# Design Considerations for Submarine Cables in Arctic Regions

Douglas G. Cunningham & Stephen Lentz & Wayne F. Nielsen

Less than 0.4% of the world's existing submarine cable inventory resides in ice-prone waters. No submarine cables exist in Antarctic waters and two systems have been constructed in waters north of the Arctic Circle. The 2,714 km Svalbard Undersea Cable System was constructed in 2003 by Tyco Electronics (now TE Subcom) between Breivika, Norway and the Svalbard Islands (78°N) and Alcatel installed the 2,050 km Greenland Connect system between Milton, Newfoundland and Nuuk, Greenland (64°N) in 2009. Both systems operate successfully although the Greenland Connect system has been subject to iceberg damage on two occasions, since remedied by reconstruction of the Nuuk landing.

This paper is intended to provide an outline of the unusual design requirements of network design in hostile Arctic conditions and has been based upon the design work undertaken for Arctic Fibre's planned 15,167 km Tokyo to London backbone due to come into service in 2014Q4. It is the authors' intention to create a post-commissioning paper for presentation in two years based upon the actual installation experience.

**Need for Polar Circumvention Cables**

In an environment where most submarine cables operate at a fraction of design capacity one would question the necessity to install fibre optic submarine cables in ice-prone regions of the world. The Arctic Fibre project is premised upon the following requirements:

1. The pent-up demand for economic broadband connectivity in northern regions of Canada and the United States beyond the reach of terrestrial fibre and microwave networks and serviced only by satellite links which are subject to ongoing interference from solar transitions and climatic interference;
2. The ongoing requirement for global network operators to diversify their existing subsea networks away from geographically-concentrated cable landing stations, notably on the east and west coasts of the United States;
3. The need to diminish network operating risk by avoiding high-risk areas subject to high frequency incidents emanating from subsea earthquakes, volcanic activity, fish trawling, ship anchors;
4. A preference by certain carriers to establish geopolitically-neutral routes which are not subject to governmental surveillance or physical interruption or undue taxation;
5. A growing requirement for ultra low latency (ULL) networks to serve high frequency trading networks and synchronous networks serving the burgeoning cloud computing sector; and
6. The overall growth in international bandwidth requirements, bolstered primarily by social media networks.

**Extent of Arctic Issues**

The Arctic Fibre backbone will encompass 15,167 km of subsea fibre between Maruyama, Japan and Bude, Cornwall, United Kingdom. A separate trunk line will branch off the backbone and traverse approximately 1,390 km of ice-prone waters in Hudson's Bay. Initially six remote communities in Alaska and seven in Canada will be served by spurs. Additional branching units will be installed to provide eventual service to an additional 24 communities, defence installations and mine sites through a combination of trunks and spurs. (See attached map).

Approximately 29 km of the Arctic Fibre network will be terrestrially situated on the Boothia Peninsula, thereby obviating construction of a 1,730 km bypass to around the Boothia Peninsula through the shallow waters of the Rae Straits and the iceberg-infested waters of the Parry Channel.

Along the Japan to United Kingdom backbone, approximately 6,897 km or 45% will be situated in waters that are subject to ice cover at some point during the year. Approximately, 5,700 km is situated in waters along the Alaskan coastline and within the Canadian Arctic that is subject to ice-cover for at least seven months per annum. As indicated in the chart below, all elements of the network are accessible at some point during the year, although the ice-free window on the east side of the Boothia Peninsula is limited to about six weeks in recent years. As recently as the mid-1970s, much of the Gulf of Boothia remained ice covered year round. Global warming has enabled the 40-year dreams of British engineers for a circumpolar cable route to become a reality.

The balance of the backbone routing between Japan and the United Kingdom is subject to the normal design considerations of transatlantic and transpacific fibre with one caveat. The length of the system necessitates a mid-point Cable Landing Station (CLS) which will be situated at Cambridge Bay.

A 1,388 km trunk from the backbone will extend down from the Hudson Strait through Hudson's Bay to Chisasibi, Quebec where terrestrial fibre will carry the signals south to Canadian and American interfaces.

**Specific Technical Design Challenges**

During the design process, Arctic Fibre personnel, supported by WFN Strategies and with the benefit of the expertise offered by Alcatel Submarine Networks (ASN) and TE Subcom (TES), identified the following main issues which had to be addressed in the physical design of the technical network elements.

- *Segment Length* – The Maruyama/Bude subsea distance is estimated at 15,167 km, well beyond the existing 11,000 km scope of 100G wavelength technology. The signal regeneration point would also have to take into account the potential 1,800 km extension of the network to Chongming from a pre-built BU situated about 470 km southeast of Maruyama. Cambridge Bay is situated approximately 9,830 km from Chongming, 8,400 km from Maruyama and 6,700 km from Bude;

- *OADM Design* – Arctic Fibre combines express fibre pairs for end-to-end traffic with an OADM fibre pair to provide capacity to communities along the route. The use of OADM allows some wavelengths to transit each spur cable while others pass only through the trunk cable to provide a restoration path in case of damage to a spur cable.
- Availability of Power – The availability of electricity is not often a constraint at most CLS. In the Canadian Arctic, virtually all electricity is generated from diesel fuel, which has to be barged in once per year during the ice-free window from refineries in Atlantic Canada or Vancouver. Few of these communities have sufficient surplus capacity to handle demand over and above existing requirements. Arctic Fibre will utilize the resources of the existing early warning radar site, but will also be required to self-generate. A portion of the self-generation will be derived from solar power. Normally solar power would not be a viable source in a community situated at 64* north latitude but when diesel-supplied electricity costs upwards of $1.02 /kwh in some communities, solar becomes viable. Extensive battery storage will be deployed to harness energy garnered in the land of the midnight sun well into the dark months of January and February. Solar power may be utilized exclusively at some remote microwave stations providing connectivity between CLS and inland communities and mines sites;
- *Variable Power Feeds* – As noted previously, electricity at the Cambridge Bay CLS is extremely expensive. By contrast our Chisasibi CLS will be located near the spillway of one of the largest hydroelectric developments in the world where electricity pricing is less than $0.04 per kwh. Arctic Fibre's network through Hudson's Bay, the Eastern Canadian Arctic and most of the Atlantic Ocean will be powered from the province of Quebec and can be adjusted as circumstances (and power costs) vary;
- *Extreme Terrestrial Temperatures* – The crossing of the Boothia Peninsula will entail installation where terrestrial temperatures can sink to -55C. Across the 29 km Boothia Peninsula terrestrial crossing, cables specified for -60C operation will be employed.

**Specific Marine and Physical Deployment Issues**

In an age where proponents of ultra-low latency networks attempt to shave yards off their networks in order to improve their competitive position on transoceanic routes, Arctic Fibre adopted a specific list of routing principles at the outset to ensure that the technical integrity and MTBF was not comprised by taking physical shortcuts. To that end, Arctic Fibre and its consulting engineers adopted the following measures:

- A minimum ice margin of 10m as defined by the vertical distance between the known or predicted depth below sea level of pack ice bummocks or the fins of floe bergs and icebergs.
- Adherence to the deepest route through ice-prone waters or channels irrespective of distance considerations in order to meet the 10m margin.
- Seabed burial in all ice-prone waters where the ice margin is less than 30m.
- Avoidance of festoon landings of the backbone network to dramatically eliminate the risk of ice incidents albeit at additional capital cost for additional branching units.

- Addition of a fourth fibre pair to ensure that express traffic remained on the first three fibre backbone pairs in the cable with spurs being deployed to individual Arctic communities.
- Near shore landing margins of at least 2.0 m between the armored cable and the deepest recorded ice scour on the seabed at any particular location which necessitates the use of plows with a 3.0 m capability or horizontal boring and several locations.
- Burial to at least 1.8m in shallow water approaches less than 30m depth to obviate the risk of cables being broken, not by lateral ice flows, but by the vertical crushing action of pack ice which is subject to tides twice per day. Articulated pipe to be installed where necessary.
- Avoidance of high-risk seismic zones offshore Japan to provide an element of physical redundancy from other subsea networks.

**Specific Terrestrial Installation Issues**

Arctic Fibre faces several unique issues in transitioning from a subsea environment to a harsh Arctic climate in seven Canadian Arctic and six Alaskan communities and its traversal of the Boothia Peninsula. Two route alternatives were considered. The first involved a combination of a 5 mile trench along an unpaved, but year-round accessible trail followed by a 24 km surface lay on a shallow, ice-covered lake and a further 2km shallow trench through an esker, tundra and granite. Issues related to protection of the cable in a lake which can often freeze to the bottom and the impracticalities of transporting vessels capable to the lake rendered this alternative impractical.

Instead the company will utilize installation methods already proven up elsewhere in Canada's Arctic and the State of Alaska where a tread-equipped tractor with a ditch witch and rotary cutting wheel will be utilized to traverse 29km of tundra, granite and eskers in a winter installation to minimize terrestrial damage and access terrain which would otherwise be inaccessible during the short summers.

Many Arctic communities received heavy goods once per year in a sealift making it nearly impossible to mobilize and construct in the same time frame. Arctic Fibre will have to pre-stage equipment this summer and airfreight in some trenching equipment and fibre reels just prior to the terrestrial installation.

Arctic Fibre is mitigating construction risk by using existing terrestrial infrastructure where possible. In most communities we will collocate or SLTE equipment and PFE (where applicable) in the existing premises of the local telephone companies who are Arctic Fibre's primary customers. They provide the space, electricity, smart hands and will install and maintain the terrestrial fibre from the BMH to the central exchange, normally a distance of less than one kilometre.

Other unique deployment issues involve:

- Flexible and prefabricated beach manhole installations to accommodate frost heaves and permafrost.

- Burial of low-temperature-rated repeatered fibre across tundra and permafrost which requires a winter time installation interval.
- Installation of electric generators, both primary and back-up, at Cambridge Bay CLS to meet our longer-term energy requirements at our crucial midpoint landing station.
- An ice-free window as short as 4-6 weeks in the Foxe Basin in which to undertake a marine survey.
- Pre-installation of beach landings and near shore approaches in communities where civil equipment can be limited to a single backhoe.
- Adverse weather and ice conditions which could delay installation within the Arctic waters beyond a single summer.
- Avoidance of icebergs during the installation phase in the Labrador Sea, although the number of icebergs appears to be waning as global warming has devastated many of the source glaciers.

**Conclusion – A Little Ice is Nice!**

Construction of a network of this length is not unheard of nor is construction of a subsea network in ice-prone waters. Nearly two thirds of the network is situated in waters where the Arctic Fibre will face subsea risks common to all subsea cables. The balance is situated in an environment where the ice cover provides protection for up to ten months per year and where many of the risks normally associated with cable breakage (fish trawling, anchorages, and sabotage) are negligible or non-existent. The Arctic polar cap is generally benign from a seismic perspective and we have attempted to mitigate risk offshore Japan by taking a wider SE passage into Maruyama bypassing the most active seismic zone.

Application of the cable fault rates outlined in *Trends in Submarine Cable System Faults* by Maurice Kordahl, Seymour Shapiro and Gordon Lucas to Arctic Fibre's desk top study routing and depth suggests the Arctic Fibre network should actually be more resilient than the typical network with an estimated MTBF of 26.8 years on the Tokyo to London backbone with the probability of a service-impacting failure within ice-prone waters being one in 44.8 years. A little ice is nice.