Polar Networking

A View from Layer 1

Presented to the NITRD JET by

Patrick Smith

NSF/OPP/AIL

21 May 2019
SATCOM Issues: Polar Regions are not a Market Driver for Commercial Satellite Communications

Construction and launch costs for modern geosynchronous communications satellites are between $200M to $600M. Service lifetimes are nominally 15 years. Satellite operators place satellites in global regions and target service where revenue will be generated to produce a positive return on investment for shareholders:

• Land masses with high population densities
• Global shipping and airline routes
• FCC requires operators to provide service between 70°N to 55°S
• **Latitude > 54°S (Tierra del Fuego)**
  - Not many people
  - Not many ships
  - Not many aircraft
  - **NO SUBSTANTIVE REVENUE**

∴ Operators are marginally interested in the Arctic and not incentivized to provide service to Antarctica
Polar Region Satellite Communications Basics

Conventional Geostationary Earth Orbit (GEO) satellites cannot provide coverage at latitudes greater than ±81°. At greater latitudes, the satellite is obscured by the Earth’s horizon.
Global Fiber Cable Connectivity Basics

TeleGeography Submarine Cable Map of the World
https://www.submarinecablemap.com/
The North
Undersea Cables Important to the Arctic

**Quintillion Subsea Cable Network**
- **RFS:** 2017 December
- **Cable Length:** 1,900 km
- **Owners:** Quintillion
- **URL:** http://www.Qxpressnet.com
- **Landing Points:**
  - Kotzebue, AK, United States
  - Nome, AK, United States
  - Point Hope, AK, United States
  - Prudhoe Bay, AK, United States
  - Utqiaġvik, AK, United States
  - Wainwright, AK, United States

**Greenland Connect**
- **RFS:** 2009 March
- **Cable Length:** 4,780 km
- **Owners:** TELE Greenland
- **URL:** http://www.telepost.gl
- **Landing Points:**
  - Landeyjar, Iceland
  - Milton, NL, Canada
  - Nuuk, Greenland
  - Qaqortoq, Greenland

**Greenland Connect North**
- **RFS:** 2017 December
- **Cable Length:** 680 km
- **Owners:** TELE Greenland
- **URL:** http://www.telepost.gl
- **Landing Points:**
  - Aasiaat, Greenland
  - Maniitsoq, Greenland
  - Nuuk, Greenland
  - Sisimiut, Greenland

**Svalbard Undersea Cable System**
- **RFS:** 2004 January
- **Cable Length:** 2,714 km
- **Owners:** Telenor
- **Landing Points:**
  - Breivika, Norway
  - Longyearbyen, Svalbard, Norway
Anchorage, Fairbanks and Prudhoe Bay are interconnected by terrestrial fiber along the Alyeska pipeline route.
More on Quintillion

- **PHASE 1**: Quintillion Terrestrial Line RFS 2017
- **PHASE 2**: Existing Systems
- **PHASE 3**: Quintillion Terrestrial Line RFS 2017

Locations:
- Nome
- Kotzebue
- Anchorage
- Whittier
- Homer
- Whak
- Fairbanks
- Wainwright
- Utqiagvik
- Prudhoe Bay

Map showing key locations in Russia, Arctic Ocean, Alaska, and the Pacific Ocean.
The South
US Antarctic Program

- The National program in Antarctica
- NSF assigned Executive Manager by Presidential Memorandum
  - Three year-round stations
  - Active & influential presence expressed via science research
USAP Global Wide Area Private Network

- Centennial: 2 x 200 Mbps
- McMurdo: 18/10 Mbps
- Palmer: 6 Mbps
- South Pole:
  - 2 x 7 kbps
  - 1.5 Mbps
  - 5/225 Mbps
  - 30/10 Mbps
- Port Hueneme: 20 Mbps
- Christchurch: 100 Mbps
- Punta Arenas: 10 Mbps
- Charleston: 6 Mbps
- Alexandria: 20 Mbps
Satellites Supporting US Antarctic Program’s Layer 1

**Maritime Satellites**
- Inmarsat 5-F2
- Inmarsat 4-F1
- Inmarsat 4-F3

**Fixed Satellites**
- Intelsat 15-23
- Optus D1

**Inclined Satellites**
- NASA TDRS F6
- UK MoD Skynet 4C
- US DoD DCS 387
Maritime Networking Constraints

- Deck space limits practical antenna size to ~1m
- Satellite availability limits coverage and capacity
- High Rate is modest (2 Mbps/512 kbps)
- OPEX can be an issue

Research Vessel/Icebreaker Nathaniel B. Palmer

Typical USAP ship operating region

Gap in USAP ship operating region

Low data rate region

High data rate region

Low data rate region
South Pole Challenge – Big Science – Big Data

Astrophysics
Ice Cube Neutrino Telescope

Astronomy
Cosmology – Echoes of the Big Bang

CMB S4 Telescope
Proposed

10 TB/day by 2027-ish

South Pole Telescope
Challenge: Networking by the Clock...

0000 UTC

0600 UTC

1200 UTC

1800 UTC
Present Day South Pole Science Data Exfiltration

Max Daily Capability = ~ 470 GB/day
Slicing the Bandwidth Salami at McMurdo

- The present McMurdo Station service just fits into one satellite transponder
McMurdo Station Network Bandwidth History

Jan 1983
Observation Hill
Internet
1.2 kbps

Jan 1985
Blk. Is
Internet
4.8 kbps

Feb 1989
Blk. Is
Internet
9.6 kbps

Feb 1992
Blk. Is
Internet
1 Mbps

Feb 1993
Blk. Is
Internet
1.5 Mbps

Feb 2004
Blk. Is
Internet
3 Mbps

Dec 2007
Blk. Is
Internet
8 Mbps

Jan 2010
Blk. Is
Internet
10 Mbps

Jan 2011
Blk. Is
Internet
18 Mbps In
10 Mbps Out
A Note on the UX

Meeting the needs of a small town of 1,000 people with bandwidth available in remote, rural America...

At Home

At McMurdo
The Aurora Australis and the Milky Way shine over Black Island in the middle of winter. Black Island is a telecommunications facility that provides internet, phone and television services for McMurdo Station, about 25 miles away.
Backup
Prospective NewSpace Satcom Operators

It’s been a busy time at the FCC ... Filings totaling **14,536** potential satellites received in recent years

| Sample of Filings - License applications and petitions for U.S. market access for communications systems filed with the FCC since January 2014 |
|---|---|---|
| 1. The Boeing Company | Communications | 6. Space Exploration Holdings LLC (SpaceX) | Communications |
| 2. LeoSat MA, Inc | Communications | 7. Space Norway AS | Communications |
| 5. Kepler Communications | Communications | 10. WorldVu Satellites Limited (OneWeb) | Communications |
NewSpace Examples that Support the Polar Regions

- **SpaceX**
  - Constellation size:
    - Initial: 4,728 satellites
    - Extended: 7,518 satellites
  - Deployed in stages
  - Expect polar coverage ≥ 2025+
  - Different orbit planes tailored to geographic coverage
  - 2 test satellites in orbit

- **Telesat**
  - Spectrum rights secure
  - Optical inter-satellite links
  - Gigabit networking

- **LEOSAT**
  - $3.6B total cost
  - Japan JSAT GSO operator a Series A investor
  - 78 satellites
  - Planned start of service: 2021
  - Conducting Series A investment rounds ($100M)
  - Series B investment estimated as $175M

- **OneWeb**
  - $3.5B total cost
  - ≥ $1.5B investment raised
  - 720 satellites
  - 1st launch at 10 satellites by 4Q CY2018
  - Successive launch cadence of 34-36 satellites per launch every 21 days
  - Planned start of service to Alaska in 2019

- **Telesat**
  - > $? total cost
  - $20M in Canadian Gov commitments
  - Looking for investment partners
  - 117 satellites
  - Planned start of service: 2021
  - Different orbit planes tailored to geographic coverage
  - 1 test satellite in orbit

- **OneWeb**
  - > $? total cost
  - $5.1M angel investor seed funding
  - 140 satellites
  - Test satellite launched Jan 2018
  - IoT, M2M service

- **LEOSAT**
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  - $1B in capital raised

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- **LEOSAT**
  - Spectrum rights at issue
  - Optical inter-satellite links
  - Gigabit networking
Iridium NEXT

- Replenishment and upgrade of current constellation
- 75 new satellites: 66 operational, 9 on-orbit spares

- All satellites successfully launched
- Full service by mid 2019
- Higher data rates (Certus)
- New “hosted payload” services
  - Aircraft tracking,
  - Ship tracking

- New DoD contract with Iridium to begin October 2019
- Continue fixed cost/unlimited use for low bitrate data
- New metered cost for higher data rates, starting at 352 kbps
South Pole Station Satellite Network Connectivity

- **Skynet-4C**
- **DSCS 3B-7**
- **NASA TDRS F6**
- **Multiple Patch Antennas**

- **Airbus Space & Defense**
  - RAF Oakhanger, UK
  - 1.5 Mbps bidirectional

- **International Antarctic Center**
  - Christchurch, NZ
  - 10 Mbps Outbound
  - 30 Mbps Inbound

- **NASA Second TDRSS Ground Terminal**
  - White Sands, NM
  - 225 Mbps Outbound
  - 5 Mbps Inbound

- **DISA Iridium Gateway**
  - Wahiawa, HI
  - ~14.2 kbps bidirectional
DEFENSE SATELLITE COMMUNICATIONS SYSTEM

Christchurch – South Pole Operational Link Established March, 2016

Q: Why a DSCS satellite ground terminal in NZ?
A: NZ can see both satellites made available to NSF

• A legacy US Military SATCOM system
• Generation 3 (DSCS 3) first launched Oct 1982
• Now nearly replaced by Wideband Global Satellite (WGS)
• Available for NSF use for Antarctic SATCOM
• Operating in highly inclined orbits that enable direct contact with South Pole Station
• To be used for moving 100’s of Gbytes of science data via the USAP.GOVT network
• As years pass, the daily contact window at South Pole increases in time
How McMurdo SATCOM Bandwidth Compares to Home

Comparison of McMurdo SATCOM Bandwidth With US Domestic Internet Trends

Legend
- McMurod Upload
- McMurod Download
- US Household Average Internet Speed
- US Household Peak Average Internet Speed

Mbps

McMurdo Upload
McMurdo Download
US Household Average Internet Speed
US Household Peak Average Internet Speed

0 10 20 30 40 50 60 70 80 90 100

Comparison:
- McMurod Upload: 0, 0, 4, 5, 6, 10, 10, 10, 10, 10
- McMurod Download: 10, 10, 18, 18, 18, 18, 18, 18, 16, 19
- US Household Average Internet Speed: 0, 0, 4, 5, 6, 10, 10, 10, 10, 10
- US Household Peak Average Internet Speed: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

Trends:
- McMurod Upload: Steady increase from 0 to 104 Mbps
- McMurod Download: Steady increase from 10 to 104 Mbps
- US Household Average Internet Speed: Steady increase from 0 to 10 Mbps
- US Household Peak Average Internet Speed: Steady increase from 0 to 10 Mbps
2.5: Average US Household Size
18.75 Mbps: Average US Internet Bandwidth
7.4 Mbps: Average Per Person, Per Household Bandwidth
104 Mbps: Average Peak US Internet Bandwidth
40 Mbps: Average Per Person, Per Household Peak Bandwidth

McMurdo is Equivalent to a Small Town Sharing a Single Internet Connection

871: Average Peak Population (165 are DoD)
18/10 Mbps: McMurdo Internet Bandwidth
0.025/0.014 Mbps (25/14 kbps): Average Per Person Bandwidth

McMurdo to service ~1000 people for base operations, science, medical services, educational outreach, phone service and personal use/morale, 24x7x365, with just a single network connection the size of an average household in middle-America...
This is what the McMurdo Network Ops Center Sees...

McMurdo Weekly SITREP: Week Ending 24 Dec 2017

• Lines represent max bandwidth
  • Red = Inbound
  • Dark = Outbound
• Green fill represents inbound network traffic, which is the most congested
• Graph “A” shows actual bandwidth use, with total inbound critically approaching the max limit (gaps are maintenance outages)
• Graph “B” shows the “effective” bandwidth after various network traffic optimization steps (compression, content filtering, selective prioritization, etc.)
• We have squeezed better performance out of the basic link, but we’ve hit the limit.

For good service, the green should rarely peak above here...
McMurdo Challenges – Few Options

- McMurdo can barely see satellites above the horizon (3.5° is the best elevation clearance of the smooth Earth horizon)
- McMurdo’s location south of Mt. Erebus and the surrounding hills blocks part of the view to the sky where active satellites are located
- Few satellites visible from McMurdo have antenna coverage patterns that cover McMurdo with service
- Of the satellites visible with service, even fewer have the high capacity capability that McMurdo needs
- This drove the initial McMurdo satellite communications earth station to be located on Black Island

The Black Island Telecommunications Facility (BITF), ~ 20 mi south-southwest of McMurdo and far enough from Ross Island so as to see the geosynchronous arc as far east as the 183°E orbit slot before Mt. Erebus blocks the view. There are no current or expected commercial satellites east of this point.

Mt. Erebus, Elev. 12,448 ft. ASL has an apparent elevation of ~6° as seen from McMurdo Station, blocking the northern sky.
Black Island Telecommunications Facility

- First implemented in 1985
- Current structures initiated in 1991
- 7.2 m antenna
  - Commissioned in 1992 @ C-Band
  - Re-commissioned in 2007 @ Ku-Band
- 11 m antenna
  - Commissioned in 1995 @ C-Band
  - Re-commissioned in 2010 @ Ku-Band
- Designed for un-attended operations
- Requires crewing in austral summer for maintenance
- Inspection and corrective maintenance winter traverses
- Services by 20 mile length microwave communications link
- Current facility is over 20 years old and has grown piecemeal over the years
- Many major subsystems have reached end of life, requiring life cycle replacements (nearly complete)
- NSF partner tenants (NOAA) has expressed concern about reliability
- USAP Blue Ribbon Panel has cited as a program single point failure
- ROM cost to modernize/replace the facility (not earth stations): ~ US $25M
And More Challenges for Winter Ops

- Access to Black Island for repairs and service restoration requires an arduous, time-consuming overland traverse.
- Response times can take up to a week due to weather and surface conditions.
Drivers for McMurdo change

1. **USAP Blue Ribbon Panel Recommendations (2012)**
   § 4.7.3.4. McMurdo Station Communications and the Black Island Telecommunications Facility
   Action 4.7-5. Assess the risk posture of the Black Island facility and develop and implement a plan to modernize it over the next five years.

2. **NOAA Sponsored EUMETSAT Antarctic Data Acquisition**
   A component of the NOAA-EUMETSAT Joint Polar System Agreement
   Second Generation Metop environmental satellite launch in Sep 2021 dramatically increases data flow via McMurdo, outstripping current capacity

3. **NOAA SATCOM Service**
   NOAA contract providing current McMurdo satellite services permanently ends in Sep 2022

4. **NSF USAP Bandwidth Demand Growth**
   Increased mission op tempo and increased demand for morale communications are outstripping current network service for McMurdo, despite state-of-art optimization measures. Bandwidth increases are now essential to keep pace with demand.
Space Data User Community Driving Bandwidth Demand at McMurdo Station

Present and Future Users

- USAF Defense Meteorological Satellite Program (DMSP)
- McMurdo cited in AFSPC/SMC RFQ as option for ORS-8

Recent New User
- NOAA Joint Polar Satellite System

Present Users

- EUMETSAT Polar Satellite
- NOAA/NASA/NSF – COSMIC
- NASA – Polar LEO satellites tasked to NASA Ground Networks

Future Users

- EUMETSAT Polar Satellite – Second Generation
- NASA – Polar LEO satellites tasked to NASA Ground Networks
McMurdo SATCOM Modernization Q&A

McMurdo Commercial Satellite Communications -- Ross Island Earth Station (RIES)

Q: What is RIES?
A: A 13m dia. communications satellite earth station

Q: Where is RIES located?
A: At the base of Crater Hill, at the upper reaches of a plateau directly above McMurdo Station

Q: Why build RIES?
A: Several reasons:
1. The USAP Blue Ribbon Plan Report cited the current Black Island SATCOM facility as a risk area
2. NSF needs to provide more bandwidth for USAP and its partners (NOAA, NASA) – and a larger antenna facilitates this
3. NSF has determined that it can see modern SATCOM satellites directly from Ross Island, eliminating the need for Black Island’s view

Q: When will RIES be built?
A: Site preparation began with drilling and blasting for earth work in the 2018/19 Austral Summer. The earth station will be installed in the 2020/21 season. It must be completed to begin service by March, 2021.
New Market Entrant: Intelsat Horizons-3e

Global operator Intelsat has launched the Horizons-3e High Throughput Satellite (HTS) with high capability Ku-Band beam coverage of McMurdo Station

Next Generation Satellites: The Path for the Pacific Islands
<table>
<thead>
<tr>
<th>Cable System</th>
<th>RFS:</th>
<th>Cable Length</th>
<th>Owners</th>
<th>URL</th>
<th>Landing Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hawaiki</td>
<td>2018 July</td>
<td>14,000 km</td>
<td>Owners: Hawaiki Cable Company</td>
<td><a href="http://hawaikicable.co.nz">http://hawaikicable.co.nz</a></td>
<td>Kapolei, HI, United States, Mangawhai, New Zealand, Pacific City, OR, United States, Pago Pago, American Samoa, Sydney, Australia</td>
</tr>
<tr>
<td>Southern Cross Cable Network (SCCN)</td>
<td>2000 November</td>
<td>30,500 km</td>
<td>Owners: Spark New Zealand, Optus, Verizon, Telstra</td>
<td><a href="http://www.southerncrosscables.com">http://www.southerncrosscables.com</a></td>
<td>Alexandria, Australia, Brookvale, Australia, Hillsboro, OR, United States, Kahe Point, HI, United States, Morro Bay, CA, United States, Spencer Beach, HI, United States, Suva, Fiji, Takapuna, New Zealand, Whenuapai, New Zealand</td>
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<tr>
<td>Tasman Sea</td>
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