

must be larger to cover the same region of the planet, it is currently the case that low-earth-orbit microsatellite constellations are not the most cost effective solution in this market. In essence this derives from the fact that satellite costs for fixed and broadcast service using current technology do not scale linearly with performance. A satellite with 1/Nth of the performance a large geostationary satellite incurs greater than 1/Nth of the cost of that geostationary satellite.³

Mobile Satellite Service communication employ both geostationary satellite systems and low-earth-orbit constellations. Two of the low-earth-orbit systems in this market are large by comparison to microsatellites; both Iridium and Globalstar, employ satellites with a mass about 700kg and producing about 1500 watts of solar array power at the end of lifetime. However there is one microsatellite system; the ORBCOMM constellation of 38 spacecraft (in its first generation), each with a mass of 40 kg and generating 160 watts of power. Costing in excess of \$400M on-orbit, the constellation was in full service by 1998 and the first generation system is still operating. While the company was forced to undergo “US Chapter 11” restructuring in 2000 it now has more than half a million subscribers. Having achieved an IPO in 2006, recent business performance has justified the purchase of a second generation of satellites.³

II. POSSIBLE SOLUTIONS

Before examining the business case for Antarctic Broadband it is worth first considering alternative solutions to the problem of high speed communications for the Antarctic region. The primary drivers of any solution are the relatively low number of users, wide geographic distribution and harsh environmental conditions. The distribution of major research stations is shown in Fig 1, spread across the 4000km wide continent.⁴

II.I Terrestrial Microwave

Terrestrial microwave links can not span the distance from any continent across the Southern Ocean to Antarctica as they require a clear line of sight between transmitter towers. The shortest distance from South America requires a single point-to-point link of 1000 km, which is hidden by the curvature of the earth. Furthermore, once on the continent, transmitter towers can not be located on the ice as they will inevitably drift

with glacial movement, be buried by snow accumulation. Structures placed on the ice are also prone to tilting and rotating due to differential forces and melting rates due to the prevailing weather and higher intensity sunlight on north-facing surfaces. The distances between ice-free regions suitable for locating microwave relay stations are as large or larger than the distance across the southern ocean. Finally there is the issue of maintaining a network of unmanned transmitters at such distances in the Antarctic climate.

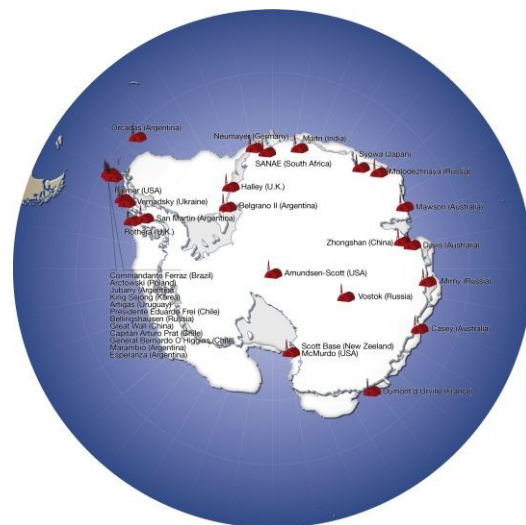


Fig 1: Major research stations in Antarctica

II.II Fibre Optic Cable

Laying and maintaining fibre optic cables to even a single Antarctic base is prohibitively expensive. Fibre optic cables can not be run across the Antarctic continent as the accumulation of snow will bury the cables, making them unmaintainable, and the movement of glaciers will cause them to break. Laying submarine cables would be extremely expensive due to the large distances, harsh sea conditions and the scraping action of icebergs that scour the sea floor in coastal regions and break any exposed cables.

II.III Geostationary Satellite

Not surprisingly then, all current operators use satellite links for what high speed communications they have. Unfortunately, traditional satellite solutions are not optimised for Antarctic users, and in much of the

continent they can not be used at all. Based in a geostationary orbit, a telecommunications satellite is only visible from the northern edge of the continent and at very low elevation angles. In order to make use of existing satellites, without dedicated beams pointed at specific Antarctic coastal bases, the Antarctic users must connect through a satellite's broad coverage beams that illuminate the entire earth that is visible to the satellite. Not only do these beam patterns have lower gain as a consequence of the broad area coverage, but the beam pattern is designed to avoid spill-over of radio energy beyond the limb of the earth, resulting in a drop-off of gain at the edges of the beam and thus a lower gain at exactly the location of the Antarctic stations. The reduced antenna gain results in a relatively low data throughput in return for the expensive leased transponder bandwidth. It also causes users to install large dishes at their Antarctic bases, which are expensive to install and maintain in the remote and harsh environment.

As a result, most coastal bases have installed a sizable dish for telecommunications. Dish sizes range up to nine meters in diameter, costing millions of dollars to install and maintain. Data rates up to 1Mbps are achieved, with service pricing up to one million dollars per year charged by the satellite provider. The alternative system, widely used at mobile, remote and inland sites, is the Iridium satellite phone and modem providing a very low data rate of 2400bps.

One dedicated satellite transponder, with a specially focused beam for an Antarctic user, was been launched on the OPTUS D-1 satellite to provide a high speed data link to the American McMurdo station. This is cost-effective for the large single user at that location where the retrieval of data from the NPOESS satellite downlink consumes practically all of the available data throughput and pays for all of the system costs. However, it is purpose-driven and location specific, and can not address the communications needs even of the US program outside of McMurdo.

II.IV Geosynchronous (Inclined) Satellite

In the unique case of the Amundsen-Scott South Pole Station, operated by the American program at the geographic south pole, there is demand for high data rates due to several significant scientific experiments and no chance of viewing satellites in geostationary orbit. This

station relies on old geostationary satellites that have been allowed to drift into inclined orbits.

As a satellite's station-keeping fuel runs low towards the end of its life and components start to fail due to accumulation of radiation effects, it is typically replaced by a new satellite. However, there is a desire not to lose the existing asset until absolutely necessary as it may provide a stop-gap service for several months or more in the event of failure of another satellite. To prolong this "hot spare" capacity the satellite's precious station-keeping fuel is not used to maintain orbit and the satellite is allowed to slowly drift into an inclined orbit due to the effect of the earth's bulge and the gravity of the sun and the moon. When the inclination exceeds around eight degrees it becomes visible from the South Pole for short periods of the day, with the inclination reaching a maximum at about 15 degrees, corresponding to seven hours visibility at the pole each day, before diminishing again.

By making use of a number of these satellites the Amundsen-Scott South Pole Station is able to receive internet access for 6-7 hours per day as well as significant data back-haul capacity (100 GB/day). However these systems are only available because they are at the end of their useful life and are therefore subject to failure or removal from service. For example, the TDRSS F1 satellite, providing most of the data back-haul capacity, was taken out of service at short notice on 21 October 2009 due to the need to re-use the orbital slot and also the failure of the transmitter amplifier tubes⁵. Similarly, the Marisat-F2 satellite was taken out of service on 29 October 2008 because the satellite's sub-systems were near the end of operating life and the satellite operator feared that it could drift into the path of other satellites⁶. While replacement satellites have so far been found to maintain a similar capability, use of such assets provides a partial and unreliable service.

II.V Low Earth Orbit

Long distances to gateway stations preclude a Low Earth Orbit bent pipe system, causing solution providers to reach for higher orbits and/or inter-satellite links. Additionally, placing a small number of satellites into a single orbital plane in a low orbit does not provide coverage of the entire Antarctic continent, requiring a significantly larger satellite constellation or a much

higher orbit. Higher satellite orbits generally have a longer dwell time but significantly higher radiation exposure, especially for circular orbits⁷ which again drives up the system cost.

Of the existing Low Earth Orbit constellations, Globalstar and ORBCOMM do not use inter-satellite links and their constellations are intentionally limited in latitude by their choice of maximum orbital inclination (52 degrees for Globalstar and 45 degrees for ORBCOMM). By contrast, the Iridium constellation does use inter-satellite links and is able to operate with a maximum orbital inclination of 86.4 degrees, giving complete coverage of the Antarctic region.

III. MARKET

III.I Government Customers

The Antarctic economy is dominated by several national antarctic programs, shown in Table 1, with total global expenditure just under one billion US dollars. Around 30 countries operate bases in Antarctica, with approximately 40 year-round stations and 30 summer-only stations. The population is approximately 4,000 in summer and 1,000 in winter, plus approximately 1,000 personnel including ship's crew and scientists doing on-board research in the waters of the Antarctic treaty region.

While these are national government agencies, there are no current government satellites systems in development and they are seeking to procure commercial services. Telecommunications are provided by commercial operators in most circumstances, although the USA also makes use of NASA's TDRSS and NOAA's GOES-3 systems at the south pole where commercial options are extremely limited.

Available data on satellite telecommunication budgets from the USA (\$8M, or 2% of total budget⁸), Australia (\$0.5M or <0.5% of total budget⁹), New Zealand (\$0.25M or 2.5% of total budget¹⁰) and United Kingdom (\$0.7M or 1% of total budget¹¹) indicate that between 1% and 2% of total national budgets are spent on satellite communications, or between 10 and 20 million dollars globally per year. The effect of the purchasing power of the US in this market will be discussed later.

The telecommunications requirements of these government programs can be categorized as "operational" and "back-haul". Operational telecommunications must have high reliability and high

availability, including voice communications for safety and logistics, real-time Supervisory Control and Data

Country	Antarctic Program Budget (USD Millions)
USA	388 (2011) ¹²
Australia	145 (2011-2012) ¹³
United Kingdom	75 (2009/2010) ¹⁴
Russia	67 (2009) (including 35M for ship construction) ¹⁵
China	44 (2010) ¹⁶
France	36 (2008) ¹⁷
Japan	35 (2010) ¹⁸
Norway	12 (2010) ¹⁹
Argentina	10.7 (2009) ²⁰
India	10.5 (2008-2009) ²¹
New Zealand	9 (2008/2009) ²²
Sweden	9 (2008-2009) ²³
Chile	2.5 (2010) ²⁴

Table 1: Major national Antarctic programs listed by budget size. All figures converted to USD at in the budget year indicated.

Acquisition (SCADA), and internet access for maintaining morale. Back-haul telecommunications is predominantly scientific data, which is typically one or two orders of magnitude larger in volume than operational telecommunications, but is less time critical. Significantly, the operational requirement, while smaller in volume, is of such importance that it drives the requirements for the back-haul telecommunications service at least in the minds of the users. It became apparent during market research that it would be very difficult for customers to commit in advance to using a back-haul service that would satisfy expanded back-haul data requirements at a low cost, unless the system could also satisfy the reliability and availability requirements for the operational service.

One factor that is driving increased communications requirements for reliable remote operations (SCADA) and back-haul is the reluctance of top scientists to spend a winter in Antarctica tending the experiments, away

from their other research interests and their fellow researchers²⁵. This is despite the scale and importance of the instruments being installed there, such as the newly-built ICECUBE neutrino observatory and the 10m millimeter-wave South Pole Telescope. While there are plans for additional large telescopes at Ridge A (Australia)²⁶, Dome A (China), Dome C (France and Italy) and Dome F (Japan) these sites are all inland and similarly have no visibility of the geostationary satellites.

III.II Tourist Operators

At least two private tour companies have bases in Antarctica. More importantly, perhaps, in the 2009-2010 season the 44 cruise operators carried over 20,000 passengers that landed on the continent and an additional 15,000 “cruise only” passengers, in a total of 239 voyages²⁷. In the 1998-1999 season Antarctic tour operator revenues were over US\$39 million serving 10,000 passengers²⁸. Current industry revenues are easily over US\$100M.

While there are more tourists in Antarctica than scientists, the vast majority are in the most northerly region around the Antarctic Peninsula and very few spend a night on the continent. The cruise ships are thus operating at the edge of the geostationary satellite footprint and have the ability to travel outside the footprint further complicating their communication needs using geostationary satellites. However there are a number of geostationary satellites offering wide-beam coverage of the American continents and it is very uncommon for cruise boats in the Antarctic Peninsular regions to travel far to the east or west. With existing maritime communications services from geostationary satellites are available this market segment is seen as secondary and has not been studied in detail.

III.III Shipping and Fishing

Fishing operators in the southern ocean will often travel outside the footprint of any one geostationary satellite and will need to switch between satellites and possibly between service providers. These operators, however, do not demand high bandwidth connections and are not a primary market for the Antarctic Broadband system.

III.IV Satellite Back-haul

Meteorological and remote sensing satellites generate large amounts of data which must be transferred to data centers for processing, analysis and storage. Data latency is a significant issue for systems making weather forecasts, for monitoring natural disasters such as storms, floods and fires, and for tracking planes and ships. To minimize latency there are a number of ground station networks that provide near-global coverage. It is not feasible to place ground stations in the earth's oceans however, introducing gaps in coverage that result in latency of over an hour for certain parts of the earth. Because remote sensing satellites are almost always in polar or sun-synchronous orbits, the most useful ground stations for limiting latency are those located at or near the earth's poles as the satellite must pass overhead these stations on every orbit. The benefit of having a ground station in Antarctic to provide data back-haul has been analyzed for NOAA's NPOESS mission, as shown in Fig 2 and Fig 3, resulting in the installation of a ground station and back-haul capacity at McMurdo, as previously mentioned²⁹.

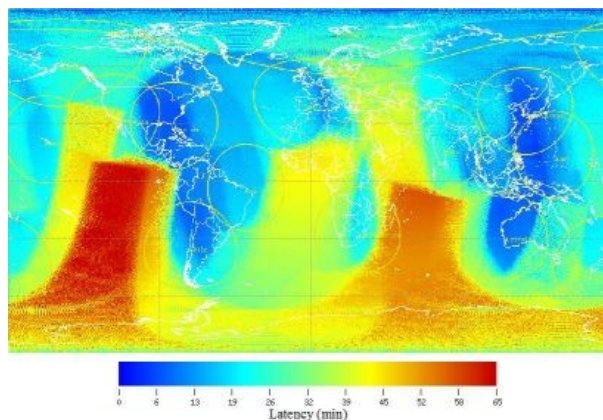


Fig 2: NPOESS System Latency (95%) without McMurdo ground station

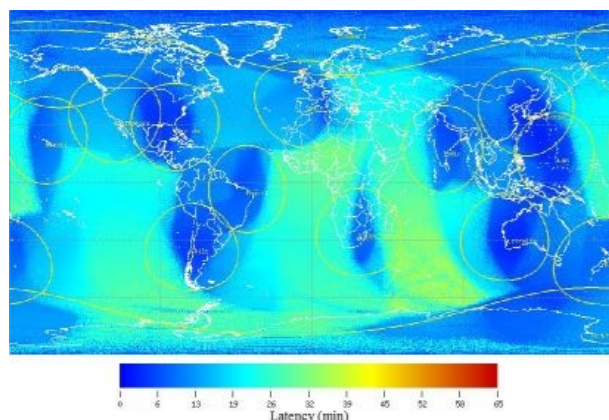


Fig 3: NPOESS System Latency (95%) with McMurdo ground station

Currently, in addition to NOAA's dedicated solution at McMurdo station, there is a commercially available back-haul service available from Kongsberg Satellite Services (KSAT) at the Norwegian base of Troll. KSAT station uses geostationary satellite links in C-band that provide a total back-haul capacity of 140Mbit/s³⁰. These services are in high demand and are likely to grow, but any new service must compete with new and existing geostationary satellites.

IV. COST STRUCTURE

IV.I Capital Expense

Two different architectures were considered that have a significant impact on system costs: a “minimalist system” and a “high-reliability system”. The primary difference between these two systems is availability and satellite-level redundancy.

The minimalist system, with careful selection of the orbit, allows a single satellite to provide 80% availability (over 20 hours per day) and provides no redundancy in case of failure. The initial cost estimate for such a satellite, including technology development and demonstration flights, is between US\$25 and US\$30M. As previously mentioned, customers are unlikely to commit in advance to using a back-haul service that does not also have high reliability and availability, therefore greater effort was spent refining the design of the high-reliability system.

The high-reliability system will provide continuous coverage, requiring a minimum of two satellites, as well

as a third satellite held on the ground ready for launch should either of the on-orbit satellites experience a failure. The capital expenditure for a second satellite is lower than for the first, however it is still substantial. The launch and orbit insertion solution can also be optimized for two satellites, lowering the cost compared to two separate launches. At this stage the cost for these satellites, including technology development and demonstration flights, is estimated to be US\$55 million, plus ground systems and associated services.

IV.II Operational Expenses

The system architecture envisaged delivers data to satellite gateway facilities in Australia and South America, which must then be linked to users in the northern hemisphere. Satellite gateways are operated commercially in both these regions, providing antennas, data links and support. While expenses will vary somewhat with customer usage, there are also fixed operation costs such as licence fees and facility leases. As a basis for preparing the business case the operating expenses are assumed to be fixed at full system capacity. In addition to this there are other business costs associated with administration, management and marketing that are fixed irrespective of system usage. Operational expenses were estimated to be constant at around US\$3M per year.

V. VALUE PROPOSITION

V.I Strategic Importance

Since before the Antarctic continent was first sighted, explorers and their backers have been interested in the region's natural resources. With the start of the Cold War, interest was generated in possible defence and strategic uses such as submarine bases, nuclear testing and intelligence gathering. Concern about these developments led to the negotiation of the Antarctic Treaty, which entered into force on June 23, 1961, establishing freedom of scientific investigation and banned military activity. In these two goals the treaty has been highly successful thus far. From the original 12 signatories, forty seven countries have now acceded to the treaty. Recently, however, major powers such as China and Russia have voiced their interest in the continent's resource potential, strongly suggesting the current prohibition of resource exploitation will be revisited after 2048. These

developments may pose a potential threat to the longevity of the Antarctic Treaty System.³¹

Countries such as Australia have long held that the best way to protect, preserve and advance its national interests in Antarctica is through a healthy and respected treaty regime, and the same holds for most of the Treaty signatories. This must be achieved by engaging to the maximum extent with all other Antarctic Treaty members in management, operations and planning for the entire region. It has been identified that Australia has a significant strategic interest in Antarctica and needs to invest in Antarctic science, logistics and other capabilities³¹. A means to achieve this is to initiate and lead projects that benefit the wider Antarctic community and provide services that are useful and even vital to all participants.

Modest investment in communications infrastructure will help maintain as robust a treaty regime as possible. Investing in communications infrastructure for all is an investment in insight and transparency – key values if the Treaty is to maintain its place as a valid and adhered to instrument in international law.

Operational benefits also accrue from executing Antarctic Broadband. It will facilitate greater occupation and the ability to access all parts of the Antarctic continent, which is of special importance for states that wish to assert or maintain territorial claims. Additionally, the system is expected to greatly assist situational awareness of all marine activities in the Southern Ocean. Leadership in Antarctic Broadband could be a clear statement of intent by Australia: this infrastructure is vital to the support of Australia's strategic interest in Antarctica.

V.II Cost-Effective Operations

Several nations and research organizations are looking to make major infrastructure upgrades in Antarctica to support science including monitoring of the environment, atmosphere and ionosphere, and research into climate, space weather, astronomy and cosmology. All of these projects have in common a very large data output and subsequent data processing requirements. Installing data centers in proximity to these instruments will become a major operating cost as the power requirements for such systems are considerable. Operating costs are already dominated by transportation costs and fuel for generators (diesel, jet fuel, etc), and

they place a major constraint on all infrastructure spending. For example, installation typically costs twice as much as the FOB cost of any equipment²⁵. Investments in reliable communications will mean Antarctic operators can virtualize the computing infrastructure for data-heavy instruments, requiring less equipment on site, less fuel for supplying power and subsequently less fuel for transportation.

V.III New Operating Paradigms

As is only reasonable, the designs of new experiments and equipment for Antarctica are constrained in scope and operations by the foreseeable communications capacity. This creates a catch-22 for installing new communications capability as there will never be proposals or plans, let alone funded programs, that require the capability until after it is available. This results in a delay in uptake of newly available capacity once it does become available. In order to use the new communications capacity, new instruments incorporating new operating paradigms must be proposed to funding agencies, designed, built and installed. This process requires a minimum of five years, and more likely between 10 and 15 years. However, once built, or once there is a commitment from a reliable funding source, the system immediately changes operating paradigms, instrument capabilities can greatly expand and the system rapidly becomes indispensable to the community.

VI. FINANCING OPTIONS

For convenience, all acquisition strategies that lower the financing requirement or eliminate the need for financing are included in this section.

VI.I Grants and R&D Assistance

Work to date has reduced the technical and business risk, resulting in a a low-risk path to launch. A small number of other government grants and development assistance programs are available in Australia that could provide a maximum of several million dollars to assist with development toward an ultimately commercial system, and similar programs exist in other countries were the project to be developed elsewhere.

VI.II Debt Financing

In purchasing assets that have residual value for resale or scrap, it is often possible to use the asset as

collateral for a loan, thus reducing the investment capital required. An alternative method to reduce capital costs is to lease the equipment and/or facilities from the manufacturer or a dedicated asset leasing company. Unfortunately such approaches to reducing capital requirements are not usually available to specialised satellite systems as the liquidation value or re-lease value can not be known. In this case the entire capital cost must be covered by other financing mechanisms.

VI.III Customer Financing

Customer participation, in the form of purchase options, long-term contracts or up-front capital equipment purchases, are not a new concept in developing capabilities in the Antarctic. These can be monetised through traditional “contract financing” mechanisms, for a fee, to provide up-front capital. Specific examples from Antarctic satellite communications include the installation by the US Antarctic Program of a nine meter dish at the south pole costing around US\$15M, a contract over 5 years for Skynet-4C service at the South Pole for US\$15M (including options), and the long term contract for a transponder on OPTUS D-1 dedicated to McMurdo. As previously mentioned, however, it is difficult for a national program to commit to a new class of infrastructure.

VI.IV International Consortium

Forming an international partnership to providing telecommunications services to the Antarctic region and the far southern oceans would meet the strategic objectives of engaging with other Antarctic operators members, fostering cooperation and transparency, and maintaining a robust a treaty regime. Member would need to provide resources to the partnership in exchange for credits toward using the capacity of the system. A managing partner would lead the development, operate the system and manage the resources of the consortium in the interest of all of the partners.

There are at least two examples in the satellite industry where, although the commercial business case was infeasible, a broad community need was addressed by the creation of an international organisation that provided services to members (and non-members) via a variety of financial arrangements. INMARSAT, original with 80 member states, operates a series of geostationary

Maritime Mobile communication satellites. INMARSAT was not profitable until well into its second generation system. INMARSAT was the operator of the first global mobile satellite communications system, with a goal to enable merchant ships to stay in touch across the oceans and to call for help in an emergency. Today Inmarsat owns and operates three global constellations of 11 satellites flying in geosynchronous orbit³². More recently, the Disaster Monitoring Constellation has 6 Member States cooperating to provide remote sensing imagery for disaster monitoring, provided by 7 microsatellites. DMC International Imaging Ltd was formed in 2004 to manage the constellation and provide commercial services using the data it generates.

VI.V Equity Financing

Investors seeking a return on investment at typical market rates will weigh the risk profile of the business and demand a compounded annual return of between 20%, for a medium risk venture, up to 40% from high risk start-ups seeking Venture Capital. Technical risks include failure of the payload, the satellite or the launch vehicle and cost over-runs in development. Market risks include an uncertain total addressable market, unknown adoption rates, potentially long sales cycles to government and significant purchasing power of a single dominant customer. As each of these risks are retired during the development process the return on investment demanded by investors will decrease, thus there is a desire to use other funding sources in the early stages of development.

Given the required rate of return it is very difficult to justify an investment in Antarctic Broadband considering the need to wait for new operating paradigms to be developed and deployed, as discussed in Section V.III. However this is countered somewhat by the likelihood that the existing market will expand given greater availability (Section V.IV). Additionally, any potential competition in the market will face the same issues, providing a barrier to entry and time to recoup the premium demanded for what is a riskier investment. This has been successfully demonstrated in the roll-out of cell phone networks in developing countries.

It has already been mentioned that Iridium, Globalstar and ORBCOMM all went through restructuring, effectively wiping out the initial investment, before achieving sufficient success to fund expansion. Other

systems have narrowly escaped a similar fate, such as the experience of Satellite Digital Audio Radio Service providers Sirius Satellite Radio and XM Satellite Radio who first merged as equals into Sirius XM Radio and later received distressed funding to avoid bankruptcy, but is now experiencing some success.

One mechanism to reduce the risk to investors is a loan or investment guarantee such as was provided by the French Export Credit Agency (Coface) for the second generation constellations of both Globalstar and Iridium. This guarantees the principal invested in case the company is unable to repay the loan or is forced into bankruptcy, and may be available depending on the satellite manufacturer. Investors often use their own mechanisms in an attempt to achieve similar ends such as liquidation preferences, debt instruments (which have a natural preference over shareholders in case of insolvency) and first rights to intellectual property or physical assets. As discussed previously, however, these are worth more if there is an easily defined residual value of assets for resale or scrap, which is difficult to justify in this case.

VII. CONCLUSION

A cost-effective solution for delivering high speed communications to the entire Antarctic continent has been developed. The capital cost of this system is relatively low compared to the various alternatives, however as an investment proposition the return on investment is not attractive for market-based financing. This analysis highlights the non-competitive nature of the market, characterised by a small numbers of customers and suppliers.

When the provision for communications is considered in the whole-of-system costing for new capabilities in the Antarctic, the cost of the telecommunication system is easily justified across a few of the larger projects. For example there are several new telescopes (radio and optical) currently under development which could benefit greatly from the new operational paradigms that high speed data would allow.

For Antarctic Broadband to be realized there must be further development of the value proposition for investing in communications infrastructure which meets the strategic needs of the Antarctic community.

VIII. ACKNOWLEDGEMENTS

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