora IV GEO satellite is designed for launch on a SpaceX Falcon 9 or equivalent launch vehicle with regard to performance and price. The Aurora IV satellite's mass and volume will enable it to share the launch with a companion satellite, reducing the total launch cost for Aurora IV to half of the price for a dedicated launch on a Falcon 9.[18]

OneWeb has contracted with Arianespace for 21 Soyuz b2 launches for initial system deployment (at least 30 satellites per launch) over a period of 18 to 24 months. Virgin Galactic has a contract for 39 launches (maximum 2 satellites each) to fill in gaps in the initial constellation and for satellite replacement / replenishment, and Blue Origin is now under contract as well for launches beginning in 2020.[19]

Ground Segment:

The Aurora IV satellite system requires only 2 to 4 HTS gateways incrementally deployed for full-up operations, to maximize its capabilities in Alaska. The gateways are fully developed and readily available, and similar gateways are already in use with HTS systems operating over the continental US.[20]

According to OneWeb, its network architecture requires at least 55 to 75 regional gateways (with ~ 10 antennas each) strategically placed to connect the countries in its service area to the OneWeb system. These gateways are the core of a totally new system architecture, that includes operations, billing and global Internet connectivity. Network gateways must be fully functional and interconnected to the global internet backbone in order for countries within their respective gateway service area to access the OneWeb system.[21]

User Terminals:

The Aurora IV system is designed to operate with low-cost, consumer-grade "fixed antenna" and user terminal equipment, such as the ViaSat Surfbeam 2 or the Hughes HT2000W. This equipment is already available for purchase at current price points of $350 USD or less, and prices are expected to continue a downward trend as consumer uptake of this equipment continues to increase on GEO HTS systems worldwide. According to PDI's primary distributor, Microcom[22], which has more than 34 years of experience as the leading provider of satellite systems and services throughout Alaska, these user terminals can be easily installed at any location, urban or rural, in less than two hours.[23]

The OneWeb user terminals (1st generation), on the other hand, currently consist of a highly expensive antenna suite: 2 to 3 mechanical satellite tracking antennas per user terminal, with multiple transceivers for frequent handoffs between satellites. OneWeb has indicated that electrically steered antennas will be available for later generations, but currently these units are more than an order-of-magnitude too expensive and have not reached performance targets. Currently, a user terminal with similar capabilities for government or enterprise use costs $25,000 USD to $50,000 USD per unit.[24]

Quality of Service:

The broadband service to be provided by Aurora IV is designed to meet or exceed baseline US FCC requirements of speed and data usage for broadband Internet services, i.e., forward / return speeds of 25/3 Mbps, and monthly data usage of at least 150 Gbps. This level of service is being delivered today by PDI's distribution partner Microcom. Quality of service will be comparable to HTS broadband services provided in the continental United States.

OneWeb's LEO satellite system will provide "one-size fits all" uniform coverage. There is no accommodation for user distribution. Quality of service is expected to be comparable to developing nations and remote ocean regions. Potential latency advantage over GEO. OneWeb's moving satellites pose considerable technical challenges that likely won't be characterized until the satellite are on-orbit. Loss of any OneWeb satellite means potential for periodic service outages until replaced (GEO satellites are built with space-grade electronic components and have built-in redundancy). Low cost, high volume production satellites are single-string and use commercial off the shelf electronics components to control complexity and cost. This combines with hostile environment of Van Allen radiation belts very close to OW orbit altitude. Failure rates are unknown.

Satellite Design Life:

The Aurora IV satellite is expected to provide continuous service to Alaska for 18+ years, so with a 2020 deployment, it should not have to be replaced until 2038 at the earliest.[25]

In contrast, OneWeb's satellites are designed to last approximately 7 years. On this basis, with a deployment between 2019 and 2022, the constellation will need to be completely replaced during the 2026 to 2029 timeframe, and then again in the 2033 to 2036 timeframe. Additionally, OneWeb's mass production strategy for its satellites trades redundancies, hardening and individual unit testing for lower costs, resulting in a higher pre-mature failure-rate across all planes, and a requirement for replacement of individual or small groups of failed satellites on a continuous basis.

CAPEX:

The entire Aurora IV GEO HTS satellite system (including satellite, launch services, space insurance and ground segment infrastructure, which is modular and upgradeable) will cost less than $200 million to implement.[26]

The space segment alone for the first generation OneWeb constellation (satellites, launch services and insurance) is estimated to cost at least $4 Billion USD to implement. The ground segment, which consists of regional gateways, back office software and other elements, is expected to cost an incremental $2 to 4 billion. However, given the potential need to replace the entire constellation twice during the 2026 to 2036 timeframe, the cost of such replacement will be considerable, particularly when added to the initial cost of the system, even taking economies of scale into account.[27]

Business Model:

The Aurora IV broadband capacity will be used for provision of retail (direct to consumer) services throughout Alaska, for wholesale sales to Alaska's fixed and mobile carriers to meet their middle mile / backhaul requirements, for backup capacity for Alaska's terrestrial networks in case of outages, and for wholesale sales to Alaskan resellers focused on the aero and maritime markets in the airspace and ocean areas across and around Alaska.

The OneWeb business model requires that satellite capacity be sold into as many of the world's 194 countries as possible, in order to achieve the subscriber base and revenues necessary to drive the economics of the system. SoftBank has agreed to purchase from OneWeb 100% of the capacity generated by OneWeb's Generation I satellite constellation for a period of ten years from the service commencement date. The purchase agreement requires Softbank to act as the primary distributor of OneWeb capacity, and to be responsible for reselling such capacity to third party distributors all over the world.[28]

Distribution Strategy:

Distribution is one of PDI's strongest capabilities. Microcom, the principle founder of PDI and the Aurora IV system, has 34+ years of experience as the largest satellite distributor for the Alaska market, with a keen understanding of the demand, costs and price points for satellite broadband services in Alaska, and strong distribution channels (direct to consumer and wholesale) throughout the State.[29] Microcom will be the primary distribution partner for direct to consumer services. Additionally, PDI will provide wholesale capacity to a range of customers.

As a result of the Capacity Purchase Agreement with Softbank, OneWeb will rely on Softbank to identify and secure distributor relationships with appropriate third-parties in each country around the world where its user terminal equipment and associated services are to be provided, to secure the requisite number of paying customers and ensure a level of service quality and customer care to retain them.

Market and Subscriber Requirements:

The Aurora IV business case closes based on Alaska demand alone, with a relatively low number of subscribers (e.g., approximately 35,000 customers) or equivalent sales of wholesale capacity.

OneWeb will need to acquire millions of paying subscribers within a couple of years in order to meet its revenue requirements. Since the satellites are capacity limited, the subscribers and system usage will have to come from markets all over the world. The ability to achieve this will be largely dependent upon the ability of Softbank and its sub-distributors to rapidly secure access to key markets and aggressively build subscribers.

Business Risks:	Aurora IV	OneWeb
Access to Radio Frequency Spectrum:	No RF spectrum constraints. Has all of the Ka-band spectrum needed to meet capacity / service requirements	OneWeb's access to Ku- and Ka-band spectrum could be limited by ITU regs to avoid interfering with GSO satellites and to share spectrum with other LEOs
User Terminal Availability and Costs:	UTs for the Aurora IV system are readily available at pricespoints of less than $350 USD each	Technology for consumer UTs not yet available; OneWeb not planning to fund R&D or production. If OEMs don't up, supply and cost of UTs could be affected
Market Access:	There are no issues or impediments to securing the necessary licenses for commencement of broadband satellite equipment and services sales in Alaska	Licenses required from each country to be served. Very difficult to secure in some countries. Indonesia, China, Russia moving to block OneWeb from market access
Distribution:	Aurora's principal founder, Microcom, hase 34+ years of distribution experience with direct to consumer and wholesale sales to carriers and businesses	OneWeb relies on Softbank for distribution agreements with 3rd parties worldwide. If Softbank fails, or 3rd parties fail to secure subscribers, OneWeb fails
Competition:	No GEO HTS systems planning to cover Alaska. Several LEO systems have announced intent, but only OneWeb and O3B next gen (mPower) announced implementation plans; mPower does not cover Alaska.	OneWeb faces global competition from GEO HTS operators and LEO competition from O3B / mPower system, which will attack OneWeb's markets ± 50 degrees north and south of the Equator
Launch Risk:	Single launch on SpaceX Falcon 9 or Ariane V, each with very successful track records	20+ launches of 30 satellites each to deploy initial constellation over 2 to 3 years. Likelihood of at least one failure is (statistically) > 70%. No track record for Virgin Galactic or Blue Origin, so can't evaluate viability
Schedule Risk:	The satellite technology is proven and the construction and launch schedule is predictable. No regulatory issues and capital acquisition requirements are manageable. Consumer-grade UT equipment is widely available.	New technology required; mega-project with large, interdependent, concurrent, development programs; global regulatory morass; UTs, market access and distribution partners in 190+ countries are real issues.
Gateway Operations:	Aurora IV will not require more than 3 or 4 gateways for the full-up system, all to be owned and operated by PDI. The technology for each of these is well developed, and the performance and costs are well known	Functionality of constellation depends on 55-75 gateways, to be owned / operated by 3rd parties. If any gateway not in place or properly operated, would negatively impact OneWeb performance
System Cost:	There is very little risk that the system cost will increase beyond current estimates. The key components of the Aurora IV system are well known	$2 to $4 billion in CAPEX for OneWeb's gateways and other ground components not included in space segment cost
Funding Strategy:	Aurora IV will be financed by private equity, capacity commitments and debt. Total equity investment, which will be offset even further by upfront payments for bulk wholesale capacity, is less than $40 million USD	OneWeb's funding strategy includes mix of financing. OneWeb plans to use Softbank capacity contract to support $3.5 billion in ECA project financing. If Softbank defaults on capacity contract, ECA financing at risk
International Business Risk:	None; Aurora IV is dedicated to coverage of Alaska	Most of OneWeb's service area is outside the US. There is significant regulatory, political and economic instability in many of the countries where OneWeb needs to provide services to achieve economic viability.
Collision with Space Debris:	There has never been a loss of a GEO satellite due to a collision. Probability is less than 0.0041	Collision risk is much greater in LEO than GEO, especially with intersecting polar orbits and 100s of sats drifting between planes. Collision debris can threaten whole constellation. Russian and Iridium sats collided in 2009 creating debris field that continues to threaten LEOs
Network Security:	Information security ("IS") per US best practices. Network security is robust by design with only one satellite and a closed network architecture of 3 to 4 gateways	IS with OneWeb system will be subject to large number of foreign entities, many in developing world. Network security uncertain with gateways managed by foreign governments / operators. Cyber-threat significant

Access to Radio Frequency Spectrum:

Aurora IV has all of the radio frequency ("RF") spectrum needed to meet its projected broadband capacity and service requirements. Its ITU filings for the Aurora IV system include the following Ka-band frequencies: 17.7 – 19.3 GHz, and 19.7 – 20.2 GHz (Forward links for users and gateway), and 27.5 – 29.1 GHz, and 29.5 – 30.0 GHz (Return links for users and gateways), for a total of 4.2 GHz in each direction.[30]

OneWeb plans to use approximately 3 GHz of Ku-band RF spectrum for user links (10.7 - 12.75 GHz Space to Earth; 14.0 - 14.5 GHz Earth to Space) and 4 GHz of Ka-band RF spectrum (primarily for feeder links - 17.8 - 20.2 Space to Earth; 27.5 - 30 GHz Earth to Space). In order to use these frequencies, it must avoid causing interference with the operation of existing and planned GSO satellites, in accordance with equivalent power flux density limits articulated in Article 22 of the ITU Radio Regulations, and must adhere to spectrum sharing requirements with other LEO systems.[31]

User Terminal Availability and Cost:

There is no technical, cost or availability risk associated with the user terminals for the Aurora IV system. The system will use consumer-grade user terminals, such as the ViaSat Surf beam 2 and Hughes HT2000W, both of which are readily available in large quantities and low price-points to distributors for sale to end users.

In stark contrast, the technology required for OneWeb's planned consumer-grade user terminals with electronically steered antennas is not yet available. Consequently, OneWeb has recently announced that it will use mechanically steered antennas for its first-generation user terminals. According to the Intelsat Confidential Offering Memorandum (published on the Internet), OneWeb has no plans to manufacture or contract for the user terminals.[32] Rather, it intends to rely on Original Equipment Manufacturers ("OEMs") for user terminal development and production on its behalf. If these OEMs do not adequately provide for the technical development and mass procurement of user terminals, the supply of user terminals could be limited, and the cost of user terminals could be substantially higher than currently anticipated. This could significantly affect OneWeb's revenue model, which could have a material and adverse impact on its strategies and business prospects.

Market Access:

For the Aurora IV system, there are no material issues or impediments to securing the necessary licenses for provision of GEO HTS broadband services and sales of associated user terminal equipment in Alaska.[33] FCC and ITU regulatory authorization processes are well understood. PDI will need to complete the ITU coordination of its orbital slot / Ka-band frequencies, and secure FCC authorization to provide broadband services in Alaska.

In the case of OneWeb, it will require multiple types of regulatory authorizations from every country in the world in which it plans to offer services; i.e., landing rights (not all countries require landing rights), licenses to provide satellite broadband services including transmission to the satellite, to interconnect to the Internet backbone, to sell user terminals, etc. Many countries have structural issues that can slow and limit penetration in this regard.[34] For example, Inmarsat started seeking national regulatory authorizations and distribution partners for its Global Xpress satellite system more than 7 years ago, and it still does not have approvals and partners in certain key countries.[35] Iridium, Globalstar, Orbcomm and most recently O3B are examples of Non-Geostationary Satellite Orbit ("NGSO") systems that have taken the better part of a decade to secure key regulatory authorizations for market access around the world, and still haven't received authorizations or found appropriate distribution partners in some countries.

Some countries, such as Indonesia (217 million people, 4th largest land mass, and the world's 16th largest economy) and China (1.4 billion people, 3rd largest land mass, and 3rd largest economy) have, for various technical, economic and / or political reasons, already moved to block OneWeb from obtaining market access. Similarly, the Australian Military has voiced objections to OneWeb, and other countries, such as Russia, have blocked certain Ku-band frequencies from OneWeb use because they plan to build their own NGSO constellation.[36]

The operation of each of OneWeb's 55 to 75 regional gateway earth stations will also require licenses or other authorizations from national and (in some cases) local governments. The grant of such licenses or authorizations will likely be subject to different decision-making processes in each country or region and may lead to additional regulatory oversight in certain countries or regions. Gateways pose additional issues with respect to the bypassing of national systems within the service area of the gateway (revenue and security). Further, OneWeb will rely on third parties in most cases to own and operate the regional gateways. If OneWeb can't establish relationships with these third parties, or if these third parties fail to properly operate and / or maintain the gateways, OneWeb's control over its satellites, market access and interconnection with the Internet could be diminished and its business harmed.

Distribution:

The Aurora IV distribution plan is already in place and very low risk.

The risks associated OneWeb's distribution strategy are extremely high. If Softbank is unable to secure the appropriate third-party distributors, or if they are unsuccessful, OneWeb's revenues and profitability could be adversely affected. Moreover, the willingness of these entities to engage in OneWeb's business also depends on a number of factors, including whether they perceive OneWeb's services to be compatible with their business objectives, whether the prices they can charge end-users will provide an adequate return, and regulatory constraints, if any. Since these resellers will "own the customers" in most markets, OneWeb will be totally dependent upon them with respect to customer care, pricing, billing, and other critical aspects of service provision and revenue generation.

Competition:

There are currently no new GEO HTS systems with announced plans to cover Alaska. Several LEO systems have announced intent, but only OneWeb and the O3B next generation system, mPower, have announced implementation plans. Noteworthy in this regard is that the O3B mPower system, with an advanced HTS payload produced by Boeing, is an equatorial system in Medium Earth Orbit ("MEO"), and only covers geographic areas between 50 degrees North and South latitude. It does not cover Alaska.

OneWeb faces significant global competition for HTS satellite broadband services from existing GEO satellite providers including ViaSat (with its ViaSat 1 and 2 satellites already operational and three ViaSat 3 satellites scheduled for global deployment beginning in 2020)[37], Hughes Jupiter satellites, Inmarsat (with its Inmarsat V satellites fully deployed and Inmarsat VI satellites in development), Eutelsat, SES, Intelsat and others, as well as the O3B / mPower MEO equatorial system, scheduled for deployment (according to the mPower satellite manufacturer, Boeing) in the 2020 timeframe[38].

These systems may have a significant impact on OneWeb's ability to obtain sufficient market share to reach economic viability and sustainability. Collectively, they will have the ability to provide between 10 and 15 Tbps of capacity, most of which will be concentrated in the areas around the world where OneWeb needs to achieve most of its subscribers and revenues. The mPower MEO system in particular, with its low-latency capabilities, poses a significant threat to OneWeb, since it is an extension of the existing O3B constellation which is already operational and already has its financing, regulatory authorizations and distribution partners in key countries in place.

Launch Risk:

Aurora IV will launch its satellite on either a SpaceX Falcon 9 or an Arianespace V launch vehicle. Both vehicles have successful track records of launching commercial GEO satellites into space. The Ariane V launch vehicle has had more than 80 consecutive successful missions since 2003.[39] The Falcon 9 launch vehicle has had 41 successful missions since its inception 7 years ago, with one failure, for a 97.6% success rate.[40] In the unlikely event of a launch failure, Aurora IV would be fully insured. The insurance rate to fully protect against any failure resulting from the launch or satellite anomaly during the first year on orbit currently ranges from 3% to 4% of the total sum insured (i.e., replacement cost for the satellite, launch service and insurance).[41]

OneWeb is relying on 20+ launches of the Arianespace Soyuz b2 launch vehicle to deploy the entire constellation of OneWeb satellites over a period of two to three years. The likelihood of one or more launch failures in this many launches, likely interspersed with launches for other customers using the same vehicle type, is greater than 70%.[42] Virgin Galactic and Blue Origin are still in the experimental stages of development, and to date have not successfully launched any satellites, so there is no operating history upon which to evaluate their ability to support OneWeb launches. Any launch delays, failures or underperformance by these launch services could have a major impact on the implementation schedule, and hence the OneWeb business plan.[43]

Schedule Risk:

Schedule risk for the Aurora IV GEO HTS satellite system is minimal. The Aurora IV satellite uses existing technology and the satellite system construction and launch schedule is fairly predictable; regulatory requirements are relatively simple (Limited to an ITU filing for orbital slot and FCC authorization for US market access); and the system has relatively small capital acquisition requirements. Consumer-grade UT equipment for this system is widely available at competitive price points.

The schedule risk for OneWeb is extreme. This is a mega-project composed of numerous, large, interdependent, concurrent, development programs (satellite, ground, launch, regulatory, user terminals, etc.). Substantial new technological developments are required. There are 194 different countries that will require various types of authorizations for market access. Distributors and resellers must be identified and secured to lead the pursuit of market access and then subscriber acquisition for each of these countries. Appropriate third parties must also be identified and secured to finance, own and operatate the 55 to 75 regional gateways. The system will require vast capital requirements.[44] There are many fundamental factors that could cause significant delays in the OneWeb implementation schedule.

Gateway Operations:

The Aurora IV system will not require more than 2 to 4 gateways for the entire system. While the gateway vendor has not yet been selected, the prospective vendors are ViaSat and Hughes. The gateway technology for each of these is well developed, and the performance and costs are well known.

OneWeb's gateways are quite complex, with at least 10 satellite tracking antennas and associated equipment for signal handoffs at each gateway. The future operations of OneWeb's satellite constellation will rely on the functionality of these gateways, most of which will be owned and operated by third parties. If these gateways are not properly operated or maintained, their performance could be affected, thereby reducing their availability and negatively impacting the performance of OneWeb's system in that region.

System Cost:

With respect to the Aurora IV system, there is very little risk that the system cost will increase beyond current estimates. The key components of the Aurora IV system are well known. If anything, the ultimate price may be significantly less than original estimates, as a result of competition among the satellite manufacturers in the formal Request for Proposal ("RFP"), which is scheduled to be issued in late October or early November, with vendor selection in early January 2018.

OneWeb's estimated CAPEX requirements can be expected to increase materially, based on the fact that it is a developmental system, and historical experience in this regard with other NGSO systems, including Iridium and Globalstar.[45]

Funding Strategy:

The Aurora system will be financed by a combination of private equity from established US satellite owner / operators; Alaskan investors, others), prepaid capacity commitments, and debt from sources such as Export Credit Agencies, Alaska-based lenders and other sources. Total equity investment, which can be offset even further by upfront payments for bulk wholesale capacity, is less than $40 million USD.

OneWeb's funding strategy is a mix of private equity, take or pay capacity contracts, vendor financing and Export Credit Agency financing. As of 24 March 2017, OneWeb had successfully raised $1.165 billion USD along with approximately $645 million USD in commitments contingent upon OneWeb obtaining loans from ECAs, ECA guaranteed lenders, development finance or other multilateral institutions. OneWeb has also secured a $4 billion USD "take or pay" capacity agreement with Softbank, with options for an additional Take or Pay contract if OneWeb proceeds with its second-generation system. OneWeb is currently seeking, but has not closed on, approximately $3.5 billion USD in loans from ECAs.[46]

Substantially all of OneWeb's revenues in the near future are expected to arise from the SoftBank Capacity Purchase Agreement. This Agreement, which is subject to OneWeb achieving and maintaining certain service stage standards, meeting customary industry service levels and force majeure events, requires Softbank to make minimum payments totaling $4 billion USD in respect of Generation I Capacity and, if SoftBank exercises its right to purchase Generation II Capacity, $6.5 billion USD in respect of such Generation II Capacity. Additionally, the Agreement requires Softbank to pay OneWeb a substantial percentage of the revenues generated from the sale of OneWeb capacity by Softbank and its resellers.[47] Were Softbank to be unable for any reason to continue with its capacity purchase or distributor obligations, it could have a major negative impact on OneWeb's business and prospects.

International Business Risk:

Since the Aurora IV system is dedicated to Alaska, there is no international business risk.

Most of OneWeb's coverage area is outside the United States. Its international operations involve varying degrees of risk and uncertainties. Such risks include tariffs, taxes, government sanctions and regulatory actions, trade barriers that may be imposed on its services, or by political and economic instability, as well as acts of terrorism or war, in the countries where OneWeb will provide services. A significant portion of OneWeb's revenues and the revenues of its distributors and sub-distributors will need to come from sales in developing countries, where such risks described above, and economic, political or diplomatic conditions in particular, may be significantly greater than would be the case in the United States and other industrialized countries. Any such disruptions or the threat of disruptions could result in financial harm to OneWeb and negatively affect its operations and economic viability.[48]

Collision with Space Debris:

The risk to Aurora IV of a collision with space debris in geostationary orbit is minimal. There has never been a reported loss of a geostationary satellite due to collision with another satellite. According to a study conducted by Lincoln Labs, the probability of such an event is less than 0.0041.[49] However, there has been at least one incident in which a GEO satellite is thought to have been struck by space debris.[50]

Collisions with space debris or other spacecraft could materially affect system performance and OneWeb's business. OneWeb's satellites operate at LEO altitudes, in a regime populated by other operational satellites, defunct satellites and other cataloged debris, and debris that is too small to be tracked. OneWeb's satellites will generally be able to maneuver around objects and react to warnings received from government authorities (JSPOC) to avoid space debris or other satellites, provided that OneWeb receives accurate data and sufficient advanced notice. Two major events in recent years have significantly increased the LEO debris population: a deliberate Chinese anti-satellite test in 2007 and an accidental collision in 2009 between an operational Iridium satellite and a non-operational Russian satellite.[51]

The risk of collision is significantly greater in LEO than GEO, especially with intersecting polar orbits, and hundreds of satellites performing autonomous orbit raising and drifting between planes. 680 operational satellites require more than 1,000 launched over first five years. A collision can threaten the whole constellation due to resulting debris scattering about the orbit.[52] The Russian Kosmos-2251 satellite collided with an operational satellite from the Iridium constellation (only 66 satellites) on February 10, 2009 generating a substantial debris field which continues to threaten other objects in LEO.

Network Security:

The risk to Aurora IV system network security is very manageable with only one satellite and a closed system of 2 to 4 gateways.

OneWeb relies on network and information systems and other technologies and a disruption, cyber-attack, failure or destruction of such networks, systems or technologies may disrupt its business, which could have a material adverse effect on its financial condition. The capacity, reliability and security of OneWeb's information technology hardware and software infrastructure are important to the operation of its business, which would suffer in the event of system disruptions or failures, such as computer hackings, cyber-attacks or other or other malicious activities. Such activities have significantly increased in recent years. OneWeb's networks, systems and technologies may also be vulnerable to such malicious activities, and thus could be exposed to significant costs, interruptions, delays or malfunctions in its operations, any of which could have a material adverse effect on its business and prospects.[53]

Conclusion

A resilient satellite component as a complement to the Alaskan terrestrial broadband network necessitates a HTS GEO element. Alaska will benefit from a local solution such as the planned Aurora IV HTS GEO system, that is tailored specifically to the needs of Alaska where capacity is concentrated exactly where it is demanded. If a LEO system is also available, it can provide services and applications that will complement those provided by Aurora IV.

Conversely, it would be a mistake to rely exclusively on a LEO system to meet Alaska's satellite broadband needs. Large LEO constellations the size of OneWeb have never been attempted. In addition to many billions of USD of capital investment, the establishment from a green field of a global value chain, and globally favorable regulatory regimes, they require not just innovation, but invention to implement. Even if all of these obstacles are overcome, they still represent a missionary enterprise offering broadband service to largely undeveloped countries. Many of these countries lack even the most basic infrastructure, such as power, to enable the use of a LEO broadband service. And while demand for broadband services is present in every country, the ability to pay for it in many is another question. Just as with the LEO narrowband systems of the 1990's, success of these enterprises is far from assured. Sole reliance of Alaska on such a system could leave Alaska another 10 years behind the digital divide. The economic downside could be profound.

Alaska needs the ability to control its own fate and to be responsible for its own well-being. It would be a mistake to rely exclusively on external sources over which it has no control. Alaska's population of 740,000 represents 1/100th of one-percent of the global population, and likewise, Alaska represents a very small percentage of the revenues that a global LEO system must generate in order to achieve economic viability. In such a context, can Alaskans exert the necessary influence on a globally deployed broadband network to assure their needs are adequately served? Should the global LEO network be diminished or cease to exist, without Alaska having any local alternative on which it could continue to function and sustain itself, it would be a huge setback and detriment.

Contact Information:

For further information, please visit our website at www.spacepi.com.

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[9] *PDI Mission Statement for its Aurora IV GEO HTS satellite system.*

[10] *OneWeb Mission Statement, OneWeb website: www.oneweb.net.*

[11] *OneWeb Global Access Presentation, page 4, Tony Azzarelli, VP Regulatory and Policy, OneWeb, at Global Conference on Space and the Information Society, 8 August 2016, www.iafastro.org/wp-content/uploads/2016/05/Tony-Azzarelli-2016.05.30-OneWeb-GLIS.pdf.*

[12] *Id. OneWeb Global Access Presentation, page 12.*

[13] *PDI's requirement specifications and the responding proposals from the prospective vendors is for at least 20 Gbps.*

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[15] *According to NOAA, (the US Government's National Oceanic and Atmospheric Administration), "The ocean covers more than 70 percent of the surface of our planet." https://oceanservice.noaa.gov/facts/oceanwater.html.*

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[19] *OneWeb Presentation to Future Sat Africa, page 13, Patrick Kariningufu, VP Middle East and Africa, 5 October 2015.*

[20] *PDI plans to use either ViaSat or Hughes for its gateways and overall satellite broadband solution. The gateways will therefore be similar to those used on the ViaSat and / or Jupiter HTS satellites.*

[21] OneWeb VG presentation to Future Sat Africa, page 6, Patrick Kariningufu, VP Middle East and Africa, October 5, 2016; OneWeb Global Access VG Presentation, Tony Azzarelli, VP Regulatory and Policy, TU Symposium, 16 June 2016.
[22] Microcom is a DBA for Sateo Inc.

[23] Confirmation by Tom Brady, CTO, Microcom, of pricing and installation time for 0.74-meter user terminal, including antenna mount and transmitter/receiver, for Aurora IV GEO HTS system, 12 October 2017.

[24] Teleconference with NSR [staff] regarding technical and economic aspects of NGSO systems, including the state of technology development, manufacturing and pricing for OneWeb UTs; LEO Roar or Whimper, Low Earth Orbit Broadband Constellations, Technical and Economic Truths, pages 20-21, ICG, 25 September 2015, https://www.edocr.com/v/mb43yade/bobritain/LEO-Broadband-Constellations-Technical-and-Economi.

[25] The bid proposals by all of the satellite manufacturers contending for the Aurora IV satellite contract, including Orbital/ATK, Thales Alenia Space and MDA/SSL have satellite design lifetimes of at least 18 years. This design lifetime is common for current generation satellites, and such lifetime is commonly exceeded by past GEO satellites and those currently in operation.

[26] The $140 million USD Not To Exceed cost for the Aurora IV system is based on formal responses to a detailed Request for Information issued by PDI in June 2017 to multiple satellite vendors, combined with published pricing for SpaceX Falcon 9 launch services, and indications from several major space insurance brokers that the current insurance rate to cover the launch of the Aurora IV system plus one year on orbit is approximately three percent of the total sum insured, or about $4.2 million USD.

[27] Excerpts from Confidential Offering Memoranda dated 24 March 2017, page 9. www.sec.gov/Archives/edgar/data/1525773/000119312517096107/d364392dex991.htm.

[28] Id., at pages 25-27.

[29] Microcom Background Summary, Microcom Website, http://microcom.tv/.

[30] See, PDI ITU Filings, FCC Online Table of Frequency Allocations, 47 C.F.R. § 2.106 Revised on August 25, 2017, https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf.

[31] Id., OneWeb Presentation to Future Sat Africa, page 9.

[32] Excerpts from Confidential Offering Memoranda dated 24 March 2017, page 9. www.sec.gov/Archives/edgar/data/1525773/000119312517096107/d364392dex991.htm.

[33] PDI has already filed with the ITU for its Geostationary Orbital Slot and associated radio frequencies, and based on its analysis of 3rd party filings for adjacent orbital slots / frequencies,

is confident that there are no regulatory impediments to its use of the entire set of frequencies from its selected orbit location. It must also secure authorization from the FCC to provide satellite broadband services to the Alaska market. PDI is not aware of any issues that would cause the FCC not to grant PDI's request in this regard. See, FCC, 47 C.F.R. Parts 0 and 25 [FCC 15–167 and FCC 16–58], Comprehensive Review of Licensing and Operating Rules for Satellite Services, Final Rule, C.F.R. Vol. 81, No. 160, Aug. 18, 2016, Rules and Regulations.

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[37] *Dankberg: ViaSat 3 Satellite Will Have More Capacity than the Rest of the World Combined, Caleb Henry, February 10, 2016, http://www.satellitetoday.com/telecom/2016/02/10/dankberg-viasat-3-satellites-will-have-more-capacity-than-the-rest-of-the-world-combined/.*

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[40] *See, SpaceX Missions, http://www.spacex.com/missions.*

[41] *Discussions at Satellite Business Week, Paris France, 11-15 September 2017, with representatives from Aon Space, Willis Towers Watson and Marsh, the world's leading space insurance brokers.*

[42] *Statistical analysis based on 20 launch events of the same vehicle type, each with 0.95 probability of success, to implement the initial global constellation.*

[43] *Excerpts from Confidential Offering Memoranda dated 24 March 2017, page 41. www.sec.gov/Archives/edgar/data/1525773/000119312517096107/d364392dex991.htm.*

[44] *Id., page 22.*

[45] *Loral Deals, Dilemmas Detailed in Retired Chief's Autobiography, Peter de Selding, Space News, 3 March 2014, http://spacenews.com/39701loral-deals-dilemmas-detailed-in-retired-chiefs-autobiography/.*

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[47] *Id., pages 25 to 27.*

[48] *Excerpts from Confidential Offering Memoranda dated 24 March 201, page 50. www.sec.gov/Archives/edgar/data/1525773/000119312517096107/d364392dex991.htm.*

[49] *Probability of collision in the geostationary orbit, Raymond LeClair & Ramaswany Sridharan, Proceedings of the Third European Conference on Space Debris, 19 - 21 March 2001.*

[50] *"ExoAnalytic Video Shows Telkom-1 Satellite Erupting Debris;" by Caleb Henry, Space News, August 30, 2017, http://spacenews.com/exoanalytic-video-shows-telkom-1-satellite-erupting-debris/*

[51] *Booker, Sullivan Press FCC on Space Debris, October 2, 2017, https://www.booker.senate.gov/?p=press_release&id=668; U.S. Senators ask FCC to Lead Debris-Mitigation Policy Ahead of Mega-Constellations' Arrival, Peter B. de Selding, 3 October 2017, Space Intel Report, https://www.spaceintelreport.com/u-s-senators-ask-fcc-lead-debris-mitigation-policy-ahead-mega-constellations-arrival/.*

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